STUDIES ON PARTICULATE MATTER IN AMBIENT AIR OF URBAN MANGALORE

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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DECLARATION

by the

Ph. D. RESEARCH SCHOLAR

I hereby *declare* that the Research thesis entitled **"Studies on Particulate Matter in Ambient Air of Urban Mangalore"** which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in Chemical Engineering is a *bonafide report of the research work carried out by me*. The material contained in this **Research Thesis** has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to *certify* that the Research Thesis entitled **“Studies on Particulate Matter in Ambient Air of Urban Mangalore”** submitted by **Gopinath K.** (Register Number: CH11F04) as the record of the research work carried out by him, *is accepted as the Research Thesis submission* in partial fulfillment of the requirements for the award of degree of **Doctor of Philosophy**.

Research Guide
Dr. Raj Mohan B.

Chairman – DRPC

Dedicated to my beloved parents and friends

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ABSTRACT

A city's ambient air quality could determine the life standard of the residing population. In a developing nation like India, the industrial sector growth is on an ever-increasing trend in order to cater the demands of the burgeoning population. With the addition of industries and automobiles which could potentially process and deliver non-environmental friendly substances result in air pollution. In the realm of air pollutants, Particulate Matter (PM) and its chemical constituents like elements, ions and organic compounds (Polycyclic Aromatic Hydrocarbons (PAHs)) are carcinogenic and mutagenic and thus requires attention to reduce the health impacts in any urban environment. Among the fast-growing cities in India, the coastal city of Mangalore accommodates various industries and educational institutes and there is a large population of natives and non-natives dwelling in the city. The given research thesis aims to identify the types of particulate matter (PM_{10} & $PM_{2.5}$) prevailing in the ambient air of Mangalore and to estimate their source contributions by using a receptor modeling technique Chemical Mass Balance (CMBv8.2). A dispersion modeling study is also carried out using AERMOD v 9.1 to estimate the dispersion of particles in the urban city of Mangalore.

Source apportionment studies on Particulate matter (PM_{10} and $PM_{2.5}$) have been carried out by identifying six sampling sites to be hotspots of urban Mangalore. The sampling sites across the city were selected with emphasis to industries, traffic junction, places of public gathering and regions near to schools. The particulate samples have been collected according to the guidelines proposed by Central Pollution Control Board (CPCB), India. The mass concentrations of PM_{10} and $PM_{2.5}$ have been measured by gravimetric technique and found to be exceeding the NAAQS limits, with the highest concentration of 231.5 µg/m^{3}of PM_{10} particles and 120.3 µg/m^3 of $PM_{2.5}$ particles were found at Town Hall and KMC Attavar sites respectively. The elemental analysis using Inductively Coupled Plasma Optical Emission Spectrophotometer (ICPOES) revealed twelve different elements (As, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Sr and Zn) for PM_{10} particles and nine different elements (Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn) for $PM_{2.5}$ particles. Similarly ionic composition of these samples measured by Ion Chromatography (IC) divulged nine different ions (F^-, Cl^-, NO_3^-, PO_4^-, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}) for PM_{10} particles and ten different ions (F^-, Cl^-, NO_3^-, PO_4^-, SO_4^-, Na^+, NH_3^-, K^+, Mg^{2+} and Ca^{2+})

for $PM_{2.5}$ particles. Estimation of PAHs for the collected samples revealed the presence of Fluorene (Flu), Acenaphthene (Ace), Chrysene (Chr), Benz(a)anthracene (B(a)A), Benzo(a)pyrene (B(a)P), Benzo(b)fluoranthene (B(b)F), Indeno (1,2,3-c,d) pyrene at significant concentrations. The Total Polycyclic Aromatic Hydrocarbons (TPAHs) concentration was observed to be higher at Town Hall sampling site with a concentration of 112.89 ng/m^3. Likewise, the chemical compositions of $PM_{2.5}$ samples collected in the school premises were analysed using ICP OES (Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Ti, V and Zn) and Ion Chromatography (F^-, Cl^-, NO^{3-}, PO_4^{3-}, SO_4^{2-}, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Na^+). A simulation study on the dispersion of particulate matter have been carried out to assess and predict the urban air quality using AERMOD, and validated with the experimental data. The performance of AERMOD is evaluated for prediction of $PM_{2.5}$ concentrations at various hotspots in the city. Future control scenarios have also been proposed VR: Vehicles older than 10 years are phased out; CF1: Diesel car to petrol car; CF2: Diesel and petrol car to CNG car; CF3: Diesel bus to CNG bus to predict the reduction in particulate concentration.

The source apportionment study for PM for urban Mangalore region in accordance with these six sample sites using USEPA CMBv8.2 revealed nine and twelve predominant contributors for PM_{10} and $PM_{2.5}$ particles respectively. The highest contributor of PM_{10} particles was found to be paved road dust followed by diesel and gasoline vehicle emissions. Correspondingly, $PM_{2.5}$ particles were found to be contributed mainly from two-wheeler vehicle emissions followed by four-wheeler and heavy vehicle emissions (Diesel vehicles). The PAHs have been contributed majorly from eight different sources with its highest contribution from diesel powered passenger cars and heavy vehicles combustion. Similarly, the predominant sources contributing to school premises was found to be Paved Road Dust, Soil Dust, Gasoline Vehicle Emissions, Diesel Vehicle Emissions and Marine Source Emissions. However, vehicular emissions contribution was found to be higher in the schools located near to any roadway than the school located away from the major roadways. The difference in location and dissimilarity in activities going on has been found to be the sole cause for variation in sources among the schools. Hence, the source apportionment study carried out for particulate matter and PAHs in urban Mangalore and for particulate matter in the school premises clearly depicts that these pollutants prevailing in the ambient atmosphere of urban Mangalore has around

70% of their contribution from vehicular emissions (both exhaust and non-exhaust). The dispersion study results show that the predicted pollutant concentrations are in satisfactory limits at all the sampling sites. The statistical descriptors such as correlation coefficient (R^2), index of agreement (d), Normalized mean square error (NMSE) and Fractional Bias (FB) have been found to be satisfactory. The proposed future control scenarios were found to reveal significant results. Among the proposed scenarios CF3 shows a higher reduction of PM concentration up to 23%. Thus, the source apportionment and dispersion modeling studies on urban Mangalore clearly portrays that the emissions from vehicular exhaust, resuspension of road dust and vehicular traffic at hotspots plays a major role in deteriorating the air quality of urban Mangalore by releasing the harmful pollutant particulate matter into the ambient atmosphere of the city.

Keywords: AERMODv9.1, Chemical Mass Balance, Particles Dispersion, Particulate Matter, Poly Cyclic Aromatic Hydrocarbons, Source Apportionment, Urban Mangalore, Vehicular Emissions.

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LIST OF ABBREVIATIONS

ARAI Automotive Regulatory Authority of India

BDL Below Detection Limit

CMB Chemical Mass Balance

CNG Compressed Natural Gas

COD Coefficient of Divergence

CPCB Central Pollution Control Board

DCM Dichloromethane

DDW Distilled Deionised Water

EF Emission Factor

HDV Heavy Duty Vehicle

IC Ion Chromatography

ICP-OES Inductively Coupled Plasma Optical Emission Spectrophotometer

LDV Light Duty Vehicle

LoD Limit of Detection

MPIN Modifed Pseudo-Inverse Normalized Matrix

NAAQS National Ambient Air Quality Standards

PAHs Polycyclic Aromatic Hydrocarbons

PCA Principal Component Analysis

PM Particulate Matter

PMF Positive Matrix Factorization

PTFE Polytetrafluoroethylene

CHAPTER 1

INTRODUCTION

Air pollution receives prime concern in India among other environmental issues due to rapid economic, urban and industrial growth with associated increase in energy demands.

India's urban air quality ranks worst in the world. Of the 3 million premature deaths in the world that occur each year due to out-door and in-door air pollution, the highest number are assessed to occur in India, resulting in high concentration of pollutants in the ambient air. The respiratory infections contribute to 10.9% of the total burden of diseases, which may be both due to the presence of communicable diseases and well as high air pollution levels(World Bank 2013)**.**

The rapid growth of urban population has led to an increase in resource consumption and higher demands for transport, energy, and other infrastructure, therefore leading to pollution problems.

Vehicular emissions play a vital part in being source of air pollution, with more than three million cars, trucks, buses, taxis, and rickshaws already on the roads. The density of motor vehicles in India has increased from 0.3 million in 1951 to 37.2 million in 1997 with 23% being concentrated.

Another key factor adding to the poor air quality has been the expansion in industrialization. India has made quick walks in industrialization, and is one of the best ten most industrialized countries of the world. This status has realized unfortunate outcomes to the environment. As indicated by the Central Pollution Control Board they have recognized seventeen categories of industries in India that fundamentally pollute the air. Small-scale industries assume a part noticeable all around deterioration as well. They have more than three million small scale units that record for 40% of the aggregate modern yield in the nation (CPCB 2016).

Subsequently, since 1950's the country's electricity generation has increased rapidly. The generation capacity comprises a mix of hydro, thermal, and nuclear plants. Among these, thermal power makes up about 74% of the total installed power generation capacity. However, increasing support on this source of energy has led to numerous environmental problems. The increase in dependence of an inferior quality coal for power generation has been associated with emissions from power plants in the form of particulate matter, toxic elements, fly ash, and oxides of nitrogen, sulphur and carbon besides ash, which required vast stretches of land for disposal. During 1998-99, the power stations consumed 208 million tons of ash posing a major disposal problem.

1.1. Significant steps implemented by the government:

Legislature of India has attempted noteworthy endeavors in the zone of environmental protection, creating ecological benchmarks for both products and procedures, requiring natural effect articulations in specific regions, and presenting environmental audits.

Following the 1984 Bhopal calamity (a lethal break from the city's Union Carbide chemical plant that brought about the death of more than 3,000 individuals) environmental awareness increased significantly. The Environment Protection Act was passed in 1986, making the Ministry of Environment and Forests (MoEF), which reinforced India's sense of duty regarding the environment. The MoEF is entrusted with the general obligation regarding regulating and authorizing ecological laws and approaches. The MoEF built up the significance of incorporating environmental methodologies into any development for the nation.

In Vehicular Sectors, emission limits for gas and diesel fueled vehicles became effective in 1991 and 1992. Emission standards for traveler autos and business vehicles were fixed in 2000 at levels proportional to the Euro-1 models of the European Union, while the considerably more stringent Euro-2 benchmarks have been set up for the metropolitan zones of Delhi, Mumbai, Chennai, and Kolkata since 2001. Additionally the sulfurcontent of motor fuels in the four urban areas has been limited to 500 parts per million since 2001 so as to be good with more tightly vehicle emission standards. Engine fuel sulfur content in every single other locale of India has been restricted to 2,500 ppm since January 2000

India still faces critical difficulties in adjusting its expanded interest for energy with the need to shield its environment from further damage.The air is highly polluted in terms of particulate matter in most cities. This has led to a greater incidence of associated health effects on the population in the form of sub-clinical effects, impaired pulmonary functions, and use of medication, reduced physical performance, frequent medical consultations and hospital admissions with complicated morbidity and even death in the exposed population.

1.2. Definition of a particle:

A single continuous unit of solid or liquid containing many molecules held together by intermolecular forces and primarily larger than molecular dimensions (> 0.001µm). A particle may also be considered to consist of two or more such unit structures held together by inter particle adhesive forces such that it behaves as a single unit in suspension or upon deposit (John H . Seinfeld and Spyros N. Pandis 1998).

Particles suspended in the air are classified by size (aerodynamic diameter) and chemical composition, and are often referred to as Particulate Matter (PM) or aerosols. Airborne particles are classified by size into coarse, fine, and ultrafine particles.

1.3. Particle size distribution:

PM is generally measured in terms of the mass concentration of particles within certain size classes

- Total suspended particulates (TSP, with diameter <~30 microns (µm)
    - PM_{10} (with diameter less than 10 µm, also referred to as coarse)
    - $PM_{2.5}$ (with an aerodynamic of less than 2.5 µm, also referred to as fine)
    - Ultrafine PM are those with a diameter of less than 0.1 micron

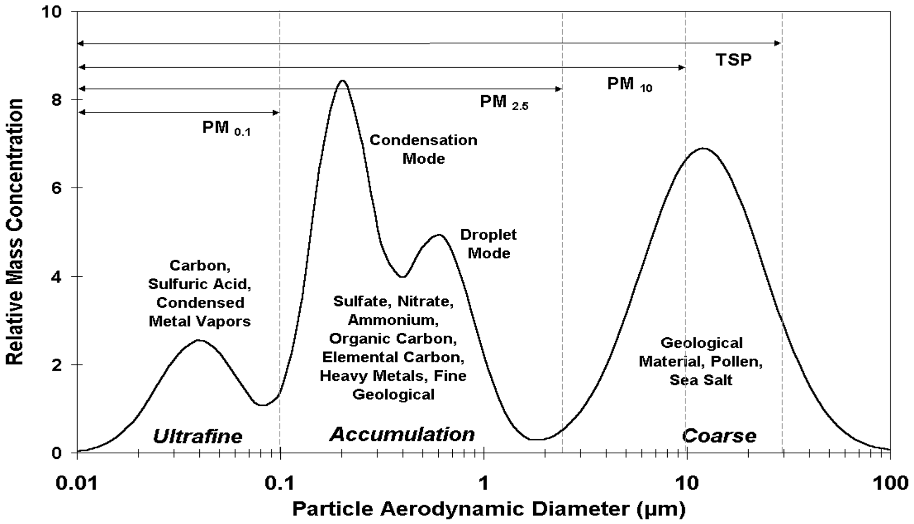


Fig.1.1. Particle Size Distribution of Particulate Matter

Adapted from: SIM-air Working Paper Series: 10-2008

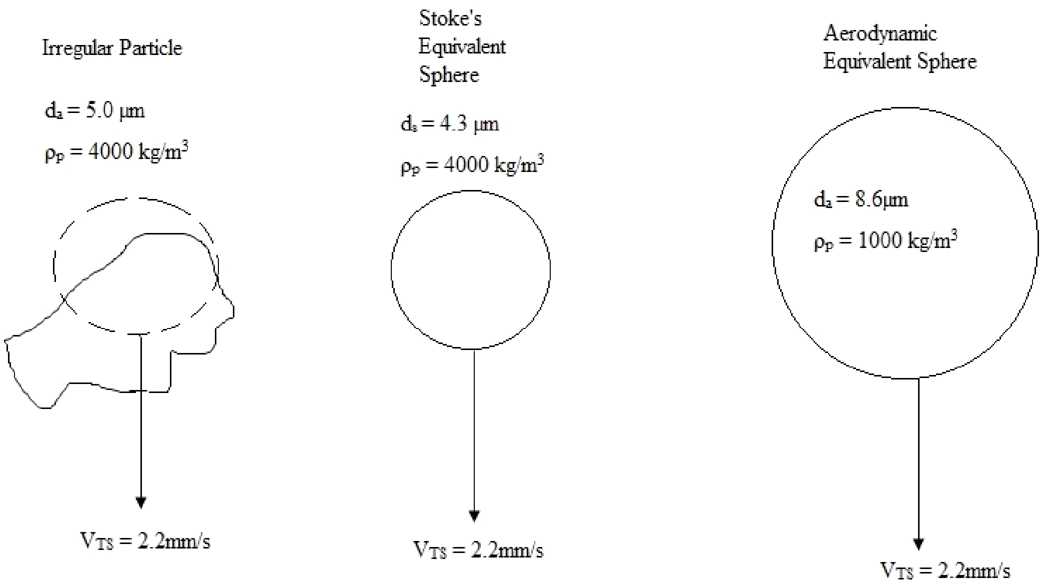


Fig 1.2. Aerodynamic Particle diameter estimation

Adapted from: SIM-air Working Paper Series: 10-2008

$$d_a = d_e\left[\frac{\rho_p}{\rho_0 X}\right]^{1/2} = d_s\left[\frac{\rho_b}{\rho_0}\right]^{1/2}$$

and, for spheres

$$d_a = d_p\left[\frac{\rho_p}{\rho_0}\right]^{1/2}$$

Where , d_a = Aerodynamic diameter of the particle;

d_e= Equivalent diameter of the particle;

d_s = Stokes diameter of the particle;

ρ_p= Density of the Particle;

ρ_b = Normal density of the bulk material of the particle;

ρ_0 = Standard Particle density (1000 kg/m^3)

The distinctions in particles size (coarse and fine particles) depends upon the mechanism of particle formation, which lead to the variation of composition and properties. The range of sizes also affects the atmospheric lifetime, spatial distribution, indoor-outdoor ratios, temporal variability, and health impacts of particles.

The size and shape of the particles affects the particles life time. The average life time of coarse particles were (resuspension before they settle on a canopy or wet deposited due to precipitation) between minutes to hours, whereas the life time of fine particles average from days to weeks. Likewise, the coarse particles travel distances from 1 to 10's of kilometres range and the fine particles average from 100's to 1000's of kilometres.

1.4 Classification of PM:

In terms of emissions mechanism, PM is broadly classified into, primary and secondary particles.

- The particles which are emitted directly into the atmosphere from sources such as burning, industrial activities, road traffic, road dust, sea spray, and windblown soil and are composed of carbon and organic compounds, metals and metal oxides, and ions are termed as primary particles.
- The Secondary particles are formed through the chemical transformation of gaseous pollutants such as Sulphur Dioxide (SO_2), Nitrogen Oxides (NOx), certain Volatile Organic Compounds (VOC’s), and Ammonia (NH_3) among others, into Sulphates, Nitrates, Secondary Organic Aerosols, and Ammonium Ions.

1.5. Composition of PM:

Although some countries are still monitoring for TSP, The focus on finer fractions viz. PM_{10}, $PM_{2.5}$, and sub-micron PM has increased significantly in a number of urban centres. Six major components account for nearly all of the PM mass in most urban areas:

1. Geological material (oxides of Al, Si, Ca, Ti, and Fe)
2. Organic matter/carbon (OC- consisting of hundreds of different compounds)
3. Elemental carbon (EC) (also termed black carbon or soot)
4. Sulphates
5. Nitrates
6. Ammonium

1.6. Possible pollution sources of PM:

The variation in PMpollution over the developing nation’s urban communities relies on the organization, sources and spatial appropriation. Aside from the effect of neighborhood sources inside urban territories, long-go transport of air contamination adds another measurement to the current vulnerability in the evaluation of PM sources and concentrations.

The sources of pollution in urban areas of developing nations are normally more extensive than those observed in their industrial country counterparts. This is a direct result of the fast change amongst country and urban economies in many emerging nations. The outcome has been that in quickly creating urban territories sources incorporate those normally thought of as rustic, (for example, cooking with solid fuels) notwithstanding the sources ordinarily thought of as urban, (for example, petroleum derivative based transportation and industry). To put it plainly, financial improvement normally brings about more engine vehicles and more industries, which will bring about more noteworthy PM pollution unless they are very much controlled, yet many developing nation urban areas consistently possess huge divisions of conventional sources like consumption of biomass, so air quality administration programs additionally need to deliver these pollutants to be effective.

Industrial Emissions Road Dust Vehicular Emissions

Garbage Burning Mining Operation Material Handling

Fig1.3. Sources of Particulate Matter

As far as source contributions, it is basic that the commitment of different sources to the emissions isn't same as the contributions to the ambient concentrations. The prominent sources, for example, power plants and industries have a tendency to be a piece of the long range transport and getsdeposited at places other than the source zone where as the ground level sources, for example, vehicular fumes, residential emissions, and fugitive emissions have a tendency to contribute more at the neighbourhood surrounding levels. Thus, despite the fact that the part of ground based emanations may be little, their relative contribution to atmospheric levels can be high.

Table1.1. Various Sources and its composition

Emission Sources	**Marker Elements**
Soil	Al, Si, Sc, Ti, Fe, Sm, Ca
Road dust	Ca, Al, Sc, Si, Ti, Fe, Sm
Sea salt	Na, Cl, Na^+, Cl^-, Br, I, Mg, Mg^{2+}
Oil burning	V, Ni, Mn, Fe, Cr, As, S, SO_4^{2-}
Coal burning	Al, Sc, Se, Co, As, Ti, Th, S
Iron and steel industries	Mn, Cr, Fe, Zn, W, Rb
Non- Ferrous metal industries	Zn, Cu, As, Sb, Pb, Al
Glass industry	Sb, As, Pb
Cement industry	Ca
Refuse incineration	K, Zn, Pb, Sb
Biomass burning	K, Cele, Corg, Br
Automobile gasoline	Cele, Br, Ce, La, Pt, SO_4^{2-}, NO_3^-
Automobile diesel	Corg, Cele, S, SO_4^{2-}, NO_3^-
Secondary aerosols	SO_4^{2-}, NO_3^- $NH4^+$

Adapted from: SIM-air Working Paper Series: 16-2009

1.7. Particulate pollution and health impacts:

Epidemiological investigations, in industrial and developing nations distinctly portrays that increased ambient PM levels prompt an expanded danger of mortality and morbidity. Wellbeing impacts extend from minor eye irritation, chronic respiratory illness, coronary illness, lung tumor, and demise. Air pollution has been appeared to cause intense respiratory diseases in kids and incessant bronchitis in grown-ups. It has additionally been appeared to decline the state of individuals with previous heart or lung ailment. Among asthmatics, air contamination has been appeared to aggravate the recurrence and seriousness of attacks. Both short and now and long haul exposures have likewise been connected with untimely mortality and decreased life expectancy. (Pope III and Dockery 2006).

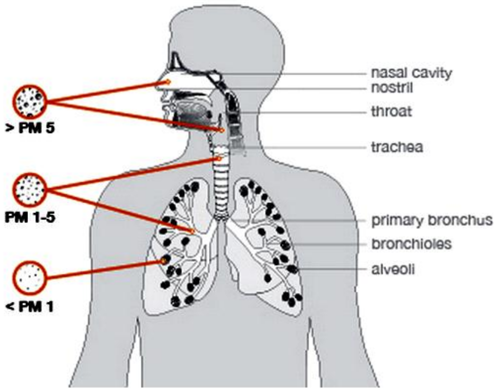


Fig1.4. Effects of PM on Human Health

The wellbeing effects of air pollution rely upon the type of pollutantconcentration in the air, length of exposure, other pollutants in the air, and individual susceptibility. The undernourished, exceptionally youthful and extremely old, and individuals with previous respiratory sickness and other sick wellbeing, might be more influenced by similar concentrations than sound individuals. Also, developing nation poor have a tendency to live and work in the most vigorously polluted regions. Accordingly, their hoisted hazard because of wellbeing factors is exacerbated by their expanded exposure to PM(Dominici et al. 2003).

Studies in India have demonstrated that acute respiratory infection (ARI) in kids under 5 is the biggest single illness classification in the nation, representing around 13 percent of the national burden of disease, and kids living in family units utilizing solid fuels have 2-3 times more danger of ARI than unexposed kids. The guilty pollutant in India is accepted to be fine PM. While evaluations of wellbeing impacts are viable in raising general worry about air quality, they don't particularly answer the topic of the sources of fine PM, nor what measures ought to be taken to lessen the effects related with exposure (TERI 2015).

1.8. Particulate pollution and environmental impacts:

In spite of the way that wellbeing impacts of PM drive the majority of the worry about air quality in developing nations. It is found that PM also affects regional and global atmospheric chemistry and the radiation balance. Aerosol particles scatter and absorb solar radiation, and also alter the formation of cloud droplets. These physical interactions change the earth’s radiation balance, affecting local and global temperatures and possibly precipitation.

PM pollution can also impact visibility in urban centres. Mountains or buildings once in plain sight can suddenly be blocked from view. Air pollution that reduces visibility is often called haze or smog. The term smog originally meant a mixture of smoke and fog in the air, but today it refers to any visible mixture of air pollution. The incidents of haze and smog in cities are increasing, which typically starts in cities and travels with the wind to appear in the more remote areas. One consequence of smog over any given area is that it can change the area’s climate. Certain dark particles, such as carbon, absorb solar radiation and scatter sunlight, helping produce the characteristic haze that is filling the skies over the world’s megacities and reducing visibility.

1.9. Polycyclic Aromatic Hydrocarbons (PAHs):

PAHs are a group of condensed benzene ring compounds produced by either incomplete combustion process or high pressure process. These are present in each and every compartment of environment, including air, water, and soil sediments(Barra et al. 2005; Kanaly and Harayama 2000)PAHs are carcinogenic, mutagenic, and teratogenic in nature as it shows acute toxicity (Cerniglia, C.E. and Heitkamp 1989). US Environmental Protection Agency (USEPA) has classified some of PAHs as human probable carcinogens. These compounds are of environmental and human health concern.

The properties of PAHs compounds are dependent on molecular weight, molecular structure and angularity. Increase in the molecular weight and angularity of a PAH molecule results in relative increase in hydrophobicity and electrochemical stability (Ronald G. Harvey 1997). PAHs molecules persistency increases with increase stability and hydrophobicity. Due to their hydrophobic nature, low volatility and high octanol /water ratio, PAHs tend to adsorb onto the particulate matter in the air and settle down in the water column by adsorbing on to sediment(James W. Moore 1984).

PAHs are released into the environment from natural and anthropogenic (Man-made) sources. Natural sources include volcanoes and forest fire, while the man-made sources include burning of wood, automobile exhaust, industrial power generators, incinerators, production of coal tar, coke, asphalt and petroleum, incomplete combustion of coal, oil, gas, garbage, tobacco and charbroiled meat. PAHs are present in relatively high concentration in products of fossil fuel refining (e.g., Petroleum) and transport activities. PAHs released into the environment from many sources, diesel and gasoline fuel combustion, tobacco smoke (Anderson et al. 1974; Kanaly and Harayama 2000). PAHs may be attached to dust or ash causing lung irritation. Skin contact with PAHs may cause redness, blistering, and peeling. These may penetrate into the bronchial epithelium cells where metabolism takes place. Chronic exposure may lead to Cancer, Reproductive Effects and problems in unborn baby’s development, organ System damage (lungs, liver, skin, and kidneys) respiratory problems and behavioural effects (CPCB).

PAHs are present in trace quantities in the environment. It has become a great menace to human health because of it widedistribution in various environmental segments, so the sources of PAH have received attention. U.S government agencies have established standards relating to the PAH is 0.2 mg/m^3 and 0.0001-0.0004 mg/L (USEPA) in the work place and in drinking water respectively. Carcinogenic, mutagenic and the toxicity nature of polycyclic aromatic hydrocarbons (PAHs) make them as one of the prime interest in environmental monitoring.

1.10. Urban air quality management:

In recent years India has experienced substantial increases in vehicle kilometres traveled (VKT) due to the swelling urban population and increased volume of motorized traffic in cities. This scenario has resulted in severe air pollution affecting the surrounding environment and human health. In particular, pollutant concentrations close to significant crossing points and roadways in the city are surpassing the Indian National Ambient Air Quality Standards (NAAQS).Thus, users (motorists, pedestrians, residents, etc.) in these corridors are exposed to unhealthy pollution levels(Nagendra and Khare 2002). The motorized transport is the principle source of local urban air pollution in mega cities of developing countries because of the increased vehicular population. This rapid growth of motor vehicles activities in Indian cities is causing a wide range of serious health, environmental and socio-economic impacts by generating the pollutants, particularly particulate matter.

The World Health Organization (WHO) has estimated that in developing countries, increasing Urban Air Pollution (UAP) has resulted in more than 2 million deaths per annum along with various cases of respiratory illnesses (WHO 2009). Subsequently, the estimation of the levels of PM existing in the urban environment is a prime necessity for air quality administration and air pollution reduction.The success of urban air quality management plan (UAQMP) mainly depends upon air quality monitoring and prediction, emission control strategies, policy implementation and evaluation. The air quality prediction and forecasting by air quality models plays an important role in formulating air pollution control and management strategies. Air quality modeling provides the ability to assess the current and future air quality in order to enable (informed) policy decisions. Many mathematical models have been widely used for urban air quality management in developed countries. Be that as it may, the uses of urban air quality administration are constrained in developing nations like India because of absence of promptly accessible information, time and cost engaged with gathering the required model input data.

1.11. Background of the study:

In recent times, India is experiencing a rapid growth and economic development reflected by industrialization, urbanization, rise in income and motor vehicle use, which results in the increase in release of pollutants and its concentrations from various sources into the atmosphere.

In the previous decades, many investigations featured the part of atmospheric airborne particulate issue (PM) as a vital ecological pollutant for a wide range of cardiopulmonary ailments and lung malignancy. Various epidemiological examinations in the previous 30 years found a solid exposure-response connection between PM for short and long haul impacts or aggregate wellbeing impacts (morbidity, lung tumor, cardiovascular and cardiopulmonary sicknesses, and so on) (Athanasios Valavanidis 2008).Particulate matter alludes to solid or fluid particles noticeable in the air and gets discharged from many sources which can be either primary or secondary in inception. Primary PM is discharged straightforwardly and can be either coarse or fine, while secondary PM which has a tendency to be finer in size is formed in the ambient environment through physical and chemical conversion of vaporous precursors, for example, nitrogen oxides (NOx), sulfur oxides (SOx), and unpredictable natural mixes (VOCs). While most air contaminations are characterized as for a specific chemical composition, PM is a generic term that incorporates an expansive scope of physical characteristics and chemical species(Bell et al. 2004). Size-selective sampling of PM refers to collecting particles below, above, or within a specified aerodynamic size range usually selected to have special relevance to inhalation and deposition, sources, or toxicity. Because samplers are incapable of a precise size differentiation, particle size is usually defined relative to a 50% cut point at a specific aerodynamic diameter (2.5 or 10 µm). Furthermore, particles indicated by $PM_{2.5}$ can be breathed more deeply into the lungs, remain suspended for longer periods of time, penetrate more readily into indoor environments, and are transported over much longer distances. PM_{10}, an indicator for inhalable particles that can penetrate the thoracic region of the lung, consists of particles with an aerodynamic diameter less than or equal to a 10µm (Pope III and Dockery 2006).

To effectively address the pollution problem in Mangalore city a thoroughand meticulous is required on mass concentration of particulate matter; analysis of the composition of particulate matter such as heavy metals and Ions has to be determined qualitatively and quantitatively. This can be achieved by Chemical Mass Balance method. These results will be validated from the emission inventory study identifying major air pollution sources and their contributions to ambient air pollution levels. These studies including receptor and dispersion modelling that are desirable for taking short and long-term control measures.

1.12. General description of the city:

1.12.1. Demography:

Mangalore is located at 12.87°N 74.88°E in the Dakshina Kannada district of Karnataka. It is the administrative headquarters of the Dakshina Kannada district, the largest urban coastal centre of Karnataka, and the fourth largest city in the state. It has an average elevation of 22 metres (72 ft) above mean sea level Surrounded by the Arabian Sea to the west and Western Ghats to the east. The municipal entity of Mangalore city spans an area of 200 km^2. Mangalore has a population of 619,664 as per the 2011 census of India, while the Mangalore city metropolitan area has a population of 484,785 (Directorate of Census Operations Karnataka 2011).

1.12.2. Climate:

Mangalore has a tropical monsoon climate and is under the direct influence of the Arabian Sea branch of the southwest monsoon. It receives about 95% of its total annual rainfall within a period of about six months from May to October, while remaining extremely dry from December to March. The months from June to September is termed to be Monsoon season with an average rainfall of 826mm, October to January is termed to be Post-monsoon season with temperatures recording as low as 21° C and from February to May is termed to be summer season with temperatures recording up to 37° C. The annual precipitation in Mangalore is 3,479 millimetres (137 in). Humidity is approximately 75 per cent on average.

Fig1.5. Mangalore City Map

1.13. Need for the study:

Over many decades Mangalore is known for its educational hub and it draws in students from all over the country for education in many medical, paramedical, engineering and management courses. It has been claimed to be one of the growing commercial city in south India because of its expanding Mangalore Special Economic Zone (MSEZ), International Airport, busy traffic New Mangalore Port Trust (Gateway for Karnataka) and many upcoming commercial and residential complexes.

The Central Pollution Control Board (CPCB) had carried out Comprehensive Environmental Pollution Index (CEPI) for Mangalore. The CEPI for Air Environment of Mangalore is 61.75. This indicates that the air quality in Mangalore falls in upper limit of severely polluted region and very close to the critically polluted condition (63 and above are critically polluted regions). The nature of emissions and effluents from industries in and around Mangalore are varied and are industry specific.

The main pollutants from these industries (mainly chemical and fertilizer industries) are particulate matter, oxides of sulphur and nitrogen, hydrocarbons. In the recent past, the growth of industries in Mangalore has been oriented towards information technology, biotechnology and related industries. The heavy use of captive diesel generators in these industries, IT firms, commercial and residential complexes contribute to increased air pollution loads. Hence a continuous monitoring and analysis of the air pollutants level in the atmosphere of Mangalore becomes essential. Mangalore being an industrial and education hub, the effects of the air pollutants, particularly heavy metals, carbon and its derivatives in particulate and gaseous forms pose to have a very high adverse impact on the health of the public in this region. The revised national ambient air quality standard (NAAQS 2009) of our country emphasizes the on stringent measurement of certain parameters like $PM_{2.5}$, Arsenic, Nickel, Benzene and Benzo (a) Pyrene (BaP) in the ambient air and presently there is no data on the ambient air quality of many cities across the peninsular country including Mangalore. Hence there is a necessity to generate a data base on the ambient air quality of this fast-growing city.

CHAPTER 2

LITERATURE REVIEW

For quite a long period, people have comprehended that outside air pollution hurts human wellbeing. Air contamination has been widespread across human existence because fire, a significant pollution source has been utilized for cooking and warmth. This early recognition of the risks of air pollution, industrialization and fossil fuel– based transportation during and after the Industrial turbulence caused air pollution concentration to ascend in numerous regions (Bell et al. 2004). Particulate Matter, a kind of air pollutant is gaining its significance in air pollution since it affects the environment, human health and overall climate change. It can be characterized by number of features including size, density, shape, and composition. Generally, the particle size is related to the properties, health and environmental effects, and fate of particles. The smaller the particle the greater the distance of transport from the emission source and the deeper and more efficient the penetration into human lungs. The particulates composition is important since it impacts the size, density, volatility, reactivity, and toxicity of the particle. Several studies have shown that there are two rough size-based categories of particles.

These particulate groupings are referred generally as fine and coarse particles, with median sizes of around 1 mm and 10 mm, respectively. This approximate size classification is based on general observations of many studies. The origin, composition, and properties of ambient particles will be different for each location based on very complex combinations of local and regional geology, climate, and land use. Particles bearing aerodynamic diameter less than 2.5 mm and 2.5 to 10 mm size fractions will be termed as fine and coarse particles respectively(Environmental Protection Agency 2008).

2.1. Global dawn of regulations for PM:

In the early 1970's Canada and the United States both developed ambient air standards for total suspended particulate (TSP). In the year 1987, EPA replaced the TSP standard with a National Ambient Air Quality Standard (NAAQS) for $PM_{10}$with respect to the research response which portrays the role of these smaller particles in posing a greater health risk due to their ability to penetrate deeper into the lungs. Sustained study has revealed that fine ($PM_{2.5}$ and finer) particulate displays a much greatest health risk, causing research, monitoring, and regulatory efforts to shift to $PM_{2.5}$. In 1997, EPA revised the NAAQS by adding new standards for $PM_{2.5}$. Canada-wide standards (CWS) for PM_{10} and $PM_{2.5}$ are currently being developed under the Environment Standards Sub-Agreement(US EPA 1996).

In India, the Air (Prevention and Control of Pollution) Act was passed in 1981 to regulate air pollution and there have been some measurable improvements. Under the provisions of the Air (Prevention & Control of Pollution) Act, 1981, the CPCB has notified fourth version of National Ambient Air Quality Standards (NAAQS) in 2009 (CPCB 2011)

2.2. Standards for emissions:

The permitted standards for emission of pollutants in the air are listed below. USEPA (http://epa.gov/air/criteria.html)

Table2.1. Standard for Emission of Pollutants

Pollutant	**Type**	**Standard**	**Averaging Time**
SO_2	Primary	365 µg/m^3	24-hour
SO_2	Primary	80 µg/m^3	Annual
SO_2	Secondary	1300 µg/m^3	3-hour
PM_{10}	Primary and Secondary	150 µg/m^3	24-hour
$PM_{2.5}$	Secondary	35 µg/m^3	24-hour
$PM_{2.5}$	Primary	15 µg/m^3	Annual
CO	Primary	40 mg/m^3	1-hour
CO	Primary	10 mg/m^3	8-hour
O_3	Primary and Secondary	235 µg/m^3	1-hour
O_3	Primary and Secondary	150 µg/m^3	8-hour
NO_2	Primary and Secondary	100 µg/m^3	Annual
Pb	Primary and Secondary	0.15 µg/m^3	3 months

2.3. Studies on particulate Matter:

An aerosol sampling and monitoring study was carried out at six monitoring sites in the thickly populated and industrialized California's San Joaquin Valley for a period of one year, from June 14, 1988 through June 9, 1989. The results indicated that respirable particulates (PM_{10}) concentrations were reported to be high during winter and dominated by fine particles ($PM_{2.5}$). The coarse aerosol fraction constituted more than half of PM_{10} mass during the summer and fall. PM_{10} concentrations of secondary ammonium nitrates were elevated during the winter at all sites. Conversely, concentrations of coarse particle iron, indicative of geologically related dust, were higher under less humid conditions during the summer and fall. Region wide meteorological and chemical transformation processes influence the secondary (nitrate and sulfate) components of PM_{10}(Chow et al. 1993)

2.3.1. Receptor modeling studies on particulate matter:

The chemical mass balance (CMB) receptor model was applied to the chemically speciated diurnal particulate matter samples acquired at nine locations in California's South Coast Air Basin as part of the Southern California Air Quality Study (SCAQS),Source profiles applicable to the Los Angeles area were used to apportion $PM_{2.5}$ and PM_{10} to primary paved road dust, primary construction dust, primary motor vehicle exhaust, primary marine aerosol, secondary ammonium nitrate, and secondary ammonium sulfate. Suspended dust was the major contributor to PM_{10} during the summer, whereas secondary ammonium nitrate and primary motor vehicle exhaust contributions were high during the fall. Secondary ammonium sulfate contributions were uniform across the South Coast Air Basin. Marine aerosol contributions were lower during the fall than during the summer(Watson et al. 1994).

The present study reviews selected data on the major and minor component composition of $PM_{2.5}$ and PM_{10} particulate matter showing quite major geographic variations in composition which are not reflected in the exposure-response coefficients determined from the epidemiology which show remarkably little spatial variation. Overall, the data presented provides little support for the idea that any single major or trace component of the particulate matter is responsible for the adverse effects. The issue of particle size is currently unclear and more research is warranted (Harrison and Yin 2000)

PM_{10} and $PM_{2.5}$ mass and elemental concentrations were measured in five major Chilean urban areas. Mg to Pb elemental range was detected in the aerosol samples using X-ray fluorescence (XRF). Sources of PM_{10} and $PM_{2.5}$ were estimated using Factor analysis (FA). The identified sources comprise of both natural and anthropogenic sources with soil and sea to be themajor contributors to coarse particles (PM_{10}–$PM_{2.5}$), whereas their contributions to $PM_{2.5}$ were negligible. Cu smelters and oil refineries emissions (and/or diesel combustion) were identified as major contributors of $PM_{2.5}$, particularly in the industrial cities of Rancagua, Valparaíso, and Viña del Mar. Lastly, vehicular and wood burning emissions were found to be the significant contributors of both $PM_{2.5}$ and PM_{10}(Kavouras et al. 2001).

The study employs a systematic method combining water and diluted-acid extractions have been developed to manifold the evaluation of soluble and insoluble fractions in ambient aerosol. The cellulose membrane filter was pre-washed and used as a collection medium of a low-volume air sampler. Sampling period of 7–14 days was necessary to collect sufficient amounts of sample for the systematic analysis. The extraction procedures were recommended to be simple and efficient (using the filtration of water and 0.1M hydrochloric acid) in order to acquire information about the dissolution behaviours of various elements in the aerosol. Soluble components in both the extracts were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES) and ion chromatography (IC). These extraction procedures were also preferred for X-ray fluorescence spectrometry (XRF) to prepare thin-layer specimens for insoluble components. XRF calibrated with thin-layer standard specimens prepared with activated carbon determined the elemental compositions of the extraction residues conveniently. The estimation of the 17 representative elements (Na, Mg, Al, Si, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Cu, Zn, Br, Pb) in these three fractions of an aerosol sample was performed rapidly within 4 h. This systematic method was applied to $PM_{2.5}$ and PM_{10} aerosol samples collected in Kofu City, Central Japan (Kyotani and Iwatsuki 2002).

The atmospheric respirable particulate matter (PM_{10}) from four typical districts of Harbin was collected in four seasons. The sources of PM_{10} were identified by means of enrichment factor (EF) analysis and chemical mass balance (CMB) receptor model. The results indicated that Cu, Pb, S, Zn, As, and Cd came mainly from anthropogenic sources, which varied evidently with season and space; Al, Ba, Ca, Cr, K, Mg, Mn, V, and Sr came mainly from natural sources, Ti, Na, and Si were attributed mainly from natural sources. Results from CMB receptor model indicated that major sources in Harbin were traffic dusts, road dusts, coal burning dusts and dusts from petrochemical plants. Among these sources, the traffic dusts contributed the highest ratio in all seasons, road dusts ranked the second in spring, dusts from petrochemical plants ranked the second in summer and coal burning dusts ranked the second in winter (Huang et al. 2010).

PM_1 (particles having aerodynamic diameter < 1.0 μm) concentrations were measured at a sampling site inside the Indian Institute of Technology (IIT) Kanpur campus. The sampling was carried out for all the major seasons of India. Average PM1 concentration was found to be highest (199 µg/m3) during winter and lowest (31 µg/m3) during monsoon season. Nitrate and sulfate were the two most predominant anionic species contributing to almost 80%–90% of total anionic concentrations. Crustal elements (Ca, Mg, and Fe) were the main contributors within the total elemental concentrations. Overall, it was found that anions contributed up to 35% of the total PM1 mass. Factor Analysis of chemical speciation data and UNMIX (Version 6) revealed that secondary sources and vehicular emissions were the two main sources contributing to PM_1 mass with minor contributions from paved road dust and coal combustion sources (Chakraborty and Gupta 2010).

Particulate matter samples were collected using a dichotomous sampler at a residential area of Vashi situated in Navi Mumbai. The sampler facilitates the simultaneous collection of atmospheric particulates in coarse and fine size fractions. The filter samples collected were analysed for trace elements using Proton Induced X-ray Emission (PIXE) technique. The particulate matter trends show higher concentration during winter season compared to other seasons. High concentrations of elements related to soil and sea salt were found in the coarse fraction of particulate matter. Enrichment Factor (EF) analysis with respect to Fe showed enrichment of Cu, Cr, and Mn only in the fine fraction suggesting their origin from anthropogenic sources. The EF value was observed to be maximum for As, Pb and Zn in the fine particulates. However, crustal and marine derived elements showed very low EF values indicating their origin from soil and sea salt respectively. The Principal Component Analysis (PCA) based multivariate studies identified soil, sea salt and combustion as common sources for coarse and fine particles (Kothai et al. 2011).

A study of the chemical composition of atmospheric particulate matter has been carried out in the city of Delhi. The results show that during these periods, pollutants produced by combustion sources constituted 6 –7 % of the total mass, and that the rest of it, in the absence of desert storms, was evenly divided among species coming from the soil, inorganic secondary compounds formed in the atmosphere and organic species. The results of the analysis of levoglucosan concentration showed that during the cold season in the atmosphere of Delhi about one fifth of the organics was directly produced by biomass burning. It has been found that PM_{10} composition varies according to the season: soil components increase during the summer while secondary pollutants and organics increase during the post–monsoon and the winter (Perrino et al. 2011).

A report by (Parkhurst et al. 1999), summarizes a $PM_{2.5}$/PM_{10} particulate matter data set consisting of 861 $PM_{2.5}$/PM_{10} sample pairs collected with dichotomous samplers by the Tennessee Valley Authority (TVA) from 1982 to 1991. Annual average $PM_{2.5}$ concentrations ranged from 12.6 to 21.3 micrograms per cubic meter (mg/m^3), with an overall mean of 15.7 mg/m^3. Likewise, annual average PM_{10} concentrations ranged from 17.8 to 33.7 mg/m^3, with an overall mean of 23.7 mg/m^3. High summer-low winter seasonality was evident, particularly for $PM_{2.5}$, with the highest monthly $PM_{2.5}$ and PM_{10}concentrations in August (26.4 and 37.5 mg/m^3, respectively) and the lowest in February (9.9 and 15.3 mg/m^3, respectively). A strong association was found between $PM_{2.5}$ and PM_{10} mass with $PM_{2.5}$ mass contributing, on average, 67% of PM_{10} mass. Daily $PM_{2.5}$ mass appears to be reasonably well associated with maximum hourly ozone during the warmer months (spring through fall). Sulfate compounds comprise a major portion of the measured $PM_{2.5}$ mass, with that fraction being highest in the summer months.

Samples of particulate matter of size 10 micron (PM_{10}) were collected in Talcher, Orissa (India) from six sites with different land-uses. The ambient mass concentration and the elemental composition in these PM_{10} samples were determined. The annual average concentrations of PM10 samples at each site were 144 ± 29 μg/m3, 191 ± 61 μg/m3, 90 ± 28 μg/m3, 60 ± 15 μg/m3, 106 ± 35 μg/m3, and 150 ± 36 μg/m3 respectively, indicating severe air pollution levels in Talcher. Variation of particulate matter with meteorological parameters like wind speed, relative humidity and temperature was observed. The study reveals that the particulate matter concentration drops substantially with the rise of wind speed above 1m/s. Elemental concentrations of PM_{10} were analyzed using an atomic absorption spectrophotometer. Correlation and multivariate analysis techniques, such as principal components analysis, were used for source apportionment to identify the possible sources of PM_{10} and quantified trace elements (Roy et al. 2012).

In this study variation of PM_{10} was investigated and primary statistics were employed. The results show that, the PM_{10} concentrations values ranged from 6.00 to 646.74 μgm^{-3}. The average value of PM_{10} is equal to 114.32μgm^{-3}. The high values were recorded in April and May (155.17 μgm^{-3} and 171.82 μgm^{-3}, respectively) and the low values were noted in February and December (73.86 $\mu gm^{-3}$and 74.05 μgm^{-3}, respectively). The average value of PM_{10} of the hot season (125.35×10^{-6} gm^{-3}) was higher than its value for the cold season (89.27 μgm^{-3}). In addition, the effect of weather elements (air temperature, humidity and wind) on the concentration of PM10was determined. Finally, the PM_{10} concentrations were grouped depending on their associated atmospheric stability class. These average values were equal to 122.80±9 μgm−3 (highly unstable or convective), 109.37±12 μgm^{-3} (moderately unstable) and 104.42±15 μgm^{-3} (slightly unstable) (Adam 2013).

2.3.2. Characterization of $PM_{2.5}$ and source estimation:

The purpose of this work is to characterize trace elements associated with atmospheric particulate matter of 2.5 μm and smaller in size ($PM_{2.5}$) over the New York–New Jersey (NY–NJ) Harbour Bight. Using low-volume $PM_{2.5}$ samplers, aerosol particulate samples were simultaneously collected. Sample analysis for trace elements was accomplished by inductively coupled plasma mass spectrometry. Many elements in ambient air exhibit strong spatial gradients from urban centers to the coast. Seasonal patterns are not apparent for most elements at all locations, suggesting continuous contributions from their sources. The elements Pb, Cd, Zn, Cu, Ni, V, Sb, are enriched by factors of 200 to 20,000 relative to their natural abundance in crustal soil. Major sources that contribute to the atmospheric loading of these elements include fossil fuel combustion, oil combustion, metal processing industry, and waste incineration. Atmospheric dry deposition of these trace elements associated with $PM_{2.5}$ to the coastal waters of the NY–NJ estuary may account for a significant portion of the total dry deposition fluxes for these elements(Gao et al. 2002).

A test protocol for characterizing stationary source contributions, including primary and secondary aerosols, to ambient $PM_{2.5}$ has been developed. Since data representative of current designs and operating practices regarding emission of $PM_{2.5}$ and its precursors, especially organic compounds and aerosols, from stationary petroleum industry combustion sources is sparse. Tests were performed on refinery combustion sources using both conventional source sampling methods and a dilution sampling approach. This study discusses about the approaches for characterization of $PM_{2.5}$ and its precursors from stationary combustion sources and initial results of field measurements made using traditional and dilution sampling techniques (England et al. 2000).

The study carried out in Montana for $PM_{2.5}$, Indicates that samples were collected for six days for a period of 4 months.Using a Chemical Mass Balance computer model (Version 8.0), these data were used to apportion the sources of $PM_{2.5}$ in the Libby valley. CMB modeling results revealed that emissions from residential wood combustion were the major source of $PM_{2.5}$ throughout the winter months in Libby, contributing an average of 82% of the measured $PM_{2.5}$. Levoglucosan, a well-known chemical marker for wood smoke, had the highest measured concentrations of any of the 95 polar organic compounds quantified from the fine fraction, accounting for over 15.5% of the measured organic carbon fraction. Other semi-volatile organic compounds with high measured concentrations during the program were four phenolic compounds commonly found in wood smoke, including phenol, 2-methylphenol (*o*-cresol), 4-methylphenol (*p*-cresol), and 2,4-dimethylphenol. The modeling results support that residential wood combustion was the major source of $PM_{2.5}$ (Ward et al. 2006)

In this study Particulate matter (PM) less than 2.5µm in size ($PM_{2.5}$) source apportionment by chemical mass balance receptor modeling was performed to enhance regional characterization of source impacts in the south eastern United States. Secondary particles, such as NH_4HSO_4, $(NH_4)_2SO_4$, NH_4NO_3, and secondary organic carbon (OC) (SOC), formed by atmospheric photochemical reactions, contribute the majority (>50%) of ambient $PM_{2.5}$ with strong seasonality. Source apportionment results indicate that motor vehicle and biomass burning are the two main primary sources in the southeast, showing relatively more motor vehicle source impacts rather than biomass burning source impacts in populated urban areas and vice versa in less urbanized areas. Spatial distributions of primary source impacts show that each primary source has distinctively different spatial source impacts. Results also find impacts from shipping activities along the coast. Spatiotemporal correlations indicate that secondary particles are more regionally distributed, as are biomass burning and dust, whereas impacts of other primary sources are more local (Lee, Sangil Russell and Baumann 2007).

Atmospheric particulate matter in two size fractions 2.5-10 µm and ≤ 2.5 µm were collected on nucleopore polycarbonate filter papers and were analyzed for elements using NAA (Neutron Activation Analysis) and EDXRF (Energy Dispersive X-ray Fluorescence). Varimax rotated factor analysis identified five major sources contributing to coarse and fine particulate mass. FA (Factor Analysis)-MLR (Multiple Linear Regression) technique is applied to apportion the sources. The studies showed maximum contribution of the coarse fraction was from sea salt (35%) and crustal (25%) sources. A considerable amount of the mass was also contributed from industrial (14%), vehicular (10%) and fugitive emissions (7%). These results also showed the percentage contribution of soil, two-stroke emission with fugitive dust, industrial emission, motor vehicles and sea salt to the average fine mass concentration was 3%, 18%, 23%, 29% and 9%, respectively. The contribution of each source to their constituent elements also has been determined using the same technique (Kothai et al. 2008).

The study is focused on investigation of source contribution estimates of dusts fallout in an urban-industrial area, Raipur, India. Six sampling sites have been identified on the basis of land use for development plan of anthropogenic activities and factors related to the transportation and dispersion pattern of atmospheric dusts. 12 samples of dusts fallout has been collected from each site (one in each month) and subjected to chemical analysis of selected chemical constituents known as markers of selected major dust emitting sources. Chemical profiles along with SPECIATE of USEPA have been used for the preparation of source profiles. Source apportionment has been done using Chemical Mass Balance (CMBv8). Variations in source contribution estimates of selected indicator species has been occurred and justify the significant contribution of local area and line sources of dusts emission in various parts of the study region. Coal-fired steel making industries have shown dominating contribution compared to other sources (Balakrishna and Pervez 2009).

An effort to understand the sources of $PM_{2.5}$ in the Fairbanks airshed, source apportionment using Chemical Mass Balance (CMB) modeling was conducted at four locations in Fairbanks over a three-winter period. At each of the four sites, $PM_{2.5}$ concentrations averaged between 22.5 ± 12.0 µg/m^3 and 26.5 ± 18.9 µg/m^3, with frequent exceedence of the 24-hour NAAQS on the scheduled sample days. The results of the CMB modeling revealed that wood smoke was the major source of $PM_{2.5}$ throughout the winter months in Fairbanks, contributing between 60% and nearly 80% of the measured $PM_{2.5}$ at the four sites. The other sources of $PM_{2.5}$ identified by the CMB model were secondary sulfate (8–20%), ammonium nitrate (3–11%), diesel exhaust (not detected-10%), and automobiles (not detected-7%). Approximately 1% of the $PM_{2.5}$ was unexplained by the CMB model. Additional research is needed to confirm the wood smoke results of the CMB model, as well as determine which sources contribute to the measured secondary sulphate (Ward et al. 2012).

Fine particulate matter ($PM_{2.5}$) composition data from the Speciation Trends Network (STN) site in San Jose, CA, were analyzed by positive matrix factorization (PMF) using U.S. Environmental Protection Agency (EPA) PMF version 5.0. The eight identified sources include secondary sulfate, secondary nitrate, fresh sea salt, aged sea salt, diesel emission, road salt, gasoline vehicles, and wood combustion. The contributions to $PM_{2.5}$

of these eight sources were 13.1%, 20.0%, 5.5%, 7.8%, 9.4%, 5.1%, 14.8, and 24.3%, respectively (Wang and Hopke 2013).

2.3.3. Epidemiological studies on PM:

In this study, the authors estimate the association between air pollution and mortality using different timescales of variation in the air pollution time series to gain further insight into this question. The authors' method is based on a Fourier decomposition of air pollution time series into a set of independent exposure variables, each representing a different timescale. The authors then use this set of variables as predictors in a Poisson regression model to estimate a separate relative rate of mortality for each exposure timescale. The method is applied to a database containing information on daily mortality, particulate air pollution, and weather in four US cities (Pittsburgh, Pennsylvania; Minneapolis, Minnesota; Seattle, Washington; and Chicago, Illinois) from the period 1987–1994. The authors found larger relative rates of mortality associated with particulate air pollution at longer timescale variations (14 days–2 months) than at shorter timescales (1–4 days). These analyses provide additional evidence that associations between particle indexes and mortality do not imply only an advance in the timing of death by a few days for frail individuals (Dominici et al. 2003).

The review discusses about the history, methods, and findings of the time-series studies estimating health risks associated with short-term exposure to particulate matter. However, much of the discussions are on epidemiology studies,especially on air pollution.The critical role of epidemiological studies in setting regulatory standards and the PM epidemiology history and time-series analysis has also been reviewed. The author also summarizes recent results on time-series studies and conclude with a discussion on current and future perspectives on time-series analysis of particulate matter, including mortality displacement research and the resolution of results from time-series studies (Bell et al. 2004).

The epidemiological studies have demonstrated coherent associations between daily changes in concentrations of ambient particles and cardiovascular disease mortality, hospital admission, disease exacerbation in patients with cardiovascular disease and early physiological responses in healthy individuals consistent with risk factor profile deterioration. In addition, evidence was found that annual average $PM_{2.5}$ exposures are associated with increased risks for mortality caused by ischemic heart disease and dysrhythmia. Thereby, evidence is suggesting not only a short-term exacerbation of cardiovascular disease by ambient particle concentrations but also a potential role of particles in defining patients' vulnerability to acute coronary events(Peters 2005).

(Stölzel et al. 2007) in their study reported the role of particle size fractions with respect to total and cardio-respiratory mortality in Erfurt, Germany, between 1995 and 2001. Number concentrations (NC) of PM were measured using an aerosol spectrometer consisting of a Differential Mobility Particle Sizer and a Laser Aerosol Spectrometer to characterize particles between 0.01 and 0.5 and between 0.1 and 2.5 mm, respectively. The data were analyzed using Poisson Generalized Additive Models adjusting for trend, seasonality, influenza epidemics, day of the week, and meteorology using smooth functions or indicator variables. The result shows statistically significant associations between elevated ultrafine particle (UFP; diameter: 0.01–0.1 mm) NC and total as well as cardio-respiratory mortality, each with a 4 days lag. The relative mortality risk (RR) for a 9748 cm^{-3} increase in UFP NC was RR=1.029 and its 95% confidence interval (CI)=1.003–1.055 for total mortality. For cardio-respiratory mortality: RR=1.031, 95% CI=1.003–1.060. No association between fine particle MC and mortality was found.

The existing monitoring data in the region around Toronto and within Toronto itself were utilized to estimate that 30–45% of the $PM_{2.5}$ is from local sources, which implies that 55–70% is transported into the area. Detailed $PM_{2.5}$ chemical characterization data were collected in Toronto in order to apply two different multivariate receptor models to determine the main sources of the $PM_{2.5}$. Both approaches produced similar results, indicating that motor vehicle related emissions, most likely of local origin, are directly responsible for about 20% of the $PM_{2.5}$. Gasoline engine vehicles were found to be a greater overall contributor (13%) compared to diesel vehicles (8%). Secondary $PM_{2.5}$ from coal-fired power plants continues to be a significant contributor (20–25%) and also played a role in enhancing production of secondary organic carbon mass (15%) on fine particles. Secondary fine particle nitrate was the single most important source (35%), with a large fraction of this likely related to motor vehicle emissions (Brook et al. 2007).

The relationship between breast cancer mortality and air pollution was examined using an ecological design. The study areas consisted of 61 municipalities in Taiwan. Air quality data for recorded concentrations of fine particulate matter ($PM_{2.5}$) from study municipalities for 2006–2009 were obtained as a marker of traffic emissions and were used as a proxy for polycyclic aromatic hydrocarbons (PAHs) exposure. Age-standardized mortality rates for breast cancer mortality were calculated for the study municipalities for the years 1999–2008. A weighted multiple regression model was used to calculate the adjusted risk ratio in relation to $PM_{2.5}$ levels. Results showed that individuals who resided in municipalities with the highest $PM_{2.5}$ were at an increased risk of death from breast cancer. The findings of this study warrant further investigation into the role of air pollutants in the risk of breast cancer (Hung 2012).

2.3.4. Seasonal variations of PM concentrations:

The PM_1 concentration in the samples varies significantly from monsoon to post monsoon season. During monsoon season due to high relative humidity, heavy rainfall and less turbulence in the atmosphere PM_1 concentration is found to be significantly lower than post monsoon .Elements which are of mainly crustal origin and mostly associated with coarse medium size range like Ca, Mg, Fe found to be higher in post monsoon also the PM1 mass concentration increases significantly from monsoon to post monsoon season due to low humidity, less rainfall which allows the re suspension of crustal dust. In the post monsoon season the variability in PM_1 concentration is higher than in monsoon season because in monsoon season almost all the days are calm and cloudy while in post monsoon season some of the days are cloudy and other days are sunny and windy (A chakraborty 2009).

The paper contributes to $PM_{2.5}$ and PM_{10} concentrations in terms of temporal and horizontal distribution in Buenos Aires. The measurements were carried out for one year. During this period, particulate matter (PM) was continuously measured at one reference station and alternatively for shorter time periods at six different sites. The cold season, which had the lowest values of the ventilation coefficient, indicated higher probabilities of poor air quality and this was confirmed by the higher concentrations of PM_{10} and $PM_{2.5}$ measured. The correlation between PM_{10} and $PM_{2.5}$ concentrations and frequencies of wind directions showed that the concentrations during land wind events exceeded the Buenos Aires $PM_{2.5}$ annual limit value. The ratio of $PM_{2.5}$ to PM_{10} was 0.44, which indicates the coarse particles (>2.5 μm) originated from road dust, soil re-suspension and abrasion processes are the dominated fractions of PM. Results showed that $PM_{2.5}$ was more homogeneously distributed over the city than PM_{10}(Arkouli et al. 2010).

In this study, seasonal source apportionment of $PM_{2.5}$ aerosol is attempted for five rural/remote sites in Europe. Source types are lumped into primary emissions from fossil fuel combustion and biomass burning, bio aerosol, and secondary organic aerosol from precursors emitted by fossil and non-fossil sources. It has been found that while fossil-related sources predominate EC throughout the year at all sites, the sources of OC are primarily biogenic and markedly different between summer and winter. In winter biomass burning primary emission is the main source, with sizable additional contribution from fossil fuel combustion. In contrast, in summer secondary organic aerosol (SOA) from non-fossil sources becomes predominant (63–76% of TC), with some contribution of SOA from fossil fuel combustion. The results agree well with recent findings of other authors who established the predominance of biogenic SOA for rural sites in summer in Europe (Gelencsér et al. 2007).

Aerosol samples in the size range up to 2.5μm were collected from January to December, 2005 at New Delhi, India, as a pilot experiment and analysed for organic (Oxalate and Formate) and inorganic (Sulfate, Ammonium, Nitrate, Potassium, Chloride, Sodium, Calcium and Magnesium) chemical components. Initial results show that the mean annual average $PM_{2.5}$ concentration was 98.7μg/m^3, which varied between 38 to 285μg/m^3. The water soluble inorganic fraction constituted only 9% of $PM_{2.5}$ with $SO4^{2-}$, $NH4^{+}$ and $NO3^{-}$ being the dominant ions followed by potassium. Annual cycle shows higher concentration of $PM_{2.5}$ during winter season (October to January) and the lowest during monsoon. It is attributed to the enhanced production of aerosols and prevailing meteorological conditions. The $PM_{2.5}/PM_{10}$ ratio (0.86) coupled with the Hy SPLIT air-mass back trajectories indicated that $PM_{2.5}$ was dominated by fine particles (Tiwari et al. 2008).

PM samplesfrom Shinjung station in New Taipei City, Taiwan (PM_{10}, $PM_{2.5}$ and $PM_{0.1}$) were investigated. A dichotomous sampler (Andersen Model SA-241) and a MOUDI (MSP Model 110) were used to collect samples simultaneously over a 24-h period from May 2011 to November 2011 at Shinjung station. Elemental analysis were done using ion coupled plasma mass spectroscopy (ICP-MS) and ionic compounds by ion chromatography (IC). The annual average concentrations of PM_{10}, $PM_{2.5}$ and $PM_{0.1}$ were found to be 39.45 ± 11.58, 21.82 ± 7.50 and 1.42 ± 0.56 μg/m^3, respectively. Positive Matrix Factorization (PMF) was used to identify PM sources. Five types of sources were identified, including soil dust, vehicle emissions, sea salt, industrial emissions and secondary aerosols, and contributions estimation were also carried out using PMF. The enrichment factors (EF) of crustal sources were calculated using Al as a reference metal for the trace metal species to identify the sources. Conditional probability functions (CPF) were computed using wind profiles and factor contributions. CPF analysis were used in identify local point sources. The obtained results propose a competitive relationship between anthropogenic and natural sources over the monitoring station (Gugamsetty 2012).

Lead in atmospheric suspended particles was fractionized using simple acid extraction to assess differences in chemical properties of lead from roadside and residential areas. Results suggest that 0.1 M–HCl extractable fractions of lead at the roadside area are significantly higher than those obtained at the residential area, especially for the coarse mode of the particulate samples. Moreover, the solubility characteristics of the roadside particulate lead have partially overlapped with those of the road dust samples. The XANES spectra for coarse mode of particulate lead also nearly correspond to that of the road dust collected around the roadside area. These results indicate effects by the re–suspension of road dust to the roadside air. This might suggest that specific lead compounds do not exist exclusively in atmospheric particles but exist as mixtures or unknown complexes (Funasaka et al. 2013).

2.4. Sources of PAHs:

Identification of the PAHs sources is important due to their toxicity. PAHs sources can be classified broadly into pyrogenic, petrogenic and biological (Tolosa et al. 1996). Pyrogenic PAHs are formed whenever organic substances are exposed to high temperatures under anaerobic conditions in a process called pyrolysis (Blumer 1976). Pyrolytic processes such as the destructive distillation of coal into coke and coal tar, or the thermal cracking of petroleum residuals into lighter hydrocarbons which also includes incomplete combustion of motor fuels in cars and trucks, the incomplete combustion of wood in forest fires and fireplaces, and the incomplete combustion of fuel oils in heating systems. These pyrogenic processes occur at temperatures ranging from about 350^{o}C to more than 1200^{o}C.

PAHs can form during the incomplete combustion of organic substances or are found in petroleum products, it is not as well-known that PAHs can be produced biologically. For example, they can be synthesized by certain plants and bacteria or formed during the degradation of vegetative matter (Blumer 1976). Thus, their mode of formation can be either natural or anthropogenic.

2.4.1. Industrial sources of PAHs:

The significant PAHs sources are coke oven, aluminium production, iron and steel foundries, coal gasification and coke production. PAHs are generally emitted to the ambient air from industries such as petroleum refining and thermal power plant. PAHs also readily emitted in occupations where coal tar, pitch, asphalt and shell oil are used.

2.4.2. Vehicular sources of PAHs:

Incomplete combustion of diesel and gasoline are the main sources of vehicular emission. Diesel run vehicles, gasoline run aircrafts are identified as the sources of PAHs.

2.5. Predominant PAHs source profile/ markers

The following Table 2.2 PAHs have been identified as markers for various sources in urban atmospheres:

Table 2.2 Source Markers or fingerprints of PAHs

Source of PAHs	PAHs markers/fingerprints
Coal combustion	Phenenthrene, fluorathene and pyrene;
Coke production	Anthracene, phenenthrene and benzo(a)pyrene;
Incineration	Pyrene, phenenthrene and fluoranthene
Wood combustion	Benzo(a)pyrene and fluoranthene
Industrial and oil burning	Fluoranthenepyrene and chrysene
Petrol powered vehicles	Benzo(ghi)perylene, indeno (123-cd)pyrene and coronene
Diesel powered vehicles	Fluoranthene and pyrene with higher ratios of benzo(b)Fluoranthene , and benzo(k)fluoranthene, plus thiophene compounds

2.6. Fate and transport of PAHs:

PAHs present in the atmosphere are found majorly in vapour and solid phases. In solid phase PAHs are found in the adsorbed form over the particulate matter. PAHs with low vapour pressure will readily adsorb to the particulate matter compared to the higher vapour pressure compounds.

PAHs are removed from the ambient air by both wet and dry depositions. Dry deposition occurs when PAHs adsorbed to particles settle down in the absence of precipitation (Manahan 2000). Dry deposition rates dependant on adsorbent particle and meteorological conditions. Wet deposition is defined as the removal of pollutants adsorbed onto particulates out of the atmosphere by precipitation, as well as the dissolution of vapour phase contaminants into precipitation(Rebecca M. Dickhut and Kurt E. Gustafson 1995). The amounts of PAHs removed from the atmosphere by wet deposition vary depending on the phase.

(Jonathan O. Allen 1997)studied polycyclic aromatic hydrocarbons (PAHs) and oxygenated PAHs (OPAHs) which are mutagenic air pollutants formed as by-products of combustion. After formation and emission, these compounds partition between the gas phase and atmospheric aerosols. The environmental fate of PAHs and OPAHs depend on their distribution between the gas and particulate phases among particle size fractions. Particle size is also has major effect on the scavenging process from the atmosphere and critically influences the deposition in the lungs. The large sized particles tend to impact on the upper regions of the lung and small particles diffuse to the surface of the alveoli.

2.7. Mode of exposure and daily intake of PAHs:

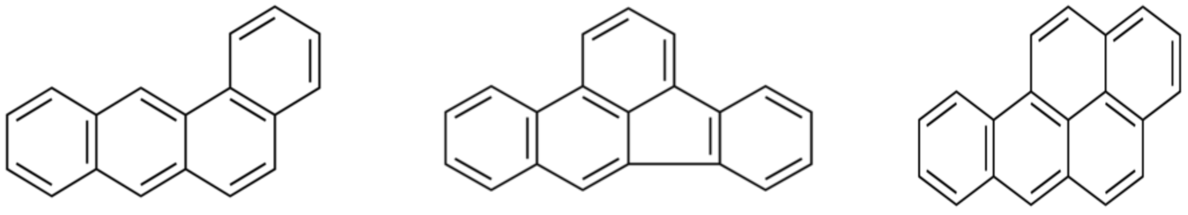
Human exposure to carcinogenic PAHs can occur through several ways due to their ubiquitous presence in the environment. An increase in the PAHs level in urban atmosphere is of much concern because of the size of the population involved and continuous exposure of the pollutants. PAHs compounds can easily reach human body by inhalation of polluted air, inhalation of tobacco, Ingestion of contaminated and processed food or water and dermal contact

- Air Inhalation - The intake of B(a)P by inhalation of polluted ambient air depends on the occurrence of PAHs in air. For example, an exposure to relatively high concentration of 50 ngB(a)P/m^3 and a deposition rate of 40% from 20m^3 air inhaled per day, the daily intake would be 400 ng of B(a)P.

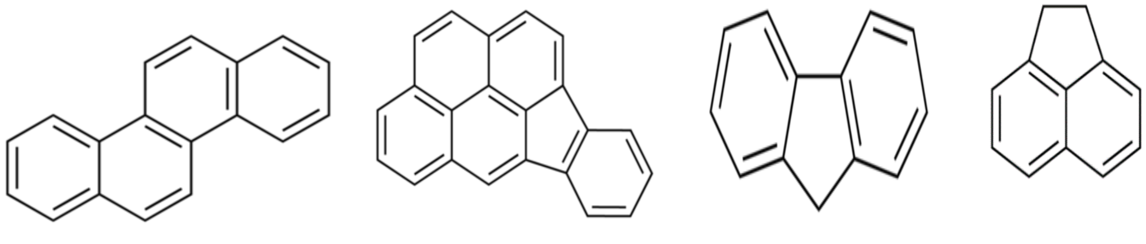
- Tobacco/Cigarette Smoking - Tobacco accounts for 30% of total mortality due to cancer every year. More than 70 PAH compounds have been analyzed in cigarette smoke. Smokers have eight times more probability of cancer attacks than a non-smoker.

2.8. Carcinogen PAHs:

Some PAHs are classified as potential carcinogens. The benzo (a) pyrene is classified as the most potent carcinogen(Sutherland, J., B.F. Rafii 1995). IARC classified the PAHs into possible carcinogens and probable human carcinogen based on potential carcinogenicity (Table 2.2). PAHs attached to particulate matter may directly enter into human body which in turn cause lung irritation. PAHs exposure showed the respiratory problems and behavioural effects. Dermal contact with PAHs may cause redness, blistering, and peeling. Chronic exposures PAHs may result in Cancer and also Reproductive Effects and problems in unborn baby’s development such as organ systems damage (lungs, liver, skin, and kidneys) Figure 2.1 shows molecular structures and Table 2.3 represents physicochemical properties of seven carcinogenic PAHs from this study.



Benz(a)anthracene **Benzo(a)pyrene** **Benzo(b)Fluranthe**



Chrysene **Indeno(1,2,3-c,d) Pyrene** **Fluorene** **Acenaphthene**

Fig 2.1 Structure of polycyclic aromatic hydrocarbons

Table 2.3 Physical and chemical properties of PAHs

Carcinogenic PAHs	No. of Rings	Molecular Weight (g/mole)	Water Solubility (mg/L)	Log K_{ow}	Cancer classification	
					USEPA	IACR
Benzo (a) pyrene	5	252.53	0.0023	6.06	B2	2B
Benz(anthracene)	4	228.29	0.0100	5.61	B2	2A
Benzo(b)fluranthene	5	252.30	0.0012	6.04	B2	2A
Chrysene	4	228.00	0.0020	5.90	B2	2A
Indeno(1,2,3)pyrene	6	276.30	0.0620	6.58	B2	2B
Fluorene	3	166.22	3.4000	4.18	NA	3
Acenaphthene	3	154.08	1.9000	3.98	NA	3

a) ATSDR, (1995), Mehdi et al. (2013) b) Cancer class from the U.S. Environmental Protection Agency (U.S. EPA) classifications B2 = probable human carcinogen.

Cancer class from International Agency for Research on Cancer (IARC). 3=not classifiable; 2A = probable human carcinogen; 2B = possible human carcinogen; Monitoring and detection of PAHs is of concern as PAHs concentration in the various cities around the world witnessed significant increase Table 2.3 (CPCB)

Table 2.4. Levels PAHs in different cities of the world

City	**Bangkok** (ng/m^3)	**Bravo Murillo, Spain** (ng/m^3)	**Londrina, Brazil** (ng/m^3)	**Tainan, Taiwan** (ng/m^3)	**Ohio (Columbus) U.S.** (ng/m^3)		**Delhi** (ng/m^3)
Duration	June'96-Apr '97	Jan-Dec, 2001	Jan 14-29, 2002	Winter,2003	-		1993 - 2000
No.of samples	6	-	14	116	-		
Naphthalene	0.25	-	97.7±10.3	2570-13500	-		
Phenenthrene	0.3	0.205±0.059	348±32.7	88.9-532	20.22-122.6	37.37	0.2 – 0.9
Anthracene	0.21	0.047±0.031	31.1±6.137.9±7.9	36.6-202	2.14 - 21.79	2.72	0.2 – 1.4
Fluoranthene	0.25	1.049±0.323	-	33.7-584	10.93-27.47	13.44	0.6 – 1.9
Pyrene	0.13	0.381±0.144	39.8±8.9	42.4-229	5.04-8.55	7.67	0.7 – 2.9
Benzo(a)anthracene	1.06	0.457±0.104	1.4±0.3	30.8-92.5	0.42-2.35	1.28	1.1 – 3.7
Chrysene	1.12	0.633±0.301	3.8±0.8	-	0.70-5.5	2.36	1.6 – 3.5
Benzo(e)pyrene	2.47	-	-	71.1-136	0.23-2.06	1.67	2.2 – 5.4
Benzo(b)fluoranthene	0.94	-	-	78.0-977	-	-	1.0 – 6.3
Coronene	1.82	-	-	-	0.13-1.68	1.44	-
Indenol	0.71	-	-	22.5-80.4	0.24 - 2.25	1.27	1.0 – 8.4
Benzo(a)pyrene	1.7	0.341±0.163	-		0.07-2.75	1.38	1.9 – 3.5
Flourene	-	-	140.2±17.3	10.4 - 429	-	-	-
Reference	Oanh et al, 2000	Castellano et al, 2003	Tavares et al, 2004	Tsai et al, 2004	Somenath, 1992		Tyagi, 2004

2.9. Advent of urban air quality management plan:

(Laxen D 1993) proposed that Air Quality Management Plan (AQMP) is a program to ensure the control of emissions to protect public health and welfare. (Longhurst et al. 1996), used the concept of Local Air Quality Management Plan (LAQMP) to emphasize the distribution of power at community level with strong communication and cooperation between actors of air quality management. However, it is reported that AQMP is a system for design and implementation of monitoring, management and policies within an urban area(Larssen et al. 1997), which further lead to the development of a software toolwhich combines air quality models with other software modules like geographical information systems, databases, expert systems and statistical analysis tools(Karatzas 2002). This tool helps in interpreting the complex interactions between various atmospheric, emission, land use and topographic parameters.

(Friedman 2001)work to estimate the impact of changes in transportation and commuting behaviours during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma resulted in a 16.1 % of decrease in PM and 13 – 30 % of Ozone during Olympic Games period. Theobtained data supported in further efforts taken to reduce air pollution and improve health via reductions in motor vehicle traffic.

The study on emission and concentration distribution of vehicular pollutants in the urban area of Beijing by (Hao and Wang 2005) using a mathematical dispersion model, showed that there was decrease in CO (74 %) and (NOx) 67 % concentrations.

(Tonne et al. 2008)performed a study on Air pollution and mortality benefits of the London Congestion Charging Scheme (CCS) proposed in February 2003, which alleviated the traffic congestion in Central London. The results depict that CCS, a localised scheme targeting traffic congestion, appears to have modest benefit on air pollution levels and associated life expectancy. Greater reductions in air pollution in more deprived areas are likely to make a small contribution to reducing socioeconomic inequalities in air pollution impacts.

(Johansson et al. 2009)have studied the effects of congestions tax on air quality and health. Vehicles travelling in and out of the charge cordon were charged for every passage during weekdays. The amount due varied during the day and was highest during rush hours (20 SEK ¼ 2.2 EUR, maximum 60 SEK per day). The modeled changes in road traffic results pose that this system resulted in a 15% reduction in total road use within the charged cordon. Total traffic emissions in this area of NOx and PM_{10} fell by 8.5% and 13%, respectively. Air quality dispersion modelling was applied to the existing scenario, with a permanent congestion tax system like the Stockholm Trial, the annual average NOxand PM_{10}concentrations would be lower by 12% and 7%along the most densely trafficked streets.

Simulation of Air Quality in Kanpur city (Sharma and Chandra 2008)using ISCST3 dispersion model and applied scenarios revealed a 48% underestimation due to unaccountable or unidentified sources, trans-boundary movement of SPM, and calibration errors in the model. The model is calibrated to overcome the error with the observed values and the calibration factors were used to obtain results for other scenarios. The study observed that introduction of CNG in different sectors would reduce the emissions substantially resulting in a 45%reduction of SPM concentrations. The scenarios PAV and PTS specifically target the vehicular sector and reduce the SPM concentrations only by 1% and 2%, respectively. The IS scenario targets the industrial sector and a 27% emission reduction is obtained. The maximum SPM concentrations reduction was found to be 81%in this scenario. This reveals that the maximum SPM concentration obtained locations were found to receive most of its emissions from industrial zones that have been shifted under this scenario. The road dust emissions were targeted in SWEEP scenario and predict10%reduction total emission loads. However, the decrease in maximumSPM concentrations is only 3%. There was agreater reduction found for average concentrations due to the uniform distribution of emission loads across the city.

Table 2.5.describes various Urban Air Quality Management (UAQM) Strategies undertaken to maintain the acceptable air quality in India reported by Central Pollution Control Board India (CPCB, 2006 and CPCB, 2010b).

Table 2.5. Urban air quality management strategies of India (CPCB, 2006 and CPCB, 2010b)

UAQM Strategies	Current status in India
Improvement in fuel quality	Properly implemented
Stringent emission norms	Properly implemented
Fitting of catalytic converter	Partially implemented
Inspection & Maintenance program	Partially implemented
Use of low and zero emission vehicles	Partially implemented
Banned on street parking	Partially implemented
Ban on entry of old vehicles, smoky vehicles and heavy goods vehicles into Low emission zone	Partially implemented
Support for cycling	Not implemented
Congestion charging	Not implemented
Low emission zone	Not implemented
Reduction in diesel vehicles	Not implemented

2.10. Source apportionment study:

Source apportionment is the estimation of the contribution of different sources to pollution. There are two fundamental approaches to determine and quantify the impacts of air pollution sources.

(1) Top-down approach or Dispersion Model

(2) Bottom-up approach or Receptor Model

2.10.1. Top down approach:

The Top-down approach begins by identifying pollution sources and their emission strengths, which are converted to emissions and then by utilizing meteorological patterns predicting pollution advection (movement) and compositions over time and space. Much is published under this approach to better understand the air pollution at urban, regional, and global levels.

The top-down approach results in

- Identification of the potential sources - physically and quantitatively (energy and emission strengths) in the city or the region
- Description of the physical and chemical processes with potential to impact the advection and chemistry of the pollutants, this includes the local topography and meteorological features
- Documentation of the formation of the secondary pollutants, along with the primary (via emissions) such as sulphates, nitrates, ozone, hydrocarbons, etc.
- A baseline mapping of the pollution and hot spots for the area of interest.
- Apportionment of the pollution by source.

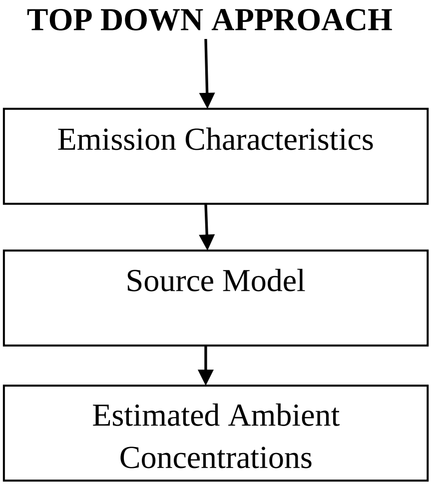


Fig. 2.2. Process flow diagram of Top-Down Approach

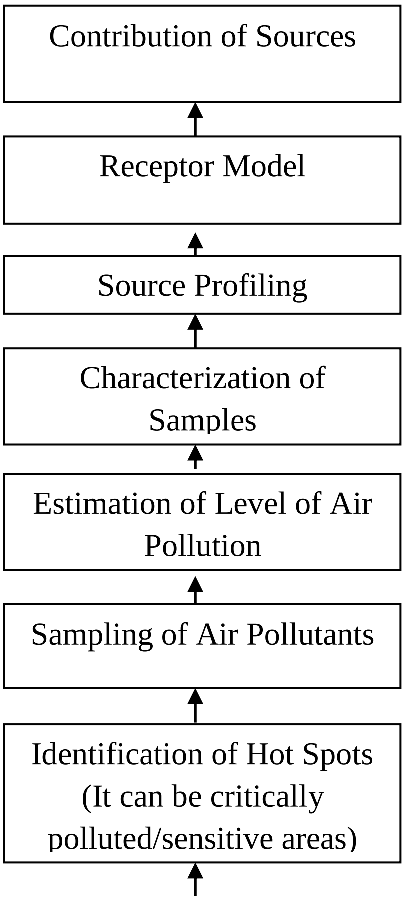
2.10.2. Bottom-up approach:

The bottom-up approach initiates by carrying out sampling ambient air in a given area and assuming the likely pollution sources by matching common physico-chemical characteristics between source and ambient air samples. Bottom-up approach offers the promise of quantifying the relative contributions of the different sources contributing ambient air pollution, where rather little may be currently known. In addition to that, bottom-up methods may require few atmospheric measurements and relatively simple analysis.

The bottom-up approach results in

- Identification of the hot spots with critical pollutant levels in the city or the region
- Identification of the chemical composition of the particulate pollution, following the chemical analysis of the measured samples
- Description of the source impact estimates, following receptor modeling based on the source profiles and statistical analysis
- Differentiation of the primary and secondary pollution at the hot spots
- Apportionment of the pollution by source

In a regulatory world, the bottom-up approach is more acceptable, primarily due to the involvement of direct pollution measurements at hot spots, analysis of the samples and determining (statistically) the various sources contributing the pollution at that particular spot. On the downside, the measurement points are few, due to the costs involved in monitoring and chemical analysis, which is (and can be) compensated by a comprehensive top-down approach to cover as many hot spots, and a better mapping of the pollution sources in the city.



BOTTOM-UP APPROACH

Fig. 2.3. Process flow diagram of Bottom-Up Approach

2.10.3. Source apportionment methodology:

The Source apportionment methodology offers information on the different source types responsible for the observed pollutants, Estimates of source contribution for multiple locations over multiple time periods, average source strength at various hot spots, a basis to develop realistic and cost-effective strategies to reduce particulate pollution. The figure illustrated below presents an outline of the necessary steps involved in a source apportionment study.

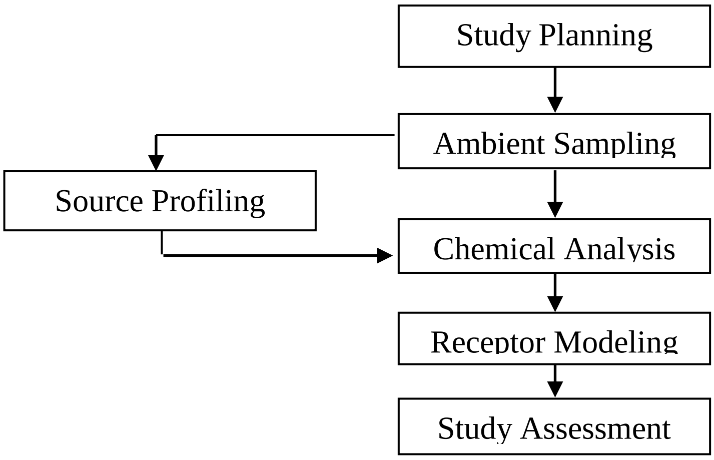


Fig. 2.4 Schematic Representation of Source Apportionment Methodology

2.11. Emission inventory studies

An emission inventory is a database that comprises of lists, by source, the amount of air pollutants emitted into the atmosphere from the community for a given time period. The inventory is utilized in establishing emission standards for current and future scenario.The critical components of air quality planning and modelling are current and future year inventories. The ultimate goal of the planning process is to identify and achieve emission patterns that do not result in violations of ambient air quality standards.

For listing the sources of air pollution, sources are classified as

1. Point sources (industries, mining, fuel terminal, etc.)
2. Area sources (biomass burning, road construction, electric generators, fuels, filling stations, dry cleaning, etc.)
3. Line sources (on-road an off-road mobile source) and
4. Natural sources (wind-blown dust, sea spray, etc.)

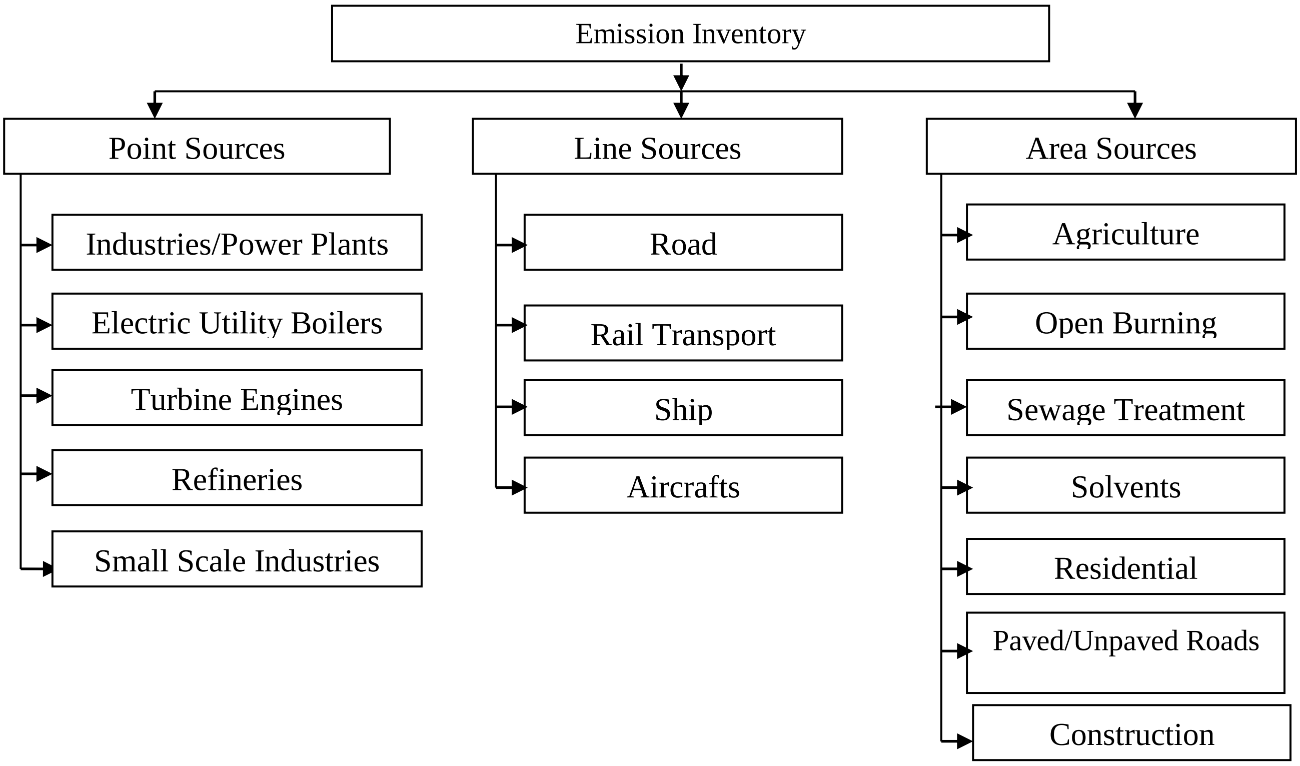


Fig2.5. Schematic representation of emission inventory study

Point sources: Air pollution sources identified on an individual facility basis or as a single source are called point sources. The emission characteristics of individual facilities vary widely and each facility is examined individually. Point sources include industrial and non-industrial stationary equipment or processes that can be identified by name and location and are considered significant sources of air pollution emissions. Point sources are subcategorized into combustion emission, process emission (industry-specific), fugitive emission (uncontrolled material handling, conveyers), storage tank emission, and the emissions from miscellaneous solvent usage.

Line sources: Non-stationary or mobile sources are called as line sources or mobile sources. On road, mobile sources include emission from vehicle exhaust of different categories, evaporative emission and crankcase emissions. Off-road mobile sources include aircraft, trains, boats, construction, and agricultural equipment.

Area sources: Stationary air pollution sources not identified individually are called area sources. Area sources also include the diverse, un-permitted small sources which individually do not emit significant amounts of pollutants but which together make an appreciable contribution to the emission inventory.

Area source can be sub-categorized into:

1. Stationary source fuel combustion emissions (industrial, commercial, residential fuels, biomass or waste-derived fuels) and evaporative emission
2. Fugitive source for VOC emission (organic solvent utilization, fuel and organic material storage and distribution, waste treatment and disposal, pesticide usage)
3. Fugitive source for particulate matter emission (paved and unpaved roads, agricultural tilling and harvest activities, construction activities, wind erosion) and
4. Fugitive source for ammonic emission (livestock, fertilizer usage, domestic ammonia)

Natural sources: Natural sources include sea spray, lightning, volcanoes, windblown dust and transpiration from vegetation.

2.11.1. Process involved in emission inventory:

Adetailed emission inventory, in its simplest form, follows the process summarised as in the figure given below.

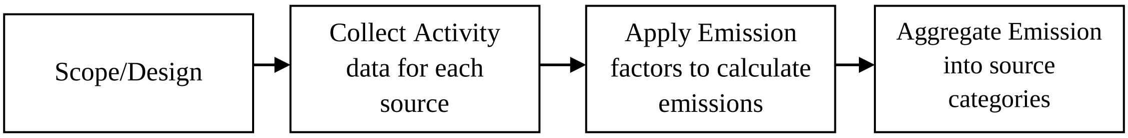


Fig 2.6. Process flow diagram for emission inventory

As depicted in Fig 2.6, the first step involves in framing scope and objectives of the study. The study area, pollutants and source categories must be selected and the preferred temporal and spatial resolutions are defined. The second step involves the collection of activity data. The data obtained should be compiled for all sources included in the inventory and must be classified according to the type of process or activity. Emission factors are then applied to the activity data to estimate the amount of emissions provided by each individual source. These results are subsequently combined into the required source groupings to quantify relative contributions to total emissions within the study area.

2.11.2. Emission factors

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per mega gram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average).

The general equation for emissions estimation is:

$$\mathbf{E = A \times EF \times (1-ER/100)}$$

Where:

- E = emissions;
- A = activity rate;
- EF = emission factor, and
- ER =overall emission reduction efficiency, %.

2.11.3. Application of emission inventories

Emission inventories arevaluable air quality management tools. They identify the major sources contributing to contaminant emissions and can (depending on the inventory) provide a breakdown of the sub-sources within each category. This information allows air quality managers to identify problem sources and introduce measures to reduce emissions from those sources. These inventories can also assist with identifying unknown sources and highlight areas where air quality monitoring may be advisable. Emission trends may be established over time (provided that inventory methodologies between years are comparable), thus enabling the effectiveness of air quality strategies on emissions to be evaluated.

2.11.4. Limitations of emission inventories

Conversely, there are a number of limitations in estimating source contributions using emission inventory.

- In general, the estimates taken in consideration are based on averaged activity rate data or fuel consumption, and averaged emission rates, leading to an approximate measure of the various sources average contribution through emission inventories. Also, determination of variations on a day-to-day basis cannot be done through these inventories.
- Secondly, these emission inventories do not quantify biogenic or natural emissions effectively. There seems to be a difficulty in quantifying Marine aerosol and soil emissions using current inventory techniques, since robust activity rates are not readily available.
- Thirdly, and most significantly, contributions of sources to emissions are likely to differ from contributions to actual measured concentrations.
- Atmospheric processes including condensation, vaporisation, agglomeration and secondary reactions can significantly change the characteristics and concentrations of emissions subsequent to discharge. Dispersion or box models must be used in conjunction with emission data to relate emissions to estimated concentrations.

Even though emission inventories are limited in scope and application, they are a vital source of information and are needed to determine and justify air quality strategies. Methods such as receptor models provide greater flexibility, can quantify natural and secondary contributions and attribute source contributions directly to concentrations on a daily basis.

2.12. Receptor modeling:

Source apportionment methods, that directly relate source emissions to quantitative impacts on measured concentrations, have been developed in recent years. Two methods are commonly used. The first is a prognostic mathematical modelling technique, known as a dispersion model, which takes atmospheric chemistry and physical processes impacting on emissions into account. These models simulate pollutant transport and transformation from the point of emission to a receptor site where the pollutant concentration is predicted. Although used widely internationally, these techniques have been limited by the resources and time required to set-up and conduct modeling.

However, rapid advances in technology will allow them to be used routinely in the near future.

The second method, receptor modelling, is a cost-effective, diagnostic technique. It takes speciated concentrations measured at a receptor (or point of impact) and works in reverse to determine the contributions of sources to measured concentrations. The relationship between measured concentrations and emission sources is inferred, without the need for simulating dispersion processes, as the model works directly with concentrations rather than emissions. The information required to conduct receptor modelling is simply knowledge of the chemical composition of particulate concentrations at the source and receptor. Additional information such as meteorology, topography, location and magnitude of sources, while useful for interpretative purposes, is not vital (John H . Seinfeld and Spyros N. Pandis 1998). As modelling of these processes is not needed, analytical costs are significantly reduced. Nevertheless, a good understanding of local air quality processes is essential to allow factors resolved during the modelling to be appropriately interpreted and identified.

2.12.1. Types of receptor modeling:

There are two different categories of receptor models: single-sample and multivariate methods. Single-sample methods, such as chemical mass balance (CMB), require independent analyses to be performed on each available sample. Multivariate methods require multiple samples and simultaneously analyse correlations between measured concentrations of chemical species. Highly correlated species are assumed to be derived from the same source, and many samples are required for the analysis to provide valid source identification. Receptor models, depending on the model used, can provide chemical profiles for each source and apportion PM concentrations to those sources on an observation (daily) basis.

2.12.2. Chemical Mass Balance (CMB)

The CMB approach was developed in the 1970s and used widely from the 1980s onwards, for air quality assessments. Detailed knowledge of the chemical and physical characteristics of gases and particles measured at both the source and receptor are required to identify sources and quantify their contributions to concentrations at a receptor site. Source apportionment by CMB is conducted by solving a series of linear equations. Each equation represents receptor concentrations for each chemical species as a linear sum of products of source compositions and contributions. The solution is derived through inverse variance weighted least-squares linear regression. The model calculates contributions from each source, uses input data uncertainties to weight data as required and estimates uncertainties associated with the derived source contributions.

The Chemical Mass Balance Model fundamental receptor equations vary according to the assumptions made with respect to the nature of the emissions under investigation as

(i) Fundamental receptor model equation for Non-reactive species;

(ii) Fundamental receptor model equation for Reactive species.

For Nonreactive Species:

$$m_i = \sum_{j=1}^{p} F_{ij} M_{aj}$$

Where,

m_i = Massof the ith species measured at the receptor;

p = No.of.Sources;

j = Source;

F_{ij} = Fractional Composition term of the ith feature from the jth source;

M_{aj} = Mass contribution from the jth source.

For Reactive Species:

$$m_r = \sum_{j=1}^{p} \alpha_{rj} F_{rj} M_{aj}$$

Where,

m_r = Mass of reactive species measured at the receptor;

α_{rj} = Miller's Coefficient of Fractionation

$F_{rj} = E_{rj} / E_{aj}$, i.e. The ratio of reactive species to the sum of conserving species measured at the source with a size segregating dilution sampler.

2.12.3. Limitations of chemical mass balance method:

- A complete information is necessary on the composition of emissions for each and every significant source (emission profiles) - these data are often limited
- The source profiles are often site-specific so cannot easily be generalised - e.g. local sources of soil and road dust are usually different from location to location

- Emission profiles vary over time so data based on short runs of measurements may not be representative - e.g. road vehicle emissions change due to short-term changes in driving behaviour and ambient conditions, and long term changes in fuel composition, vehicle design, emission control technology, and vehicle fleet composition
- This method does not directly identify the presence of unknown and unspecified sources, so a considerable proportion of the measured pollutant load may be unexplained
- Chemically similar sources may result in analytical problems
- This method does not apportion secondary pollutants, but secondary compounds can be used to identify the contribution from sources outside the studied area.

2.13. Multivariate methods:

Multivariate models are based on the assumption that chemical species from the same source are correlated and that grouped correlations represent an emission source. These methods extract a number of factors (representing sources) from a speciated dataset, provide a chemical profile for each source (factor loadings) and indicate source significance on an observation (daily) basis using factor scores. Several types of multivariate model are commonly applied to air quality data.

These include

FA- Factor Analysis

PCA-Principal Component Analysis

PMF- Positive Matrix Factorization

SMCR- Self Modelling Curve Resolution and

TTFA-Target Transformation Factor Analysis.

2.13.1. Principal Components Analysis (PCA)

PCA, in its simplest form, transforms a complex matrix dataset (e.g. a chemical species concentration matrix) into a series of independent, mutually uncorrelated variables (known as principal components-8 or factors). These components attempt to explain a maximum of the data variance, with most of the variance accounted for in the first component. The second component accounts for the maximum of the remaining variance and so on. A concentration measurement made at a receptor site is the linear combination of the eigenvectors or principal components.

The principal component solution is obtained by singular value decomposition of the data matrix. The matrix may be described as:

$$\mathbf{C = LF}$$

where,

C = a data matrix of m rows of species and n observations arranged in columns

L = the component loading matrix

F = the matrix of component scores

PCA produces a matrix of elemental factor loadings, used to compile elemental profiles for each source, and factor scores, where each observation and factor is scored to indicate days when a particular factor or source is important.

One of the limitations associated with PCA is that it only identifies the main patterns of variation present in a dataset.

2.13.2. Positive Matrix Factorisation (PMF)

PMF is a relatively new form of factor analysis developed by (Paatero and Tapper 1994). Like PCA, PMF analyses a data matrix and identifies a series of independent factors. PMF conducts a least squares analysis incorporating a data point weighting system to account for errors associated with individual concentration observations. The data are not normalised and factor scores, output in real units, may be regressed directly against PM mass to obtain daily source contributions.

PMF, is essentially a weighted, constrained, least-squares fit technique. The model solves the following:

Matrix equation: $\mathbf{X = GF}$

Where X is known and G and F are unknown.

The equivalent equation in component form, including the residual matrix, is:

(i = 1...m, j = 1...n)

Where, X_{ij} = m X n data matrix

i = observation

j = element

m = number of chemical species

n = number of observations

p = number of factors

h = factor

g = i X h matrix with (P) factors and (n) observations

f= h Xj matrix with (m) species and (P) factors

e_{ij} = residual matrix with m species and n observations

2.14. Dispersion modeling:

(Taylor et al. 1920) introduced the concept of diffusion in modelling. The first large scale atmospheric diffusion experiments were conducted by the Meteorological Department of Chemical Defence Experiment Station at porton in England in 1921. These experiments essentially led to the establishment of the Gaussian Character of the average cross wind concentration. These theoretical and experimental studies provided the background for subsequent development of atmospheric diffusion theory.

(Sutton 0. G 1932) indicated the methodology in developing the Gaussian Diffusion Theory. (F. A. Gifford 1961)defined the usage of routine meteorological observations for atmospheric dispersionestimation. However, (Pasquill F. 1961)developed stability classification scheme which establishes relationships between cloudiness to stability classes ranging from A to Fand meteorological observations of wind speed measured at 10 m, solar insolation.

Table 2.6 PASQUILL'S chart

Wind speed (m/s)	**Day incoming Radiation**			**Night cloud conditions**	
	Strong	**Moderate**	**Slight**	**Thinly overcast or > 4/8 low cloud**	**< 3/8 cloud**
2	A	A – B	B	---	---
2 – 3	A – B	B	C	E	F
3 – 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
>6	C	D	D	D	D

(Note: Neutral class D should be assumed for overcast conditions during day or night)

Table 2.7. Stability class description

Stability Class	Class description
A	Extremely unstable
B	Unstable
C	Slightly unstable
D	Neutral
E	Stable
F	Extremely Stable

(F. A. Gifford 1961) modified the Pasquill‟s dispersion scheme by converting the original formulation for dispersion into the more familiar plume spreads used in the Gaussian equation.

(D. Bruce Turner 1970) converted the qualitative description of solar insolation into ranges of solar elevation angle and cloud cover. This is why the Pasquill scheme is generally referred to as the Pasquill-Gifford-Turner (PGT) scheme.

Briggs (1975) released the results of his extensive work on plume rise estimates.

(Pasquill,F. 1983) provide an appraisal of the essential scientific background of the dispersion of wind borne material injected into the lower atmosphere. They offer an appreciation of the physical processes which bring about the dispersion of plumes of gas or fine particles, e.g. those released from power station and factory chimneys, and present a description of that dispersion in terms of meteorological parameters.

2.14.1. Gaussian plume model:

In this model, the concentration distribution of the pollutants from a continuous source perpendicular to the plume axis is assumed to be a Gaussian distribution in both vertical and horizontal planes and the plume expansion is given by the standard deviations. The original equations were developed by Sutton and further improved by Pasquill and Gifford.

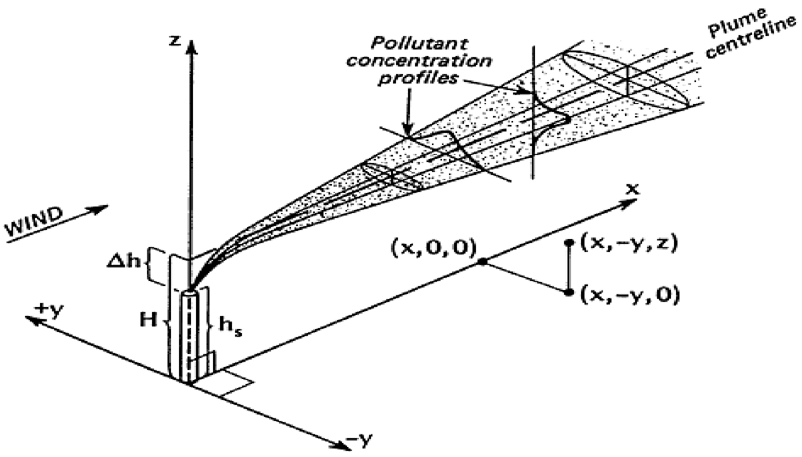


Fig.2.7. Gaussian plume model

In this model, the concentration of the pollutant C is inversely proportional to the wind velocity u in the x direction. The solution for the plume concentration is given by

$$C(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left\{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right\}\left(\exp\left\{-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right\}\right)$$

Where,

C(x,y,z) = Concentration of pollutant A along the centre line at any point (x,y,z) in space, (µg/m^3)

Q = Source strength, i.e., pollutant emission rate (µg/s)

U = Average wind speed at the source level at stack height (m/sec)

H = Effective stack height, H+Δh, where is H is physical height of the stack (m) and Δh = plume rise (m)

σ_y = Standard deviation of the pollutant in horizontal cross wind

σ_z = Standard deviation of the concentration of the pollutant in the vertical direction

No single basic physical model has been able to uniquely describe the turbulent diffusion process in the atmosphere. Instead Slade (1968), Hanna *et al.*, (1982), Pasquill and Smith (1983), Panofsky and Dutton (1984) explain two basic concepts to describe the turbulent diffusion process from which the Gaussian model is derived. The gradient transport or Eddy Diffusion model derived from a mass balance applied to differential volume. From the statistical theory of turbulence a model arises which produces the same result as the

Eddy Diffusion model. The statistical theory of turbulence can be applied to turbulent diffusion.

Based on the above concepts a Gaussian model can be derived to find out the time averaged pollutant concentration. The derived Gaussian model will be a function of source strength, average wind speed, dispersion coefficients in y and z directions (the lateral directions and vertical directions whereas the downwind distance is measured as x). We assume that the dispersion coefficients, σ_y and σ_z, are functions of the travel time and thus, the downwind distance x (Karl B.Schnelle, Jr. et al 2000). The accuracy of Gaussian diffusion model has been reviewed in a note prepared by the American Meteorological Society, Committee on Atmospheric Turbulence and Diffusion.

2.14.2. Industrial source complex model

The Industrial Source Complex (ISC) model is a steady-state Gaussian plume model most frequently used to assess pollutant concentrations from a wide variety of sources. A decade ago, it was the most commonly used model for assessing downwind concentrations from chemical and petroleum processing plants. The ISC model can be used for

- Stack design studies
- Combustion source permit applications
- Regulatory variance evaluation
- Monitoring network design
- Control strategy evaluation for State Implementation Plans
- Fuel (e.g., coal) conversion studies
- Control technology evaluation
- Prevention of significant deterioration

ISC model uses Pasquill- Gifford- Turner (PGT) scheme for calculating dispersion coefficients in the downwind directions. So, there are some disadvantages in ISC model since pasquill scheme suffers from following disadvantages.

- The relationships between meteorological observations and the variables, such as turbulent intensity, that control dispersion are semi-empirical. They are based on a small number of field studies involving surface releases, and are thus unlikely to apply to conditions different from these field studies.

- The six distinct stability classes, A to F, do not reflect the continuous nature of turbulent intensities, as well as the range of possible values.
- It does not account for variations in surface properties, such as roughness length and albedo, which can play a major role in determining the relationship between meteorological observations and the turbulence properties that control dispersion.
- The scheme-stability classes and dispersion curves- does not account for vertical variation of turbulent properties relevant to dispersion. It applies primarily to near surface releases, and is unlikely to provide an adequate description of releases in the middle of the boundary layer.

2.14.3. AERMOD:

Since Pasquill first proposed his dispersion scheme in 1961, our understanding or micrometeorology and dispersion have advanced considerably. AERMOD incorporates these advances to overcome the problems that we have identified in the Pasquill scheme.

2.14.3.1. Brief history of AERMOD:

- Developed by AMS/EPA Regulatory Model Improvement Committee (AERMIC)
- Proposed as Replacement for ISCST3 Model in April 2000
- EPRI-sponsored PRIME (Plume Rise Model Enhancement) Downwash Algorithms Incorporated in AERMOD in 2001
- Promulgated as EPA"s Preferred Model on December 9, 2005.

2.14.3.2. Meteorology and dispersion in AERMOD:

The earlier sections depict the necessity of information on the statistics of the turbulent velocities in addition to the mean properties of the atmospheric boundary layer in estimating plume spread. However,Pasquill scheme provides a surrogate for the turbulent intensity through the stability class but does not estimate turbulent velocities directly. The limitations of stability class approach that we discussed in the last section have been overcome by AERMOD using the two steps mentioned below:

- The available meteorological observations are used as inputs to atmospheric boundary layer models to construct vertical profiles of wind, temperature, and turbulent velocities in the atmospheric boundary layer. A processor called AERMET is used in accomplishing the desired task.

- AERMOD uses the outputs of AERMET in estimating pollution concentrations emitted from various sources. The empirical dispersion curves, proposed by Pasquill (1961) and Briggs (1974) are not used in AERMOD as in ISC. The micrometeorological variables from AERMET have been used to construct dispersion curves on the basis of current understanding of dispersion. These dispersion curves are found to be consistent with those used in ISC. But, unlike ISC, the dispersion formulations apply to elevated as well as surface releases.

The minimum inputs to AERMET are 1) wind at one level, 2) temperature at one level, 3) cloud cover, and 4) an early morning upper air sounding. In addition, AERMET requires and information on surface roughness, albedo, and Bowen ratio. This information, coupled with meteorological inputs 2) and 3), are used in a surface energy balance to estimate the sensible heat flux, which in turn is used to estimate to estimate the surface shear stress exerted by the wind speed. The sensible heat flux as a function of time is then used to compute the mixed layer height during the course of the day. The upper level temperature sounding provides the temperature gradient above the mixed layer, which controls the rate of growth of the mixed layer. The night time boundary layer is governed by the computed surface shear stress. The surface parameters, sensible heat flux and surface shear stress, and the boundary layer height are used in boundary layer models to construct the profiles of wind, temperature, and turbulent velocities required by AERMOD. AERMET can also incorporate measured values of these parameters in these profiles. AERMOD uses the meteorological information supplied by AERMET in dispersion models that reflect the state of the art. Unlike ISC, AERMOD explicitly accounts for the variation of meteorological parameters with height by defining effective values that represent averages over the plume depth.

Some of the features included in AERMOD are:

- Enhanced dispersion in urban areas caused by increased surface roughness and heat flux.
- Treatment of downwash associated with buildings.
- Inclusion of models to account for dispersion caused by updrafts and downdrafts in the daytime boundary layer. The Gaussian distribution in the vertical does not provide an adequate description of the concentration distribution.

- Consistent treatment of surface and elevated releases.
- Treatment of terrain effects on dispersion. Plumes are allowed to impact on the terrain when the flow does not have energy to surmount the hill.

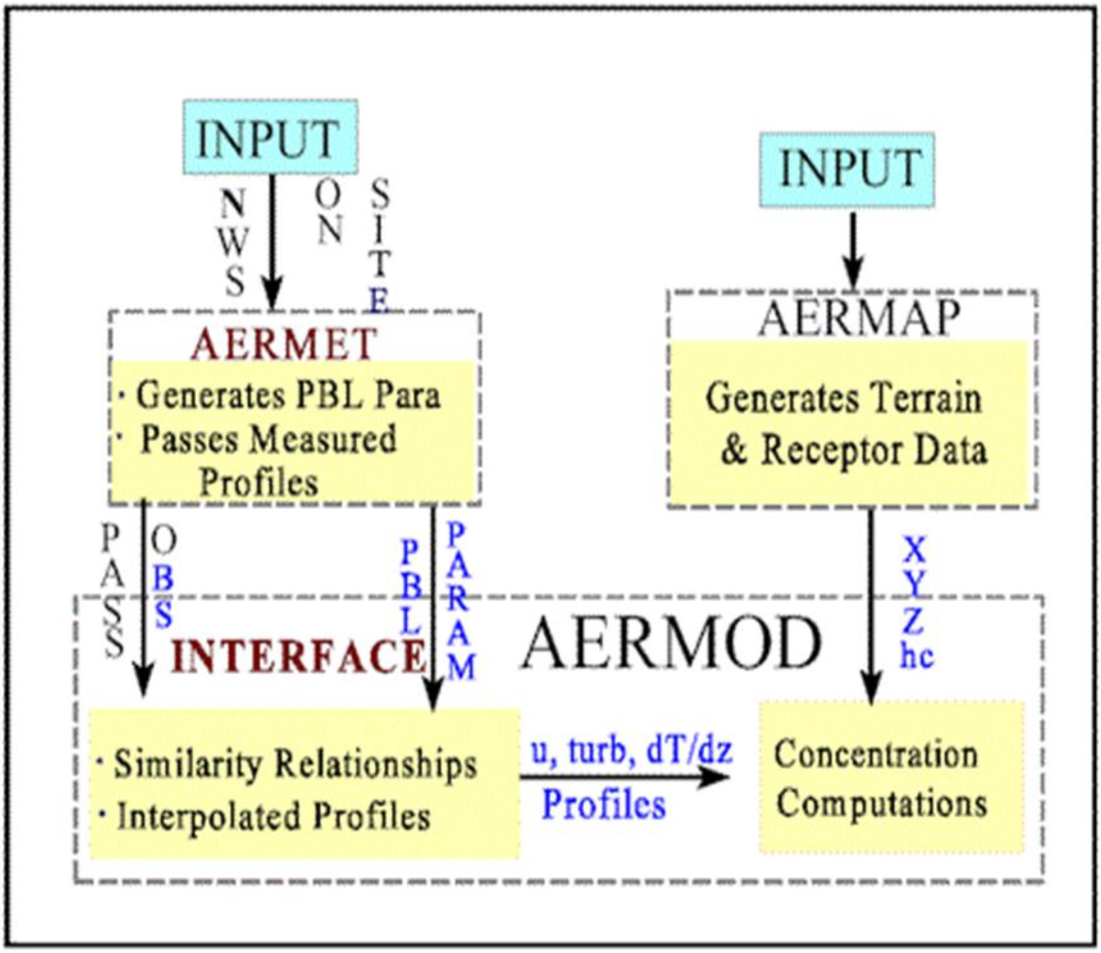


Fig.2.8.AERMOD modeling system structure

2.14.3.3. Performance of AERMOD

(Gulia et al. 2014) carried out performance evaluation of different model for urban air quality management in Indian cities. The performance of ISCST3, AERMOD and ADMS-Urban model have been evaluated in predicting CO, NO2 and $PM_{2.5}$ concentrations for different climatic conditions, i.e. winter and summer season. They have compared the Observed pollutants concentrations with predicted values from ISCST3, AERMOD and ADMS-Urban model for the Income Tax Office (ITO) intersection, one of the busiest traffic junctions in Delhi. Emission rates have been calculated from the Vehicles flowing on the roads near the junction. They observed the results in the different forms. The results indicated that all three models have performed satisfactorily for predicting $PM_{2.5}$ concentrations in both seasons. Models are under predicted for CO and $PM_{2.5}$ concentrations in both winter and summer period. However, ISCST3 and AERMOD are over predicted the NO2 concentration in winter period. Also, they observed that the change in pollutant concentrations with respect to the meteorological data given in the models. All three models are found sensitive to the wind speed and direction and perform poorly in calm condition.

Performance evaluation of two commonly used regulatory air quality models across the world namely AERMOD and ADMS-Urban was been performed using statistical measures for a sub-tropical region of Delhi in India. They have considered emissions from motor vehicles and thermal power plants of power sector (Badarpur, Indraprastha and Rajghat). Emissions were estimated over a grid network of 26 × 30 km with a resolution of 2 km covering most of the urban area of Delhi. The selected area covers that part of Delhi where most of the urban activities take place and includes all major sources of air pollution. Data for observed ambient air concentrations of total suspended particulate matter was collected for the years 2000 and 2004 in terms of average daily concentrations from the seven monitoring stations of CPCB and compared with predicted concentrations. Both the models have a tendency towards under prediction of concentrations. Irregularities and assumptions in emission input can be a possible cause. ADMS-Urban shows greater tendency towards under prediction as compared to AERMOD (Mohan et al. 2011).

The air quality around Urban Amritsar, India, was assessed using AERMOD Gaussian dispersion model. Emission inventory has done on burning of crop residue, burning of wood for cooking, emissions from coal based tandoors, emissions from Diesel generator set, emissions from vehicles, re-suspension of road dust and industries. The dominant wind direction during the study period is south east (14 %) with wind speed in the range of 0.5–2.1 m/s. AERMET has used surface meteorological data in estimating the convective mixing height. AERMOD has been set up and run for the study period of June, 2012 to December, 2012, (summer and winter).All possible sources such as traffic, wood burning; open burning of crop"s residue in the surrounding areas, restaurant tandoors, Diesel Generator sets, re-suspension of dust and all small and large-scale industries within 5 km radius has been set up for the model runs. The key pollutants were found to be emitted from industries, vehicular activity, and wood burning in the free kitchen, road dust re-suspension, and coal-based tandoors in restaurant, Diesel Generators operation during power failure and crop residues burning in the nearby fields. Among these sources, re-suspensions of road dust (47 %) followed by industries (31 %) are found to be contributing PM_{10} particles. Additionally, introduction of battery-operated vehicles (3-wheelers, 100 % and 4-wheelers, 50 %) were found to reduce the raise in PM_{10} and NOx concentrations by 14.5 and 21.7 %, respectively. Likewise, traffic restriction through the Hall gate and air pollution control equipment installations at free kitchen shall reduce the increase in pollutant concentrations significantly. Also, signification reduction of PM_{10}, NOx and SO_2 concentrations at heritage site were found to be 2.7, 9.8 and 7.0 %, respectively, due to implementation of all three scenario together (Gulia et al. 2014).

A prediction study carried out on respirable particulate (PM_{10}) and lead pollution over Madurai, India during the period of July 2005 to June 2006 using AERMOD was used for predicted concentrations ranged from 121.7 to 226.9 µg/m3 for PM_{10}. It is found that that Periyar bus stand and Goripalayam had the highest observed and predicted PM_{10} concentrations, which would have contributed directly from the traffic emissions, biomass usage for cooking, re-suspension of paved and unpaved road dusts, vehicular emissions, and diesel-based generator sets in these sampling sites. The results clearly reveal that the database generated pertaining to the predicted and observed concentrations behaved consistently, even though AERMOD under predicted pollutants by a factor of 1–1.5 in the concentrations for all the sites of measurements. The reasons for lower predicted concentrations might be attributed to the lack of viable emissions factors from non-transportation sources (Vijay Bhaskar et al. 2008).

Atmospheric dispersion modeling is the mathematical simulation of how air pollutants disperse in the ambient atmosphere. It is performed with computer programs that solve the mathematical equations and algorithms which simulate the pollutant dispersion. The dispersion models are used to estimate the downwind ambient concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases. They can also be used to predict future concentrations under specific scenarios (i.e. changes in emission sources). Therefore they are the dominant type of model used in air quality policy making. They are most useful for pollutants that are dispersed over large distances and that may react in the atmosphere. For pollutants that have a very high spatio-temporal variability (i.e have very steep distance to source decay such as black carbon) and for epidemiological studies statistical land-use regression models are also used.

2.15. Dispersion coefficients

The dispersion coefficients $\sigma_y$and σ_z are the standard deviations of the plume concentration in cross wind and vertical directions respectively. These terms reflect the growth dimension of the plume as a function of atmospheric stability, distance travelled and travel time from the source, emission rate (Q), effective height (H), wind speed, etc. Turbulence motions or eddies exist in the atmosphere all the time and they vary in size and intensity. Small-scale eddies dominate the plume growth near the point of emissions. Larger eddies affect the concentration over greater distance. Therefore, to compare the calculated and measured values of σ_y and σ_z, the sampling period must be specified.

2.16. Description of AERMODv9.1

AERMOD (version 9.1.0) is a steady-state Gaussian plume air dispersion model which was developed by the U.S Environmental Protection Agency and incorporates planetary boundary layer concepts. The growth in plume is determined by turbulence profiles that vary with height. AERMOD calculates the convective and mechanical mixing height. Under unstable conditions, AERMOD plume displacement is caused by random convective velocities. In comparison with the industrial source complex (ISC) model AERMOD holds an improved approach in characterizing the fundamental boundary layer parameters and vertical profile of the atmosphere along with better representation of plume buoyancy, penetration, and urban night time boundary layer (Cimorelli et al. 2005).AERMOD is capable of estimating pollutant concentration from point, line and area sources. Sources can be individually modeled rural or urban. The model simulates transport and dispersion from multiple points, area, or volume sources based on an up-to-date characterization of the atmospheric boundary layer. Sources may be located in the rural or urban areas, and receptors may be located in simple or complex terrain.

The model incorporates the effects of increased surface heating from an urban area on pollutant dispersion under stable atmospheric conditions and this treatment is a function of city population. For simulating the pollutant dispersion the model requires hourly surface data and upper air meteorological observations. The model the pollutant to be Gaussian in formulating probability distribution function for the concentration of pollutants in vertical as well as horizontal directions in a stable boundary layer. However, in the convective boundary layer, the horizontal dispersion is Gaussian, and the vertical distribution is represented by a bi-Gaussian probability distribution function.

AERMOD consists of two pre-processors, i.e. AERMET (meteorological pre-processor) and AERMAP (terrain pre-processors). AERMET requires hourly cloud cover observations, surface meteorological observations such as wind speed and direction, temperature, dew point, humidity and sea level pressure and twice-a-day upper air soundings. The gridded terrain data (digital elevations model data) is used by AERMAP to calculate a representative terrain- influence height (*hc*), which is uniquely defined for each receptor location and is used to calculate the dividing streamline height.

The meteorological variables that are generated based on meteorological observations using a similarity relationship are required for vertical distribution. The model possess a processor named AERMET to calculate planetary boundary layer parameters viz. friction velocity, Monin–Obukhov length, convective velocity scale, temperature scale, mixing height, surface heat flux by using local surface characteristics in the form of surface roughness, and Bowen ratio in combination with standard meteorological observations (wind speed, wind direction, temperature, and cloud cover). These above mentioned parameters are used in calculating vertical profiles of wind speed, lateral and vertical turbulent fluctuations, and the potential temperature gradient in AERMOD. The model is intended to be significant in simulating pollutant dispersion for short-range (<50 km).

SCOPE AND OBJECTIVES OF THE WORK

The detailed literature review gives us the clarity about the work done on size and number concentration of particulate matter and their health effects worldwide. Many of the literatures cited herewith give a clear understanding on the importance of investigation on the sources relating to the contribution of particulate matter. It also reveals that particle sizes play a vital role on health effects of human beings and deterioration of the environment; several epidemiological studies show the necessity for particulate matter investigation as they are responsible for many respiratory and chronic disorders.

Mangalore being a chief port city of the Indian state of Karnataka is developing rapidly in all directions viz. in the field of education, industry and commerce. This development attracts people all over the country for education and industrialization purpose which leads to an increase in usage of land and resources present. Hence there is an increase in transportation, domestic fuel usage etc., and leading to a rise in the emissions from these resources. Thus development depreciates the air quality of Mangalore proving to a need for detailed study about the air borne particles dispersed in the ambient air. No such study has been done on the ambient air of Mangalore city for the quantification of the various particulate matter pollutants contributing to the atmosphere.

The main objective of the work is to collect ambient air samples from prominently polluted places in Mangalore. The collected samples will undergo suitable chemical processes to estimate the composition of elements and ions. The data obtained from the analysis will further be utilized in a suitable receptor model to apportion the sources and their contribution to the ambient atmosphere. Hence a source apportionment technique, which is one of the effective air quality management system (AQMS) which can contribute in a cost effective manner to improve existing systems or even as the first step to begin with. An AQMS can be utilized to analyze the data and predict the sources contributing to the particulate matter in ambient air.

The following objectives will be carried out

- To estimate Particulate matter (PM_{10} & $PM_{2.5}$) concentration in ambient air of Mangalore city.
- To determine the elemental and ionic composition of Particulate matter (PM_{10} & $PM_{2.5}$).
- To investigate and trial the source apportionment method that quantifies the emission contributions.

- To carry out Sampling of $PM_{2.5}$ particles in schools premises located at the hotspots of the city and characterize the particles to identify the sources contributing them.
- To extract PAHs from air samples (PM_{10} particles) to carry out chemical profiling and source apportionment studies to quantify the emissions contributions.
- To study the dispersion of traffic emissions on air quality of Mangalore city using AERMOD software.

CHAPTER 3

MATERIALS AND METHODS

3.1 SAMPLING AND ANALYSIS

3.1.1 Outdoor samples collection:

The air samples were collected as per Guidelines proposed by Central Pollution Control Board (CPCB) for the measurement of ambient air pollutants volume – I for a period of 24 hours (8×8×8) at a flow rate of 1m^3/min. The samples were collected every 8 hours (06:00 to 14:00, 14:00 to 22:00, and 22:00 to 06:00) on Glass Fibre Filters (Whatman GF/A 20.3×25.4 cm) using High Volume RSPM Samplers (Envirotech APM460 BL) for PM$_{10}$ particles. For PM$_{2.5}$particlescollection a PTFE filter paper of 47mm diameter was used in a fine dust sampler at a flow rate of 16.67 LPM (Instrumex PM$_{2.5}$ Fine Dust Sampler, Model no. IPM-FDS-2.5µ/10µ)

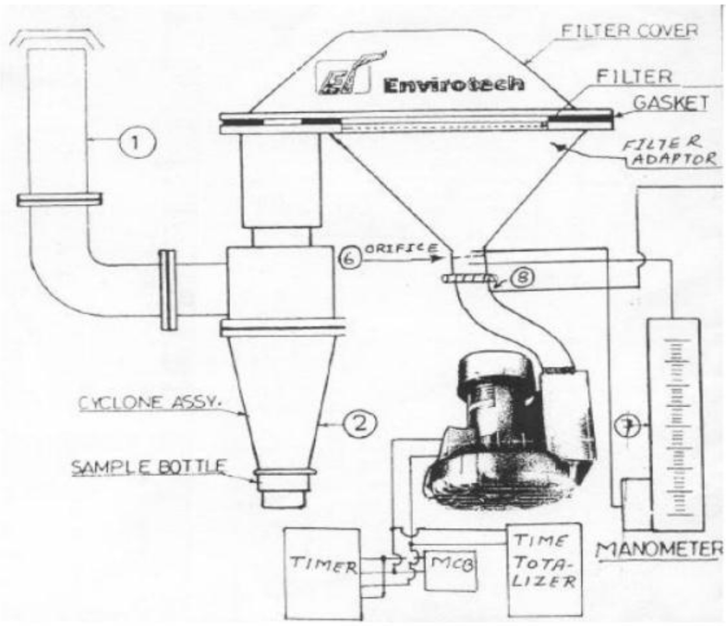


Fig.3.1. Schematic representation of High Volume Sampler for PM$_{10}$, RSPM, TSP

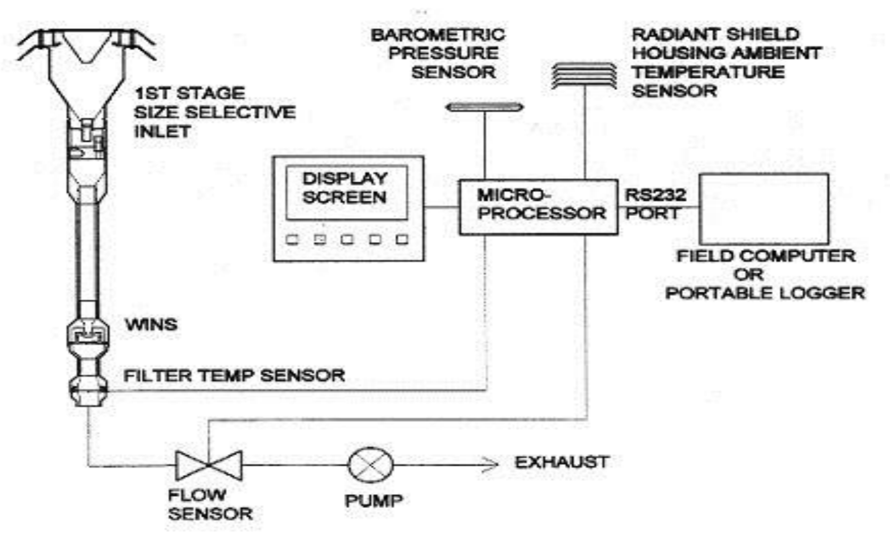


Fig.3.2. Schematic representation of $PM_{2.5}$ sampler

3.1.2 Gravimetric analysis:

The mass concentration of PM_{10} particles were measured by gravimetric technique using weighing balance (Oahu pioneer with accuracy 0.0001g). Simultaneously $PM_{2.5}$ samples were measured by using a micro balance (RADWAG MYA 5.3Y.F) with a precision of ±5 µg with automatic (internal) calibration. The filter papers were kept in a desiccator before and after sampling for 24 hours at a temperature of $27\underline{+}3^0$C and at a RH of 55 $\underline{+}$ 2% to remove the moisture present in them.

Fig. 3.3. PTFE Poly Tetra Fluoro Ethylene Membrane Filters (With Poly Propylene Rings)

3.1.3 Elemental analysis:

The PM_{10} samples collected on glass fibre filters were digested (US EPA IO - 3.1 Compendium Method) in a microwave digester (CEM's MARS 5). The digested samples were then filtered (Whatman No.1) and made up to 50 mL using deionized distilled water (Siemens Labostar, TWF water purification System (Type I, III) of resistivity 18MΩ-cm). Similarly, the exposed filters containing $PM_{2.5}$ samples were cut into 2 equal halves and one part is used for elemental analysis. The half filter paper was divided into small fragments and digested (IO-3.1, 1999) using 5ml of 69% HNO_3 and 15ml of 36% HCl on a hot plate. One third of the solution was retained after digestion. The retained solution was filtered using a whatman 41 filter paper and made up to 15ml using deionized distilled water (Siemens Labostar, TWF water purification system (Type I, III) of resistivity 18MΩ- cm). The obtained samples (both PM_{10} and $PM_{2.5}$) after digestion were transferred to vials and refrigerated until further analysis. These samples were later subjected to Inductively Coupled Plasma Optical Emission Spectrometry (ICP OES) (Agilent 5100) following the USEPA Compendium method IO-3.4 (U.S. EPA 1999) to estimate the elemental composition in them.

3.1.4 Ions analysis:

The exposed filter papers (both PM_{10} & $PM_{2.5}$ samples) were extracted and subjected to the ion analysis as per (SOPMLD064) standards. The filter papers were cut into small fragments and wetted with isopropanol marginally before extraction as the filters are hydrophobic. Further 25 mL of deionized distilled water was added to the filters and the beakers were placed in an ultrasonic bath. The samples were sonicated using baths exposed to ultrasonic waves for 60 min at 60^oC and the sonicated samples were kept overnight. These samples were then filtered using nylon filter discs (25mm, 0.45µm) and were refrigerated until further analysis. The extracted samples were analyzed for ions (anions and cations) using Ion chromatography (Dionex Thermo Corporation ICS 1100).

3.1.5 Collection of schools samples:

The $PM_{2.5}$ samples were collected on a PTFE filter paper using a fine dust sampler (Instrumex $PM_{2.5}$ Fine Dust Sampler, Model no. IPM-FDS-2.5µ/10µ). The sampling was carried out from 8 a.m. to 4 p.m at a flow rate of $1m^3/hr$ in all the four schools. Samples were collected for one complete week for various seasons on both working and non-working days. Particle concentrations of $PM_{2.5}$ in the classrooms were monitored using a

Dust Trak II aerosol monitor (Model No. 8530). This instrument provides online data of the $PM_{2.5}$ particles prevailing in the indoor school environment and the obtained data were then transferred using the Trak Pro software. The obtained samples were then subjected for elemental and ion analysis.

3.1.6 Gravimetric analysis

Filter papers used for sampling were desiccated at temperature 27 $\pm$ 3° C and RH 55 $\pm$ 2% for 24 hours before and after sampling to remove the moisture present in them. These filter papers were weighed using a micro balance (RADWAG MYA 5.3Y.F) having a precision of ±5 µg with automatic (internal) calibration. $PM_{2.5}$ particle concentrations were obtained by estimating the difference in weight of filter papers before and after sampling. The laboratory blanks (n=4) and field blanks (n=4) were collected for carrying out the procedure of QA/QC (U.S. EPA 1999).

3.1.7. Elemental analysis:

The exposed filters were cut into 2 equal halves and one part is used for elemental analysis. The half filter paper was divided into small fragments and digested (IO-3.1, 1999) using 5ml of 69% HNO_3 and 15ml of 36% HCl on a hot plate. One third of the solution was retained after digestion. The retained solution was filtered using a whatman 41 filter paper and made up to 15ml using deionized distilled water (Siemens Labostar, TWF water purification system (Type I, III) of resistivity 18MΩ- cm). The digested samples were transferred to a vial and refrigerated until further analysis. The Elemental composition was estimated using Inductively Coupled Plasma Optical Emission Spectrometry (ICP OES) (Agilent 5100) following the USEPA Compendium method IO-3.4,(U.S. EPA 1999).

3.1.8. Ions analysis:

The exposed filter papers were extracted and subjected to the ion analysis as per (SOPMLD064) standards. The filter papers were cut into small fragments and wetted with isopropanol marginally before extraction as the filters are hydrophobic. Further 25 mL of deionized distilled water was added to the filters and the beakers were placed in an ultrasonic bath. The baths were exposed to ultrasonic waves for 60 min at 60^0C and the sonicated samples were kept overnight. The samples were then filtered using nylon filter discs (25mm, 0.45µm) and were refrigerated until further analysis. The extracted samples were subjected to estimate the ionic composition (anions and cations) using Ion chromatography (Dionex Thermo Corporation ICS 1100).

3.1.9. PAHs extraction:

Each sampled filter paper containing particulate matter was cleaned by ultra-sonication in 5 ml DCM for 15 min. For MIP Extraction of PAHs, decanted solution of sample (leachate) (5 ml) was mixed with 10 mg MIP and agitated in water bath at 100 rpm for 3 hours. The MIP was then separated from the particulate leachates by centrifugation. The PAHs selectively adsorbed on the MIP were re-extracted with 1 ml methanol. This extract was spiked with 1 μgL^{-1} of a mixed standard of PAHs (10 µL) and then analysed for PAHs by fluorescence spectrophotometer. Extraction procedure was followed according to (Krupadam et al. 2009)with modifications.

3.2. Source apportionment

In this study, PM source apportionment is carried out by using Chemical Mass Balance Receptor Model, (CMBv8.2) a type of receptor modeling technique. Inclusive knowledge of the physicochemical composition of particulate matter obtained at both the source and receptor are essential insourcequantification and identification to estimate their contributions to concentrations at any receptor site. The receptor model basic principle may be expressed by an empirical relationship given in Eq. (1). The equation represents the relationship between the measured chemical species concentrations at the receptor site to those emitted from the source.

$$C_i = \sum_{j=1}^{p} F_{ij} \times S_j \qquad \text{———————} \qquad (1)$$

Where $C_i$is the concentrations of the species i, measured at the receptor site, P is the number of sources that contribute, $F_{ij}$is the fraction of the emissions of the species i starting from the source j, and $S_j$the ambient contribution of the source j.

3.2.1 Source profiles:

The source profiles data for Indian scenario have not been compiled enough; thereforethe source profiles required for the obtained elements and ions has been derived from the former studies carried out in India (Matawle et al. 2014; Pipalatkar et al. 2014; Sethi and Patil 2008).

3.3. Sampling sites selection for outdoor sampling:

Design of air quality monitoring includes the factors such as population density, meteorology, topography, etc. During the study, guidelines proposed by CPCB (Central

Pollution Control Board) were followed for the selection of the monitoring stations. Six sampling sites were selected which were representative of Mangalore Region. Final selection of monitoring stations was completed in consultation with the KSPCB committee. Each site description has been presented in next section with a view to bring out the overall characteristics of sites.

Table 3.1 Sampling sites and its characteristics

S.No	Sampling Location	Nature of Site
1	Lady Hill	Residential / Traffic Site
2	City Center	Traffic Site
3	Town Hall	Traffic Site / Commercial Site
4	KMC Attavar	Residential Site
5	KMC Jothi	Traffic Site / Commercial Site
6	KSPCB	Industrial Site

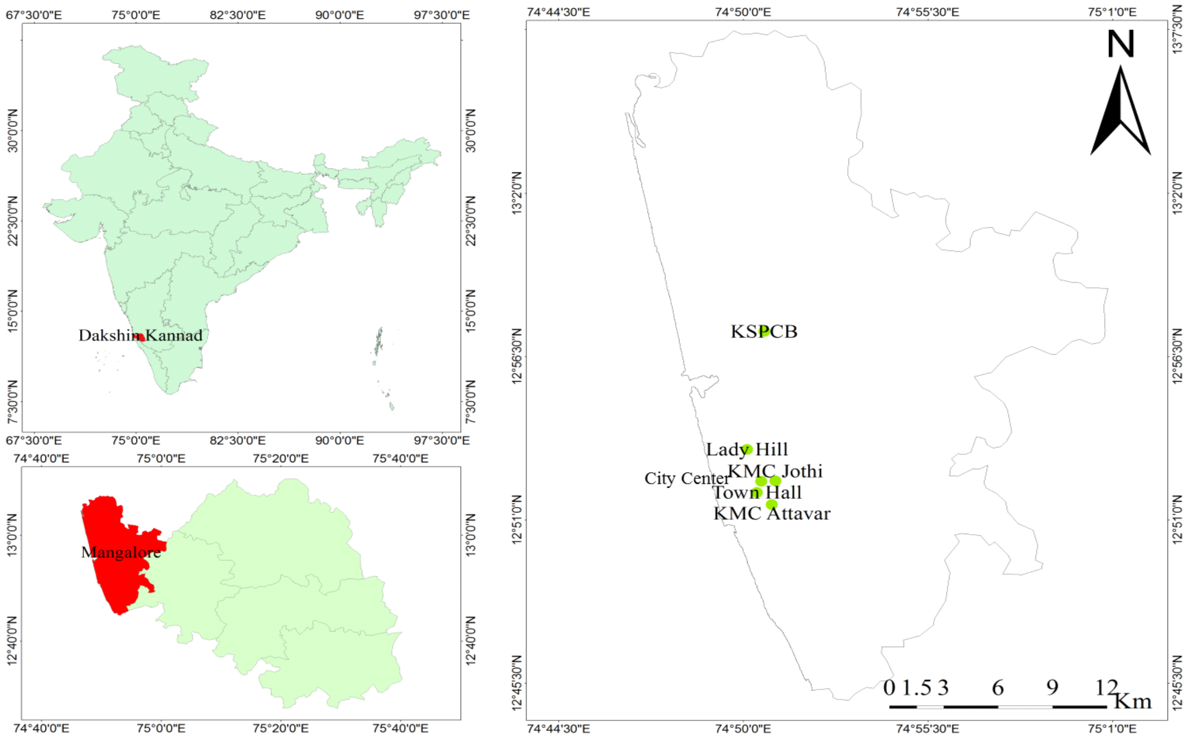


Fig.3.4. Map showing outdoor sampling sites in Mangalore

3.3.1. Lady Hill:

Site description:

Lady hill site located at $12^0$53’21.97’’N and $74^0$50’6.68’’E represents Residential / Traffic site characteristics comprising of a major junction located to a residential area with an ample amount of vehicular traffic polluting the ambient air in that area which is an residential site. The site surroundings also have temple and schools in the vicinity. Thus these conditions make this site an ideal site to be categorized under Residential / Traffic Site.

3.3.2. City Center:

Site description:

City center located at $12^0$52’17.37’’N and $74^0$50’32.00’’E represents Traffic Site. The sampling site is located in one of the major city roads (K S Rao road) in Mangalore city which is encompassed with unparalled traffic due to its smaller and congested roads during peak hours (7:30 to 10:00; 12:00 to 15:00; 19:00 to 21:00) and a moderate amount of traffic during normal hours. Moreover, the site also includes shops, hotels, restaurants and various commercial malls running diesel and kerosene generators during power shut down. The cooking activities from various types of restaurants use different types of fuels starting from wood combustion stoves to LPG stoves. Thus the site is comprised of various viable sources in contributing particulate matter to the ambient atmosphere. Thus these conditions make this site an ideal site to be categorized under Traffic Site.

3.3.3. Town Hall:

Site description:

Town hall site located at $12^0$51’55.20’’N and $74^0$50’24.03’’E represents Traffic / Commercial Site of Mangalore. The site is located in the main junction of the city surrounded by major roads which connects to various parts of the city. Also, the local bus terminal which paves connection to the neighbouring cities (Udupi, Kundapura) is located at a distance of around 300 meters from the sampling site. In addition to that the site is bounded by hospitals, schools, play grounds, major road junctions, commercial malls, roadside restaurants, electrical repair shops and markets accompanying with hefty traffic incessantly, especially during peak hours (hours (7:30 to 10:00; 12:00 to 15:00; 19:00 to 21:00) in Hampankatta road. Thus these conditions make this site an ideal site to be categorized under Traffic / Commercial Site.

3.3.4. KMC Attavar

Site description:

KMC Attavar site located at 12^{0}51’30.70’’N and 74^{0}50’50.88’’E represents Residential Site. The site is located at a distance of around 100 meters from a city roadway with moderate traffic. The site is surrounded by mostly by residential apartments and villas which are known to possess some potential sources for particulates emissions majorly through activities like cooking and waste burning. Thus these conditions make this site an ideal site to be categorized under Residential Site.

3.3.5. KMC Jyothi:

Site description:

KMC Jyothi site located at 12^{0}52’18.62’’N and 74^{0}50’57.33’’E represents Traffic / Commercial Site which is similar to Town hall site. The site is a major traffic junction and connects three busy roadways. This junction drives people from various parts of Mangalore region to major commercial and market areas of the city. Thus the site serves as a major junction for general public to change courses for their work and other necessary activities. Hence the vehicular emission contribution may be high especially public transport which may subsidize a higher concentration of air borne particulates in that site. Also, the site is surrounded by many commercial shops and hotels which may again emit a considerable amount of particulate matter from its various other activities. Thus these conditions make this site an ideal site to be categorized under Traffic / Commercial Site.

3.3.6. KSPCB

Site description:

KSPCB site located at 12^{0}57’20.29’’N and 74^{0}49’7.27’’E represents industrial site. Baikampady Industrial cluster is located at 8 km away on Northern side of Mangalore city. The site consists of a major refinery, storage of crude and finished petroleum products, LPG storage & bottling, fertilizer plant, Pharmaceutical industry, Brewery, Edible oil processing units, Sea food processing units, Lead refining unit, Cashew processing units, Paint & Dispersion unit, Iron ore pelletization plant and Pig Iron plant apart from few engineering, fabrication, plywood plants and ready-mix plants. The roads in the site become gradually unpaved due to the continuous movement of heavy vehicles. Thus these conditions make this site an ideal site to be categorized under industrial site.

3.4. Sampling sites selection for sampling school premises:

The study on school premises have been carried out by selecting four schools located in close vicinity to urban roadways and sub urban highways (Fig), viz., Lady Hill Victoria Girls High School (LHV School), BEM High School (BEM School), NITK Kannada Medium School (KMS School) and NITK English Medium School (EMS School) among all the schools Lady Hill Victoria Girls High School located at 12^{0}53’21.97’’N and 74^{0}50’6.68’’E is found to be situated close to a busy urban junction with higher density of vehicles of various categories. Simultaneously, BEM High school located at 12^{0}52’17.36’’N and 74^{0}50’6.89’’E is found to be in a close proximity to an unpaved urban roadway with on-going constructional activities and surrounded by busy commercial neighbourhood with various combustion activities. Similarly, NITK Kannada Medium School which is located at 13^{0}0’47.44’’N and 74^{0}47’35.55’’E in the suburban area and close to a busy highway (NH66) with a toll booth situated adjacent to a close quarters of the sampling site provides a greater risk of emissions due to vehicular idling and NITK English Medium School located at 13^{0}0’55.15’’N and 74^{0}47’40.57’’E is at a distance of around 100metres from the highway.

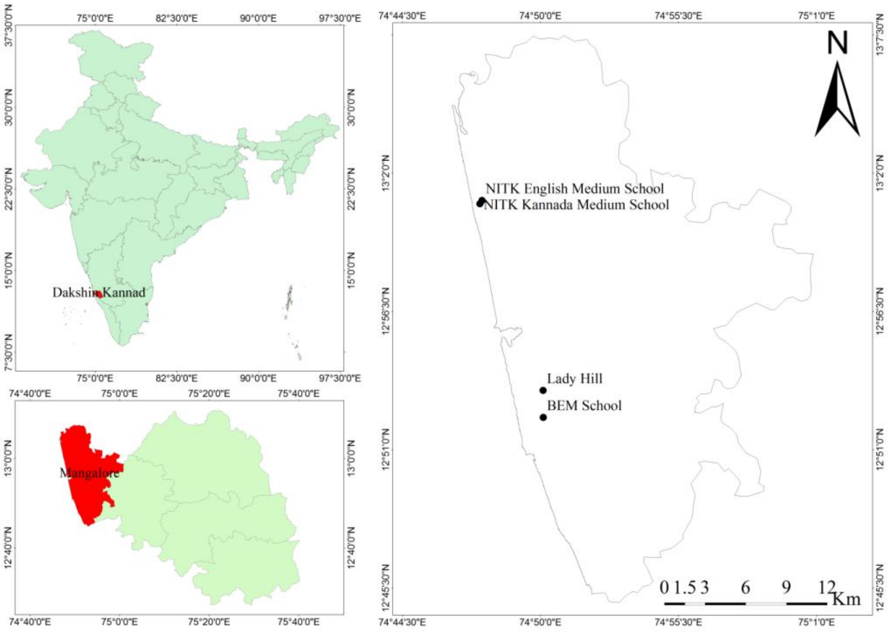


Fig.3.5. Map showing the schools sampling sites in Mangalore

3.5. Dispersion modeling study using AERMOD

3.5.1. Sampling site for AERMOD simulations

Mangalore consists of several major industrial establishments have come up to exploit the potential of this region along the coast of Arabian Sea, North of Mangalore city. Vehicular density has been increased year by year, since the increasing of population due to the industrial establishments. Approximately 200-300 / day vehicles have been registered in Mangalore Road Transport Corporation (RTO) and 41,087 vehicles have been registered in Mangalore RTO in the year of 2015 – 2016. Mangalore city has three types of road i.e. Arterial road (road which is outer side of the city i.e. National Highway), Feeder road (road which connects the National Highway and roads of interior city) and Residential road (road which is on the residential area of the city). In day time, there will be more flow of vehicles in all roads and in night time there will be flow of vehicles in National Highway due to industrial purpose. The study area is 6 km east-to-west and 6.3 km north-to-south as shown in figure. It is divided into grids of 100 × 100 m2 for different receptor location. The sampling sites for monitoring $PM_{2.5}$ are Lady Hill Circle, KMC Jyothi Circle and KMC Attavar areas have indicated in figure.

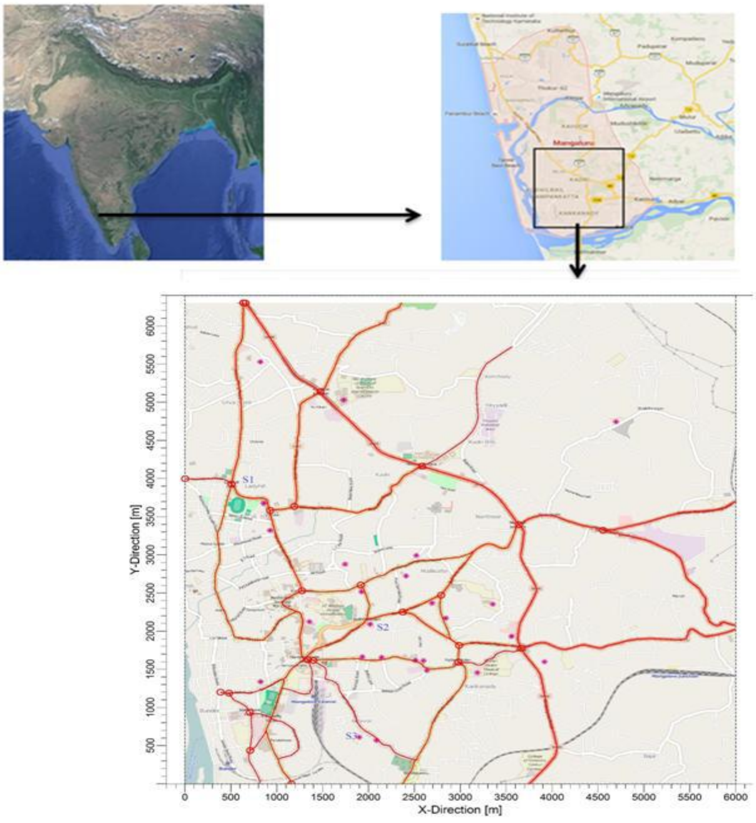


Fig.3.6.Dispersion study area and sampling sites

3.6. Methodology for AERMOD Simulation:

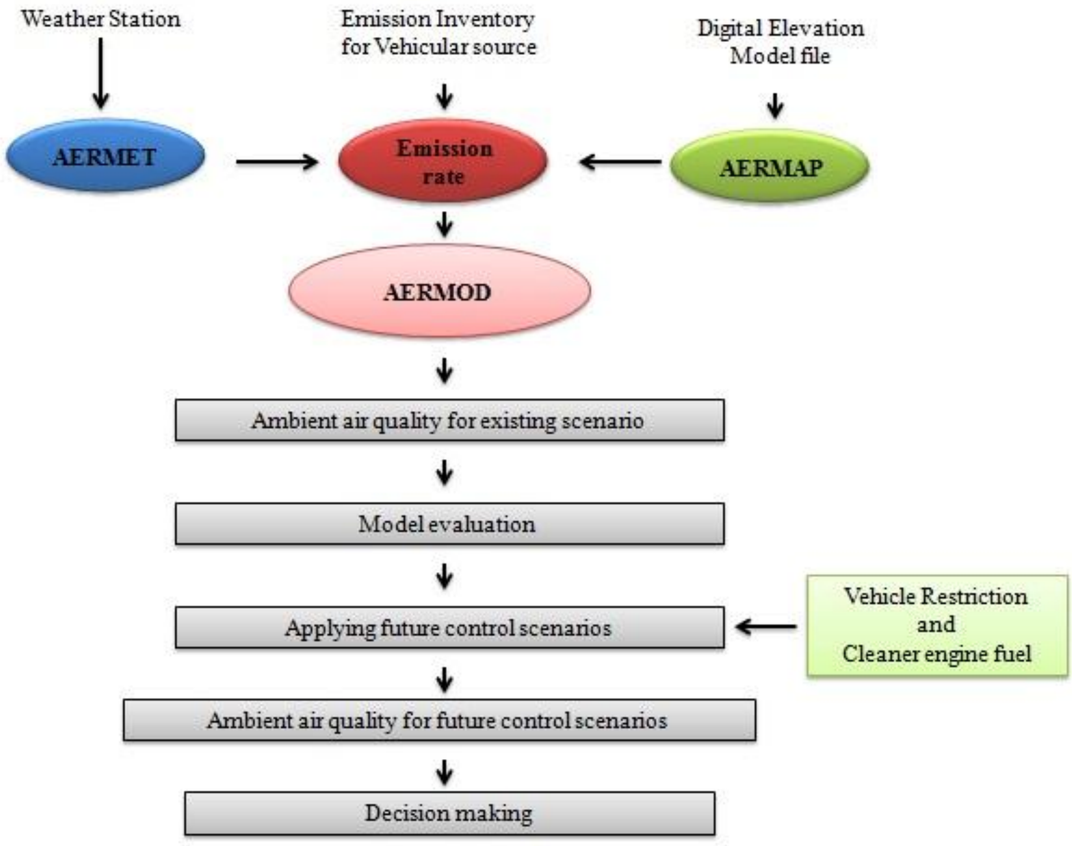


Fig.3.7. Flow Diagram of AERMOD Methodology

3.6.1. Inputs required for AERMOD

The pollutant concentrations from the model would be affected by three main input parameters. These input parameters, have to be given in AERMOD, are as follows:

i. Emission rate

ii. Meteorological data

iii. Terrain data

(i) Emission rate

The emission rate is a function of vehicle emission factor (as a function of vehicle category, fuel type, age profile, etc.) and vehicle activity (traffic volume). Hourly emission rates have been calculated as product of emission factor and vehicular activity data for each road link. All three models have been set up by using time varying emission rates. The emission rate has been calculated using the following equation.

$$P(i) = \Sigma(j)\ \Sigma\ (k)\ N\ (j, k)\ EF\ (i, j, k) \qquad \text{——————} \qquad (2)$$

where,

P(i) = Emissions rate of pollutant ‘i’ (i = $PM_{2.5}$),

N(j, k) = Number of vehicles of a particular type ‘j’ and age of vehicle ‘k’,

EF(i, j, k) = Emission factor for pollutant ‘i' in the vehicle type ‘j’ and age ‘k’ (g/km)

(*Emission factor is taken from ARAI, Pune for exhaust emissions and Abu Allaban *et a*l., 2002, Granell*et al*., 2004 for non-exhaust emissions)

j = Type of vehicle (2W – 2S and 4S, 3W, 4W – petrol and diesel, Bus and Vans, Heavy Commercial Vehicles, Light Commercial Vehicles)

For Area Source,

The emission is based on emissions per unit area. In order to calculate emissions per unit area, we must calculate the emission rate of the source and then divide by the area of the source in meters. In this work, the emissions are calculated for every hour for each type of road (road is considered as rectangular area). Once the area (road) of the source is calculated then divide the emission rate by the area of the source to get a model ready emission rate in g/s/m^2.

With the emission rate, following details have to be given in source pathway of AERMOD software.

- Emission Rate - in grams per second per meter squared, g/s/m^2.
- Release Height – height above ground in meters
- Length of x side – length of east-west direction
- Length or y side – length of north-south direction

Vehicles counting were done for each type of roads in Mangalore city to determine the emission rate and the traffic pattern is characterized. The traffic pattern in Mangalore city roads are discussed in the forthcoming section.

3.6.2. Traffic pattern

Traffic data has been collected at study region by counting actual number of vehicles flowing on the four types of roads i.e. Arterial road, Feeder road and Residential road in the Mangalore city. The traffic pattern is observed and this is shown in figure 3.10. Maximum traffic has been observed mostly between 8:00 and 10:00 am (morning peak hour) and between 5:00 and 7:00 pm (evening peak hours). The traffic fleet is composed of 2 Wheeler – 2 Stroke (1%), 2 Wheeler – 4 Stroke (57%), 3 Wheeler (5%), Petrol Car (11%), Diesel Car(14%), Light commercial Vehicles (3%), Heavy Commercial Vehicles

(4%) and Buses and Vans (5%). Figure 3.11 shows that percentage of vehicles flowing in the Mangalore city. Emission rate for specific type of vehicle was prepared by using Vehicle Kilometer travelled (VKT) and respective emission factor. Emission factor for exhaust emissions from vehicles were taken from Automotive Research Association of India (ARAI), Pune (2007). For non-exhaust emissions, emission factors were taken from Abu-Allaban*et al*., 2002 and Granell*et al*., 2004.

Emissions from vehicles at the period of 11:00 PM to 5:00 AM in Feeder road and Residential road are assumed to be 0, since there is negligible amount of emissions at this timing. For Arterial road (National Highway), we have assumed that there is constant flow of vehicles at night time between 11:00 PM to 5:00 AM. So, emission rate was calculated for 1 hr at night time and applied the same emission rate for overnight. Age of the vehicle can also affect the emission characteristic of the exhaust. An old and poorly maintained vehicle generates more emission compared to new vehicle. The assessment of vintage profiles of local traffic is very difficult job especially when traffic characteristics are heterogeneous in nature. The vintage profile data of traffic was collected by fuel station survey at different petrol pumps and CNG filling stations along the road corridor. This included finding out percentage of two stroke (2S) and four stroke (4S) vehicles in two wheeler and percentage of petrol and diesel driven vehicles in four wheeler (i.e. car categories). It has been further assumed that the vehicles plying on the road, could be represented by vehicles (in terms of their age profile, engine technology and composition) captured during the fuel station survey.

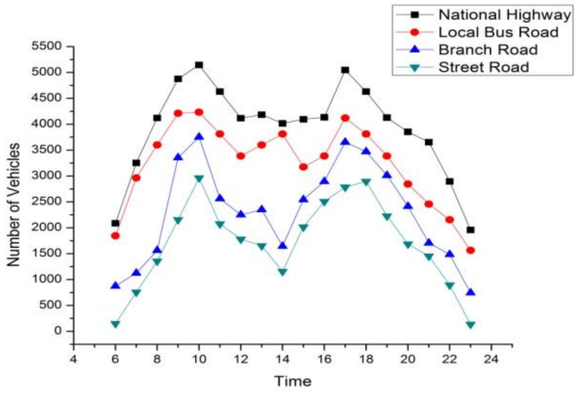


Fig.3.8. Traffic pattern of Mangalore

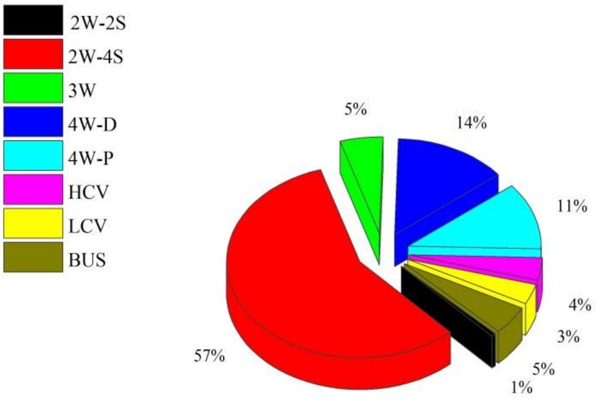
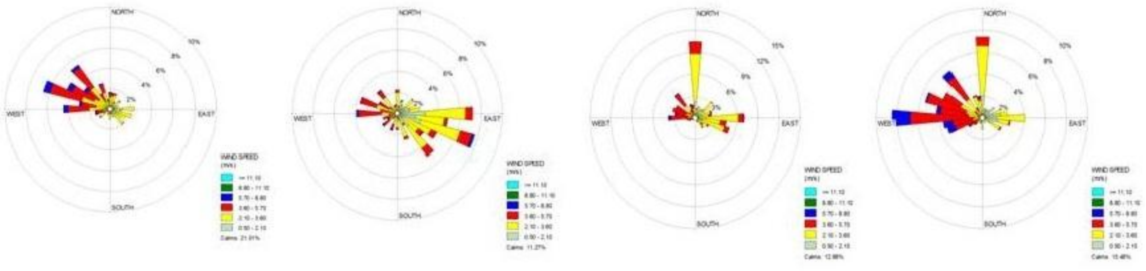


Fig.3.9. Percentage of Vehicles

(ii) Meteorological data

The hourly surface meteorological data includes cloud cover, temperature, Humidity, Sea level pressure, Wind direction, Wind speed and precipitation, collected from Mangalore Bajpe Airport, were prepared in Excel sheet and fed into AERMET which is pre-processor for AERMOD. An upper air estimator, in the AERMET based on the well referred algorithms has been used to estimate boundary layer parameters such as Monin-Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux using surface meteorological data. These parameters will be given into AERMOD as inputs.

The predominant wind directions were from west northwest to east southeast during monsoon and summer seasons. In post monsoon season, the predominant wind directions were east southeast to west northwest and in winter season, it was north and east directions. Wind speed at the study area was found to be low during monsoon (max: 3.2 m/s), average during post monsoon (max: 4.5 m/s) and winter (4.5 m/s) higher during summer (5.2 m/s). The lowest wind speeds were observed during the night and the early morning.



(a) Monsoon (b) Post monsoon (c) Winter (d) Summer

Fig.3.10. Wind pattern for different seasons in study area

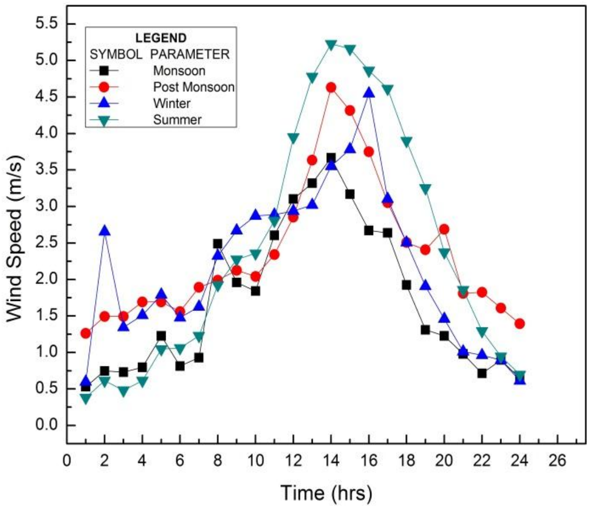


Fig.3.11. Hourly wind speed for all the seasons

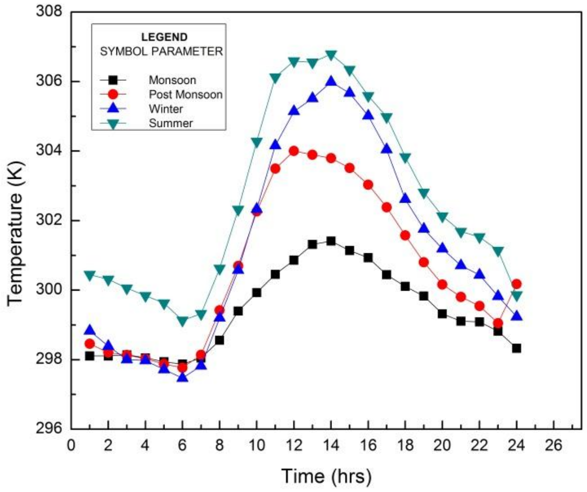


Fig.3.12. Hourly temperature for all the seasons

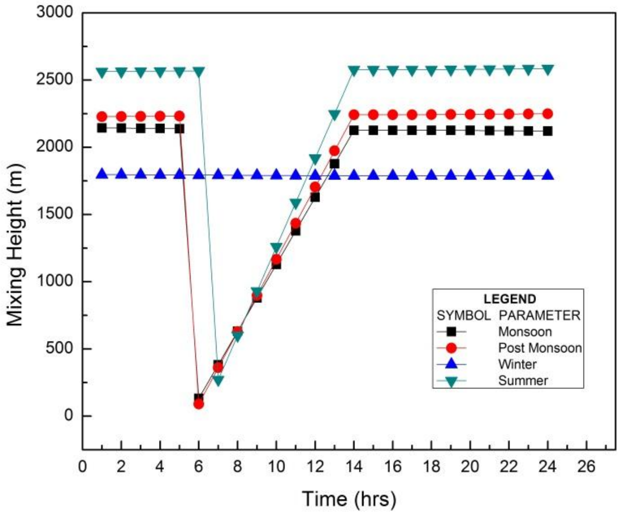


Fig.3.13. Hourly mixing height for all the seasons

(iii) Terrain data Terrain data provides a physical relationship between terrain features and the behavior of air pollutants. AERMAP (terrain pre-processor) has been used to download the terrain data at 30 m resolution of Shuttle Radar Topography Mission (SRTM). The AERMAP uses gridded elevation data to calculate a representative terrain-influence height. The gridded data needed by AERMAP is obtained from a Digital Elevation Model (DEM), and the elevation of each specified receptor is automatically assigned through AERMAP.

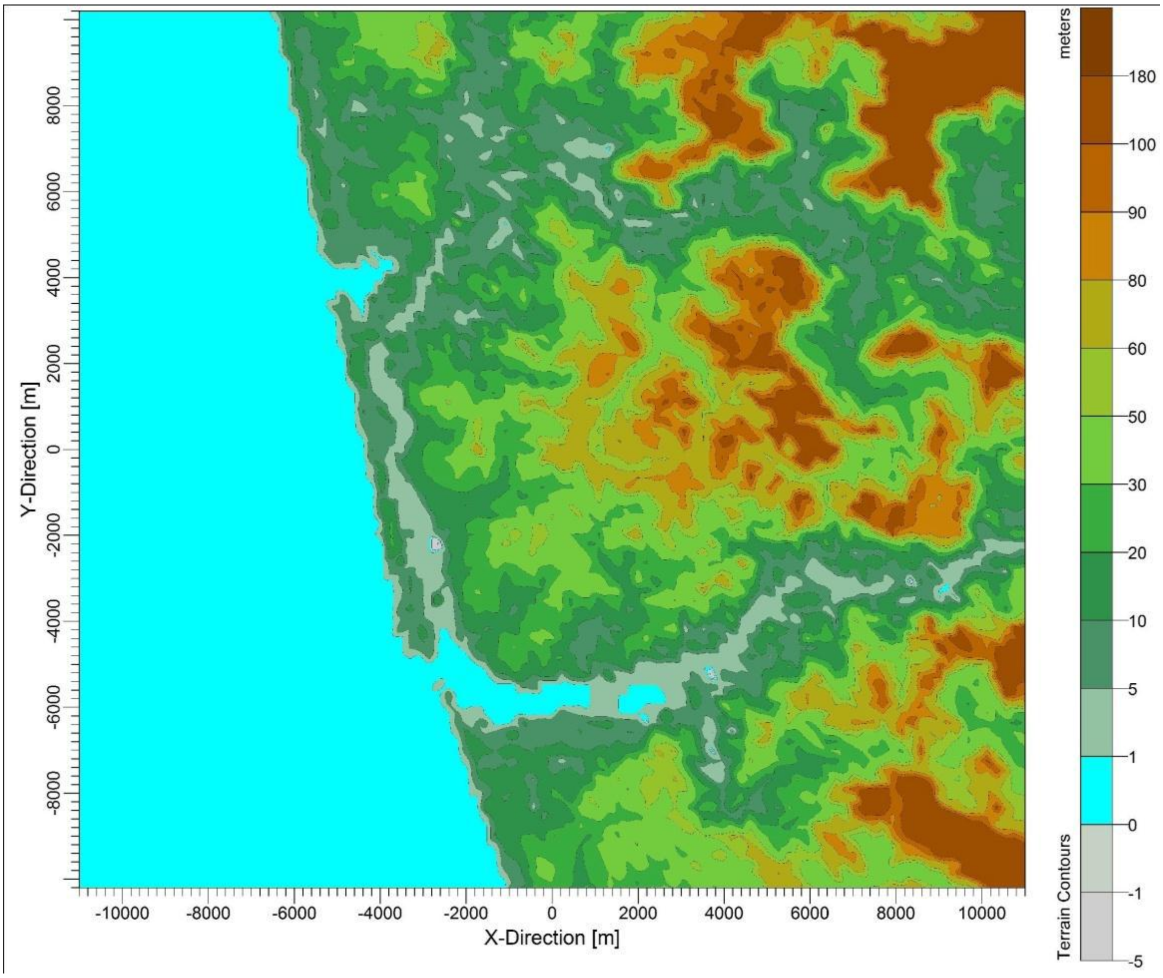


Fig.3.14. Elevation in and around Mangalore

3.6.3. Model run and evaluation:

AERMOD model was performed for four different seasons (monsoon, post monsoon, winter and summer) to predict the PM concentration from Vehicular sources. The modelling was done for 8-hr and 24-hr average PM concentration for four seasons and the model was evaluated by comparing the predicted values with observed values. Statistical descriptors, mainly correlation coefficient (r2), index of agreement (d), Normalized Mean Square Error (NMSE) and Fractional Bias (FB) have been used to evaluate the model performance. According to Kumar *et al.*, the performance of the model can be deemed acceptable if: $0.4 \leq d \leq 1.0, -0.5 \leq NMSE \leq 0.5, 0.5 \leq FB \leq 0.5$ and $FAC2 \geq 0.8$. (Kumar et al. 2006a)

3.6.3.1. Statistical parameters for model evaluation:

Fractional Bias The bias is normalized to make it dimensionless. The fractional bias (FB) varies between +2 and -2 and has an ideal value of zero for an ideal model. It is given by:

$$FractionalBias(FB) = 2\left(\frac{\overline{C_O} - \overline{C_P}}{\overline{C_O} + \overline{C_P}}\right)$$

Normalized Mean Square Error Normalized Mean Square Error (NMSE) emphasizes the scatter in the entire dataset. (Hanna and Heinold 1985) modified the equation for mean square error to obtain Normalized Mean Square Error which is a dimensionless statistic. NMSE is not biased towards models that over predict and under predict. Smaller values of NMSE indicate better performance. The expression for NMSE is given by

$$NMSE = \frac{\left(\overline{C_P - C_o}\right)^2}{C_o C_p}$$

Index of Agreement

The index of agreement (IA or d) is given by (Willmott,C.J.,C.M. Rowe. 1985)

$$IA = 1 - \frac{\left\langle (x_c - x_m)^2 \right\rangle}{\left\langle (|x_c - \langle x_c \rangle| + |x_m - \langle x_m \rangle|)^2 \right\rangle}$$

The denominator in the above equation is referred to as the potential error. IA is a non-dimensional and bounded measure with values closer to 1 indicating better agreement.

3.6.4. Control scenarios

Future control scenarios were carried out in worst weather condition to estimate the emission changes that would take place due to various interventions. Two types of control scenarios have been made and these scenarios were based on vehicle restriction and changing of fuel. AERMOD model is used to carry out the dispersion study, to estimate the concentrations of PM all over the city under different scenarios. The maximum concentration of each control scenario was estimated and the values were compared among the scenarios. The control scenarios carried out are given below.

VR: Vehicles older than 10 years are phased out

CF1: Diesel and petrol car to CNG car

CF2: Diesel bus to CNG bus

CF3: Both CNG car and CNG bus

CHAPTER 4

RESULTS AND DISCUSSION

Ambient air samples of six sites of Mangalore were collected as per CPCB guidelines in order to analyse the physico-chemical characteristics of PM_{10} and $PM_{2.5}$. The results are discussed in the following sessions.

4.1. Mass concentration of PM_{10} particles:

The average mass concentration of particles is considered to be a prime parameter to substantiate the quality of ambient air. Hence, the estimation of average mass concentration of particulate matter is a major concern. The mass concentrations of all the six sampling sites with their maximum, minimum and average concentrations are being listed out in Table 4.1. Also, the graphical representation of these values and the concentration range of PM_{10} particles at all the sampling sites have been illustrated in Fig.4.1 & 4.2 respectively.

Table: 4.1 Statistical summaries of PM_{10} particles ($\mu g/m^3$) at all the sampling sites

Sampling Site	**Max**	**Min**	**Mean**	**Median**	**SD**
Lady hill	119.2	43.4	88.7	93.8	24.5
City Center	147.3	35.2	92.2	93.5	33.1
KMC Attavar	98.9	33.3	71.7	76.7	21.4
KMC Ambedkar Circle	179.2	31.2	112.1	122.4	50.7
Town hall	231.5	46.3	131.9	125.3	55.5
KSPCB	188.2	55.7	122.5	119.15	45.6

The average mass concentration values at all the sampling sites clearly depicts that the PM_{10} particles present in the ambient air of Mangalore exceeds the NAAQS limits proposed by CPCB India. The sampling site, Town Hall recorded the highest PM_{10} concentration of 231 $\mu g/m^3$ during the month of December, 2014. This phenomenal raise in PM_{10} concentration is primarily due to the vehicular traffic and the traffic congestion as the Town hall junction connects the major arterial roads in the city. During this post monsoonal season the traffic near Town Hall is found to be higher due to more fishing business at Bunder (500 m from Town Hall). In addition, the climatic conditions during the post monsoon seasons especially in the month of December 2014 where the average temperature dropped between 20°C to 23°C and the wind speed was as low as 3 km/h to 5 km/h that very often leads to temperature inversion creating a low atmospheric convection of pollutants within a considerably lower heights of 3 to 4 meters from the ground level. Moreover, the topography of the sampling site had contributed to the raise in PM_{10} concentration, as the site is located at a lower altitude with geo and concrete structures surrounding it.

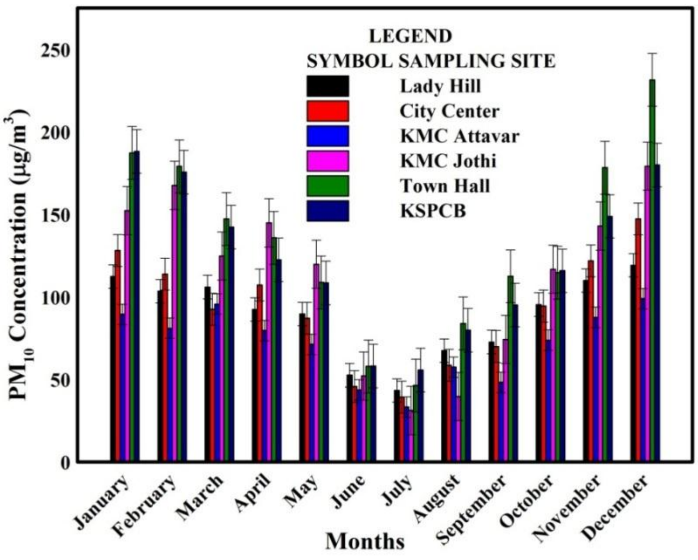


Fig: 4.1Graphical representation of annual average of PM_{10} concentration at all sites

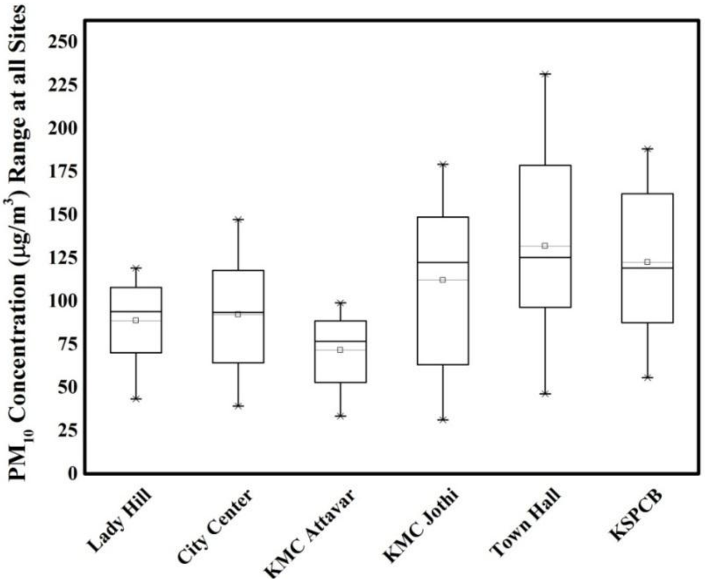


Fig: 4.2. Graphical representation of PM_{10} concentration range at all sites

Subsequently there are many restaurants located in the near vicinity of the sampling site that use coal for cooking purposes which may also would have contributed significantly. Two major playgrounds involving numerous sports activities and various other activities such as exhibitions, political meetings etc. would have also contributed to notable amounts of crustal PM_{10} in the ambient air of the sampling site.

The lowest concentration of PM_{10} among the sample sites was 31.2 $\mu g/m^3$ recorded at KMC Ambedkar circle and marked during July 2014 which is during monsoon season. The heavy rainfall during this season washes away most of the particles in the ambient air leading to a considerable decrease in the particle concentration. Additionally, the site is almost like a plateau region and has excellent cross wind ventilation which would have diluted the PM_{10} concentration.

4.1.1. Elemental concentration of PM_{10} particles:

The PM_{10} samples collected from all the six sampling sites were digested and subjected form elemental analysis using ICPOES. Elements such as As, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Sr and Zn were present in significant levels of the PM_{10} samples as shown in Table 4.2

Table: 4.2 Annual average elemental composition of PM_{10} samples at all sites

Elements	Lady Hill	City Center	KMC Attavar	KMC Ambedkar Circle	Town Hall	KSPCB
As	0.014	0.013	0.007	0.017	0.034	0.020
Ba	8.594	9.057	10.030	7.700	4.630	2.170
Cd	0.008	0.007	0.005	0.011	0.062	0.090
Cr	0.430	0.133	0.220	0.200	0.117	0.153
Cu	0.292	0.210	0.213	0.203	0.149	0.204
Fe	4.514	4.097	4.467	2.863	7.651	4.513
Mg	7.848	2.293	3.543	2.573	13.418	5.523
Mn	0.946	0.103	0.577	0.600	0.721	0.777
Mo	0.022	0.023	0.020	0.020	0.018	0.044
Ni	0.450	0.083	0.067	0.180	0.003	0.036
Sr	0.578	0.430	0.930	0.283	2.040	1.193
Zn	8.868	6.367	8.073	6.180	30.246	0.296

Among the above mentioned 12 elements, Zinc (Zn) was found to be higher with an average concentration of 30.246 ppm. The elemental composition portrays the significant contribution of heavy metals in ambient air. The highest concentration of Zn among the samples was found at Town Hall site, which may be due to traffic related emissions such as wear and tear of tyre, breaks and their resuspensions (Lough et al., 2005, Dongarra et al., 2009, Amato et al., 2011). The next major contributor in PM_{10} composition is Barium (Ba) which also has same sources like brakes, tyres and their resuspensions(Adachi and Tainosho 2004). The presence of Fe, Mg, Mn and Sr were also found in considerable concentrations in the PM_{10} samples which may be due to crustal source re-suspension (soil dust/road dust/unpaved roads/exhaust emissions from vehicles)(Canepari et al. 2008; Fabretti et al. 2009). Correspondingly, elements such as Cd, Cr, Cu, Mo and Ni may be contributed from vehicular and industrial emissions(Liati et al. 2013; Lough et al. 2005). Arsenic was found to be the lowest in concentration among the analysed elements of the PM_{10} samples and the sample collected at KMC Attavar found to have the lowest average concentration of Arsenic (As) which is 0.007 ppm. Since there are hardly any major contributors of As like smelting and fossil fuel burning(coal combustion)(Stanek et al. 2011) industries near KMC Attavar which is a residential site with and whatever amount of As detected in this sample may be due to vehicular emissions which has trace quantities of As.

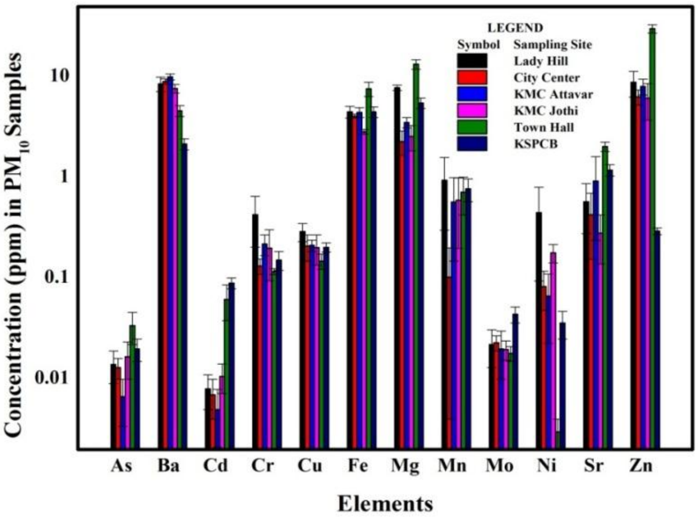


Fig: 4.3 Graphical representation for elemental composition in PM_{10} samples at all sites

4.1.2. Ions concentration of PM_{10} particles:

The collected samples were subjected to ultra-sonication and analysed using Ion chromatography to estimate the Ionic composition (Anions and Cations) present in them. The analysis revealed a total of nine ions (5 anions and 4 cations) namely F^-, Cl^-, NO^-_3, PO^-_4, SO_4^{2-},Na^+,K^+,Mg^{2+} and $Ca^{2+}$for PM_{10} samples. The composition and annual average concentration of ions present in PM_{10} samples of all sites are presented in Table 4.3. From the table Na^+ ions concentration was found to be higher. Thus notably a higher concentration of Na^+ ions in PM_{10} composition reveals the contribution of marine sources.

Table: 4.3 Annual average ions composition of PM_{10} samples

Ions	Lady Hill	City Center	KMC Attavar	KMC Ambedkar Circle	Town Hall	KSPCB
F^-	1.346	0.914	1.572	1.180	0.958	1.536
Cl^-	2.179	1.674	3.263	2.004	1.580	1.723
NO^-_3	0.433	0.374	0.314	0.675	0.953	0.267
PO^-_4	0.076	0.158	0.200	0.106	0.134	0.049
SO^-_4	1.201	0.751	0.985	0.559	0.977	1.820
Na^+	17.947	13.318	26.139	20.428	13.340	8.650
K^+	1.433	1.271	1.905	1.495	1.300	5.090
Mg^{2+}	0.505	0.362	0.694	0.451	0.887	0.530
Ca^{2+}	1.620	1.663	2.064	1.616	2.743	2.477

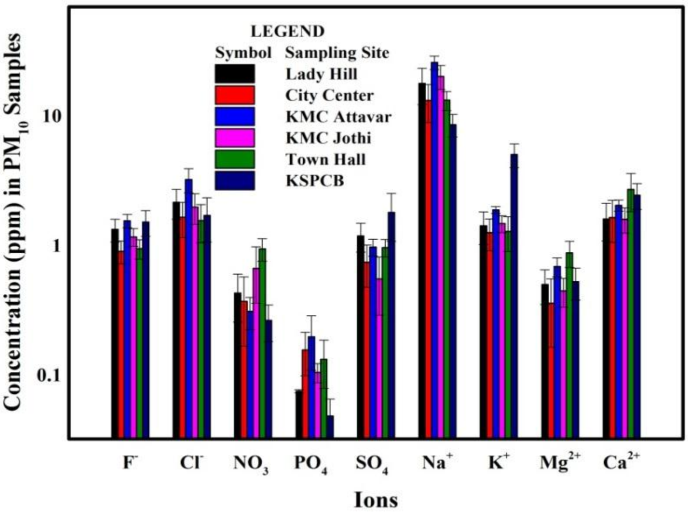


Fig: 4.4 Graphical representation for ion composition in PM_{10} samples at all sites

As Mangalore is one of the largest coastal cities of the continuous west coast line in India there are relatively higher sea showers carried over the land by the south westerly winds. Further the presence of significant amounts of K^+ and Cl^- ions in the composition of PM_{10} samples confirm the sea shower contribution as indicated by (Kumar et al. 2006b) for ions Na^+, K^+, Cl^- and Mg^{2+} in combination exhibiting marine source emissions. Likewise the ions such as Ca^{2+}, SO^-_4, PO^-_4, NO^-_3 and F^- were also found in significant quantities which confirm the contribution of non-marine sources. Among which F^- ions would have been contributed from coal combustion emissions; Ca^{2+} ions contributed from soil dust, NO^-_3 and SO_4^{2-}ions from combustion sources and car exhaust emissions and PO^-_4 ions from biomass burning(Pant and Harrison 2012). Source apportionment studies will be carried out by using CMB version 8.2 receptor modeling technique to estimate the exact percentage contribution of various sources at each sampling site.

4.2. Mass concentration of $PM_{2.5}$ particles:

The mass concentrations of all the six sampling sites with their maximum, minimum and average concentrations are being listed out in Table 4.4. Also, the graphical representation of these values and the concentration range of PM_{10} particles at all the sampling sites have been illustrated in Fig.4.5 & 4.6 respectively

Table: 4.4 Statistical summaries of $PM_{2.5}$ particles (μg/m^3) at all the sampling sites

Sampling Site	Max	Min	Mean	Median	SD
Ladyhill	91.3	4.9	40.5	40.7	23.8
City center	112.4	9.6	43.9	37.1	29.0
KMC Attavar	120.3	6.2	48.5	43.1	34.6
KMC Ambedkar circle	69.6	7.6	34.9	35.4	18.2
Town hall	89.1	8.3	37.4	29.9	24.3
KSPCB	85.4	11.3	44.5	46.2	23.6

The average mass concentration values at all the sampling sites clearly illustrate that the $PM_{2.5}$ particles prevailing in the ambient air of Mangalore surpasses the NAAQS limits proposed by CPCB India. The sampling site, KMC Attavar recorded the highest $PM_{2.5}$ concentration of 120.3 μg/m^3 during the month of December, 2014 (Fig 4.5). This notable raise in $PM_{2.5}$ concentration is primarily due to the emissions from the medical incinerator located in KMC hospital Attavar campus which is at a close vicinity to the sampling site.

Additionally, the meteorological conditions played a vital role especially during December month of post monsoon during the year 2014 where the average temperature drops down to 20°C with a lower wind speed of 3 km/h. This condition very often leads to an inversion in temperature affecting the atmospheric convection of pollutants causing the pollutants occurrence at lower height of approximately 3 to 4 meters from the ground level. The lowest concentration was recorded at Lady hill site with an average concentration of 4.9 µg/m^3 in the month of July 2014 during the monsoon season. The PM$_{2.5}$ particles precipitate due to the heavy rainfall leading to a greater decline of particles deposition at the sampling site. Moreover, the vehicular activity is considerably less compared to the other months of the sampling period which in turn affects the particles emission and deposition.

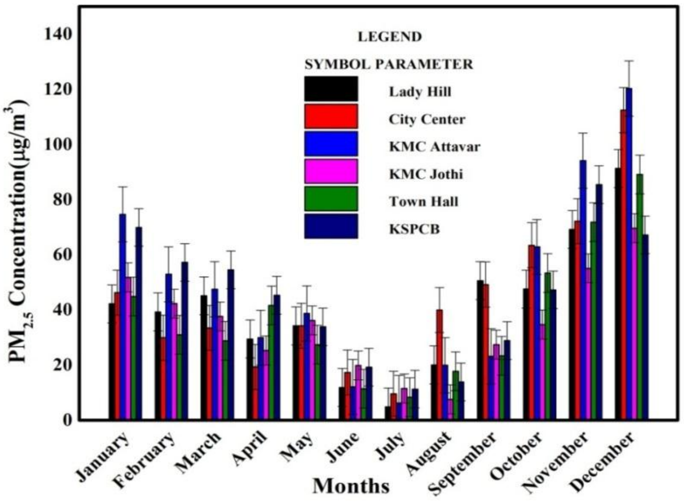


Fig 4.5 Graphical representation of annual average of PM$_{2.5}$ concentration at all sites

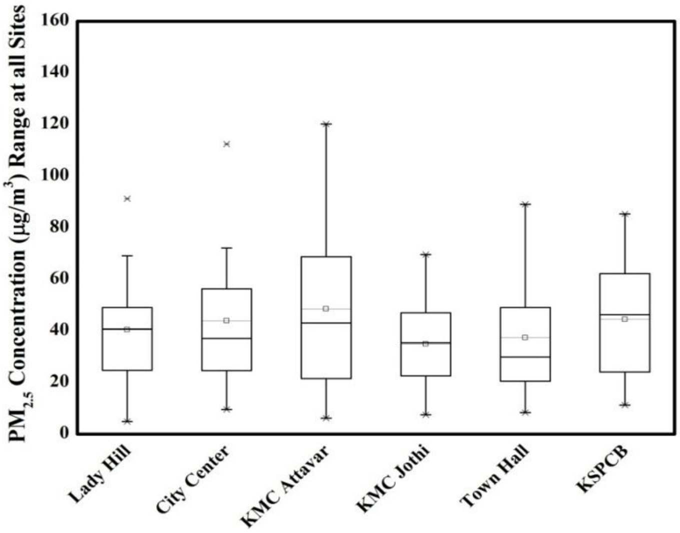


Fig 4.6 Graphical representation of PM$_{2.5}$concentration range at all Sites

4.2.1. Elemental concentration of $PM_{2.5}$ particles:

The $PM_{2.5}$ samples were digested to undergo analysis using ICPOES. The analysis yielded 10 elements namely Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn from all the six sampling sites. The annual average elemental composition for $PM_{2.5}$ samples collected at all the six sites are shown in Table 4.5.

Table: 4.5 Annual average elemental compositions of $PM_{2.5}$ samples in Mangalore

Elements	**Lady Hill**	**City Center**	**KMC Attavar**	**KMC Ambedkar Circle**	**Town Hall**	**KSPCB**
Ba	0.080	0.168	0.335	0.263	0.173	0.180
Cd	0.100	0.532	0.332	0.215	1.557	0.020
Cr	0.088	0.090	0.243	0.168	0.120	0.180
Cu	0.094	0.068	0.067	0.092	0.073	0.053
Fe	1.818	4.680	12.818	10.320	9.777	10.433
Mn	0.094	0.058	0.123	0.192	0.047	0.060
Ni	0.048	0.088	0.102	0.072	0.067	0.067
Pb	0.502	1.925	1.372	1.412	2.850	0.153
Sr	0.024	0.037	0.078	0.068	0.240	0.140
Zn	0.648	0.608	0.332	2.257	0.780	0.660

The elemental composition of $PM_{2.5}$ samples portrays the presence of heavy metals at a considerable amount in the ambient air of Mangalore. The contribution of Fe was found to be higher in KMC Attavar site with a concentration of 12.818 ppm. The contribution of Fe is mainly from crustal sources in coarse particle sizes, whereas in fine particles these heavy elements would have been emitted from the medical incinerator located close to KMC Attavar site vicinity where the combustion of wastes from hospitals along with some metal abrasions emissions may have contributed to the raise in concentration of Fe element at KMC Attavar site. The contribution of Ba, Pb and Zn would have been from road traffic emissions. However Pb would have been contributed majorly from tyre wear and Zn would have been contributed from tyre wear emissions as well as the resuspension of the tyre wear emissions with little traces from diesel and lubricating oil emissions and Ba from abrasions of brake linings(Amato et al. 2011; Dongarra et al. 2009; Lough et al. 2005). Similarly Cd would have been emitted from diesel vehicle emissions, Cr and Cu would have been emitted from brake wear emissions(Liati et al. 2013), Mn and sr would have been contributed from gasoline emissions(Chih-Chung Lin et al. 2005; Pulles et al. 2012). Also the presence of Ni exhibits the emissions of vehicular emissions especially diesel vehicles, engine wear and corrosion (Liati et al. 2013; Lough et al. 2005). A detailed source apportionment study will be carried out using a receptor model CMB version 8.2 to estimate the exact percentage contribution of various appropriate sources at all the sampling sites.

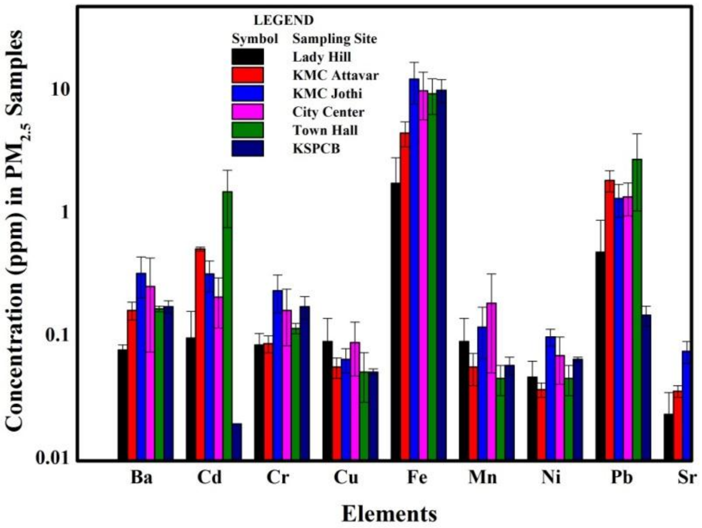


Fig 4.7 Graphical representation for elemental composition in $PM_{2.5}$ samples at all sites

4.2.2. Ions concentration of $PM_{2.5}$ particles:

The ultra-sonicated samples of $PM_{2.5}$ particles were subjected to estimate the Ionic composition using Ion chromatography. The analysis yielded a total of ten ions (5 anions and 5 cations) namely F^-, Cl^-, NO^-_3, PO^-_4, SO^-_4, Na^+, NH^+_3, K^+, Mg^{2+} and Ca^{2+} at all sites. The annual average ionic composition of $PM_{2.5}$ samples are shown in Table 4.6

Table: 4.6 Annual average ions composition of $PM_{2.5}$ samples

Ions	Lady Hill	City Center	KMC Attavar	KMC Ambedkar Circle	Town Hall	KSPCB
F^-	0.356	0.414	0.318	0.658	0.34	0.76
Cl^-	0.283	0.124	0.183	0.102	0.073	0.108
NO^-_3	0.105	0.124	0.128	0.134	0.294	0.207
PO^-_4	0.178	0.105	0.101	0.321	0.177	0.471
SO_4^{2-}	0.73	0.78	0.674	0.895	0.602	1.108
Na^+	0.735	0.514	0.554	0.622	0.346	0.861
NH^+_3	0.641	0.671	0.55	0.566	0.327	0.98
K^+	0.156	0.169	0.136	0.255	0.158	0.227
Mg^{2+}	0.756	0.954	0.485	0.816	0.83	0.824
Ca^{2+}	0.356	0.414	0.318	0.658	0.34	0.76

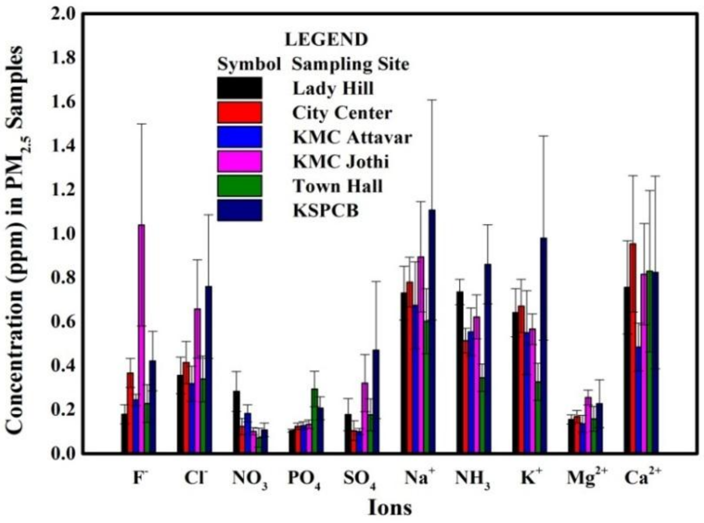


Fig 4.8. Graphical representation for ionic composition in $PM_{2.5}$ samples at all sites

The ionic composition of $PM_{2.5}$ particles have been distributed with moderate concentrations of all the ions with a higher contribution from Mg^{2+} and Na^+ ions these ions would have been emitted primarily from marine sources (Kumar et al. 2006b).Whereas the wood combustion, open burning, coal combustion and some industrial emissions may have contributed to K^+, NH^+_3, and Cl^-(Kleeman et al. 1999; Patil et al. 2013; Simoneit et al. 2004; Watson et al. 2008) The emissions from fossil fuel combustions would have contributed to NO^-_3 and SO_4^{2-}. Also, F^-, PO^-_4 and Ca^{2+}would have been emitted from non-marine sources such as soil dust, combustion sources and biomass burning(Pant and Harrison 2012).

4.3. Mass concentration of schools samples:

The $PM_{2.5}$ concentrations of particles on school premises have been studied and the average mass concentration of indoor samples in all the schools has been tabulated in Table 4.7. The $PM_{2.5}$ samples collected at the schools were found to have exceeded the NAAQS limits proposed by CPCB India. The highest annual average concentration of $PM_{2.5}$ particles was recorded at NITK Kannada medium school (KMS) with a higher concentration of 90.63 µg/m^3. The KMS School is located very close to the sub-urban highway NH66 where the vehicular emissions and resuspension of vehicular abrasions such as brake wear and tyre wears would have been contributed greatly to the $PM_{2.5}$ concentration at the sampling site.

Table: 4.7. Statistical summary of $PM_{2.5}$ particles (µg/m^3) at all the school indoors

Sampling Site	Max	Min	Mean	Median	SD
LHV	79.92	9.54	40.45	37.22	22.11
BEM	69.01	10.73	36.03	31.18	19.08
KMS	90.63	11.33	44.67	40.06	25.28
EMS	70.63	12.43	36.84	30.40	19.10

Moreover the toll booth is located in the highway which leads to traffic congestion during busy hours contributes a higher amount of $PM_{2.5}$ particles located very close to the sampling site. Similarly, the lowest concentration was recorded at Lady Hill Victoria School (LHV) with a concentration of 9.54 µg/m^3, since the sampling site is found to possess moderate amount of traffic during the sampling hours and there is a minor chance for the particles to get down washed with respect to the walls present in the entrance of the sampling site.

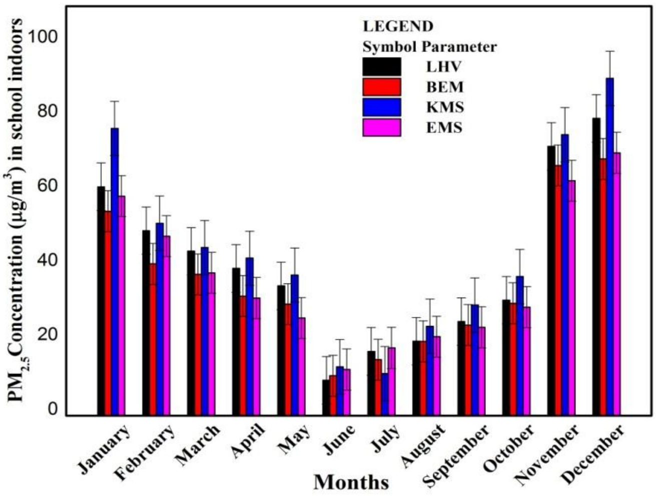


Fig 4.9 Graphical representation of $PM_{2.5}$ concentration in school premises

4.3.1. Elemental concentration of schools samples:

The $PM_{2.5}$ samples collected from school indoors were digested and subjected to elemental analysis using ICPOES. The analysis resulted with 12 elements namely Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Ti, V and Zn from all the four schools. The annual average elemental composition for $PM_{2.5}$ samples collected at all the six sites are shown in Table 4.8.

Table: 4.8. Annual average elemental compositions of schools $PM_{2.5}$ samples

Elements	LHV School	BEM School	KMS School	EMS School
Ba	0.230	0.180	0.315	0.280
Cd	0.711	0.002	0.060	0.010
Cr	0.078	0.002	0.170	0.001
Cu	0.071	0.004	0.045	0.004
Fe	0.432	0.510	0.370	1.090
Mn	0.060	0.007	0.070	0.021
Ni	0.059	0.004	0.050	0.004
Pb	0.163	0.004	0.283	0.010
Sr	0.058	0.011	0.155	0.004
Ti	0.190	0.052	0.123	0.090
V	0.090	0.004	0.173	0.019
Zn	0.862	0.072	0.565	0.063

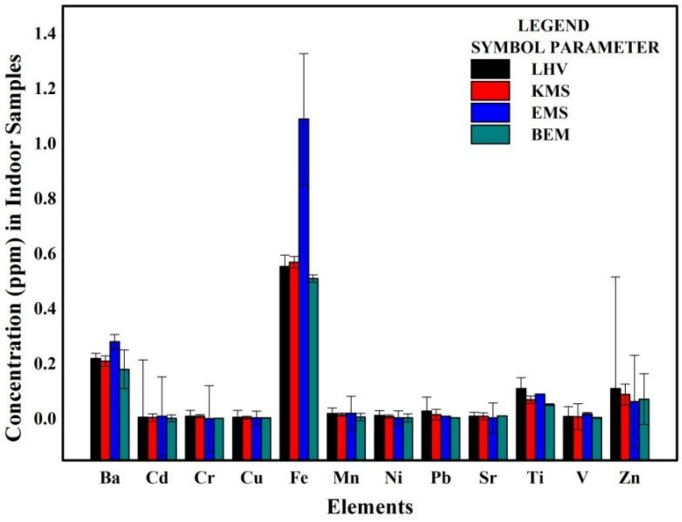


Fig: 4.10 Graphical representation of elemental composition in schools samples

The elemental composition in the school indoors was found to possess moderate amount of concentration for all the heavy elements. However, LHV School and KMS School possess some notable concentration of Zn, which would have been emitted from vehicular emissions, tyre wear and brake wear emissions (Liati et al. 2013; Lough et al. 2005) as these two sites are located very close to busy urban roadways and suburban highways. Elements such as Ba, Cd, Cr and Cu would have been emitted majorly from brake lining emissions and some traces of vehicular and crustal emissions(Canepari et al. 2008; Dongarra et al. 2009). Similarly elements such as Fe, Mn, Sr and Ti would have been emitted from gasoline emissions, brake and tyre wear and vehicular emissions resuspension(Wåhlin et al. 2006). Also Pb, Ni and V may have been contributed from fuel oil and lubricating oil combustions and vehicular emissions(Liati et al. 2013; Lough et al. 2005). Although, a detailed receptor modelling study will be performed using CMB version 8.2 to apportion the exact percentage of sources contributing to the school indoors at all sites.

4.3.2. Ions concentration of schools samples:

The $PM_{2.5}$ samples were ultra-sonicated and analysed for estimating the ionic composition using Ion chromatography. The analysis yielded a total of ten ions (5 anions and 5 cations) namely F^-, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, K^+, Ca^{2+}, Mg^{2+}, NH_4^+ and Na^+ for all the sampling sites. The annual average ionic composition of indoor $PM_{2.5}$ samples is shown in Table 4.9.

Table: 4.9. Annual average ionic composition of indoor $PM_{2.5}$ samples

Ions	LHV	BEM	KMS	EMS
F^-	0.280	0.062	0.369	0.178
Cl^-	0.832	0.161	1.070	1.492
NO^-_3	0.118	0.124	0.219	0.163
PO^-_4	0.173	0.008	0.412	0.008
SO^-_4	0.573	0.491	0.217	1.226
K^+	0.717	0.194	0.620	0.295
Ca^{2+}	0.962	0.354	1.432	0.703
Mg^{2+}	0.265	0.156	0.348	0.166
NH_4^+	1.187	0.030	0.762	3.177
Na^+	0.719	0.181	2.327	0.922

The Na^+ ions possess a higher concentration at all the sites especially with a higher concentration of 2.327 ppm for KMS School. The KMS School site is located at a very close proximity to the coastal line of Mangalore where the marine sources would have contributed majorly compared to other ions. Likewise K^+ ions would have been contributed from the open burning of waste materials with major composition of biomass (Pant and Roy 2012). The NH^+_3, Cl^- ions would have been contributed from fossil fuel combustions, NO^-_3 and SO_4^2 would have contributed from vehicular emissions as most of the sampling sites were found to be located close to the busy roadways(Kleeman et al. 1999; Patil et al. 2013; Simoneit et al. 2004; Watson et al. 2008). Also, F^-, PO^-_4 and Ca^{2+}would have been emitted from non-marine sources such as soil dust, combustion sources and biomass burning(Pant and Harrison 2012).

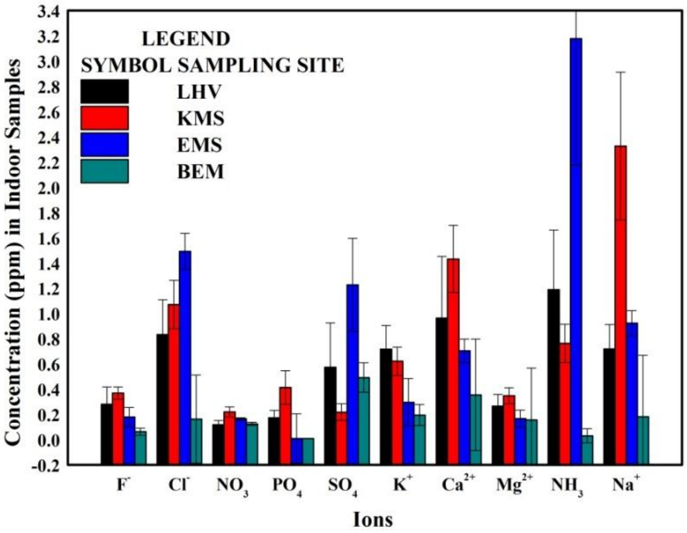


Fig: 4.11 Graphical representation of ionic composition in indoor samples

4.4. PAHs concentration profiles:

The extracted PM_{10} samples using ultra sonication and centrifugation technique were subjected to fluorescence spectrophotometer for estimating the PAHs present in them. The analysis yielded seven PAHs namely Fluorene (Flu), Acenaphthene (Ace), Chrysene (Chr), Benz(a)anthracene (B(a)A), Benzo(a)pyrene (B(a)P), Benzo(b)fluoranthene (B(b)F), Indeno (1,2,3-c,d) pyrene. The annual average mass concentrations of these PAHs are listed in Table 4.10.

The Total Polycyclic Aromatic Hyrdocarbons (TPAHs) concentration was observed to be higher at Town Hall sampling site with a concentration of 112.89 ng/m^3. This exceptional raise in TPAHs concentration is due to heavy traffic and its emissions, emissions from grilled meat vendors and restaurants located in the closest vicinity of the sampling site. In addition to that Point sources such as smoking, open burning wastes would have been some of the prime contributors of PAHs at Town hall site. The lowest TPAHs contribution was recorded at Lady Hill site with a concentration of 60.01 ng/m^3. The Lady Hill site is surrounded by schools, temples and residential buildings with a lesser contribution of emissions from fossil fuels. Also the site does not possess any type of commercial buildings or activities which in turn reduces the population motion where the emissions from point sources such as smoking, restaurant cooking and open burning does not find its part in contributing the PAHs in the ambience of sampling site.

Table: 4.10. Annual average Concentration (ng/m^3) of PAHs in PM_{10} samples

PAHs	Lady Hill	City Center	KMC Attavar	KMC Ambedkar Circle	Town Hall	KSPCB
Flu	1.14	1.81	1.54	2.35	3.30	1.05
Ace	14.78	22.40	20.83	42.53	51.68	23.77
Chr	8.31	6.12	5.85	9.10	11.47	8.68
BaA	7.42	6.65	6.25	9.35	10.42	9.03
BaP	5.78	4.87	4.80	5.79	6.89	6.13
BbF	8.03	9.10	8.18	10.75	12.62	10.77
Ind	14.56	17.01	15.42	16.14	16.53	17.39
TPAHs	60.01	67.95	62.87	96.02	112.89	76.82

Among all the PAHs, Acenaphthene (Ace) concentration is found to be higher in all the six sampling sites with a highest concentration of 51.68 ng/m^3 recorded at Town hall site. The occurrence of anthracene in a larger amount at Town hall shows that the emissions from the heavy traffic, incomplete combustion of coal used in Arabian restaurants for meat cooking, smoking and open burning activities near the sampling site.

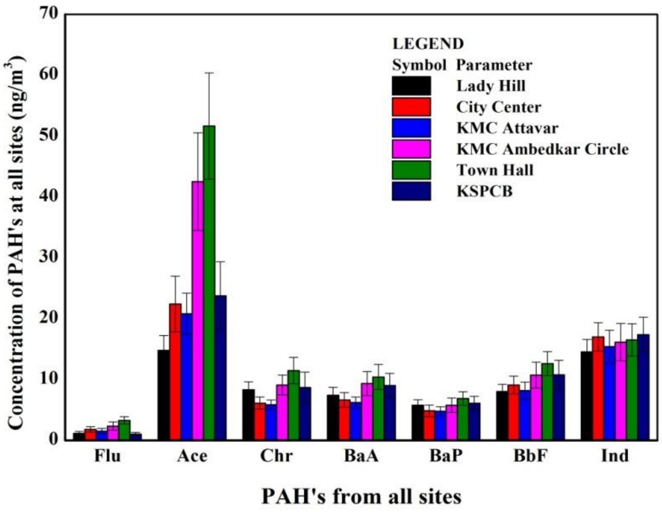


Fig: 4.12 Graphical representation of PAHs from all sampling sites

However Fluorene (Flu) contribution was found to be lower at all the sampling sites with lowest contribution of 1.14 ng/m^3 from Lady hill site revealing the fact that the contribution from gas emissions are considerably low compared to the emissions from incomplete combustion of fossil fuels such as coal, diesel and gasoline.The second largest contributor Indeno (1,2,3-c,d) pyrene holds a higher concentration 17.39 ng/m^3 at KSPCB site proving the contribution of gasoline engines, fuel oil and their combustion emissions (Smith and Harrison, 1996). Moreover, other PAHs such asBenzo(b)fluoranthene (B(b)F), Chrysene (Chr), Benz(a)anthracene (B(a)A) and Benzo(a)pyrene (B(a)P) were found to possess considerable amount of concentration in the hierarchy. This concentration profile of PAHs in Mangalore reveals that the various biofuels (cow dung and wood combustion) and fossil fuels (coal, diesel and gasoline) emissions plays a vital part in contributing these unburnt hydrocarbons from the fuels incomplete combustion and threatening the quality of ambient air(Lee et al. 1995; Li and Kamens 1993; Ravindra et al. 2008; Venkataraman and Friedlander 1994). A detailed source apportionment study will be carried out by using receptor model CMB version 8.2 to get a better clarity about the emissions and their exact percentage contribution of PAHs evaluated at all sampling sites.

4.5. Receptor modeling results:

The monitoring work was carried out at the selected six sampling sites and samples have been collected twice a week at each site during all the seasons. The samples acquired on filter papers were then subjected to analyse for elements, ions and PAHs present in them. The data generated through monitoring and analysis has been fed into the receptor model chemical mass balance (USEPACMBv8.2) to estimate the sources contributing to the urban atmosphere of Mangalore at each site individually. Sources and their profiles have been selected on the basis of primary survey, elemental and ionic composition of samples. In the current chapter, the sources contributions at each site for different particle sizes (PM_{10} and $PM_{2.5}$) and PAHs have been discussed separately for ease of understanding.

4.5.1. Source contributions for PM_{10} particles at various sites in Mangalore:

4.5.1.1. Source contributions for PM_{10} particles at Lady Hill site:

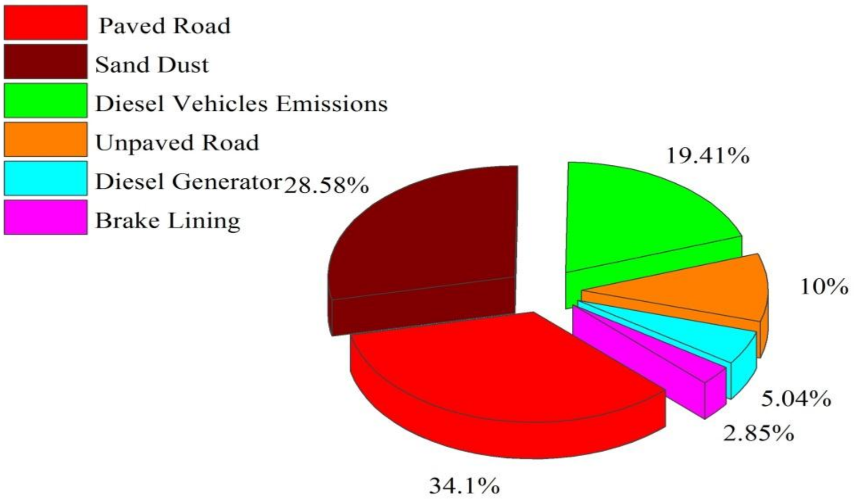


Fig.4.13. PM_{10} Source composition at Lady hill site

The sources contributing for PM_{10} particles at Lady hill site is presented in Fig.4.13. Among the above mentioned sources, paved road emissions and sand dust emissions were found to be dominant with nearly 60% of the total sources estimated for PM_{10} particles at the sampling site. However, the diesel vehicle emissions also play a vital role in particulate contribution based on its characteristic as Lady Hill is one of the major junctions in the city.Consequently, unpaved road emissions, diesel generator emissions and brake lining emissions also contribute to the PM_{10} particles to certain extent.

4.5.1.2. Source contributions for PM_{10} particles at City center site:

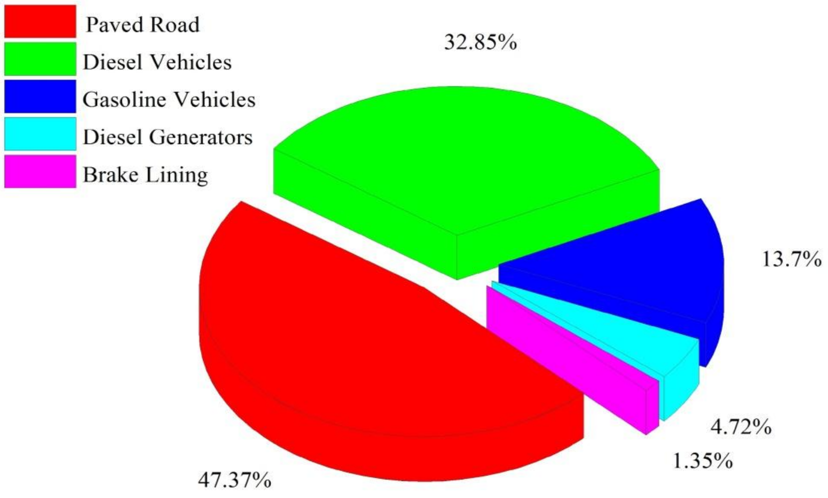


Fig.4.14. PM_{10} Source composition at City Center Site

City center site, which is located close to a busy urban roadway and a slightly commercial area, shows domination of paved road emissions (Fig.4.14). High diesel vehicles and gasoline vehicles emissions could be attributed due to moderate to heavy traffic during normal hours and peak hours of the day. Diesel generators and brake lining emissions show slight contribution at the sampling site.

4.5.1.3. Source contributions for PM_{10} particles at KMC Attavar site:

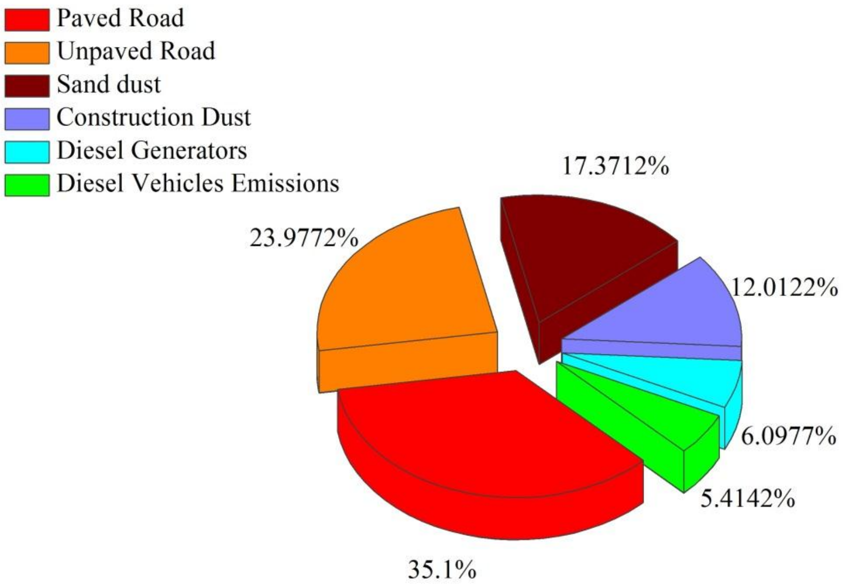


Fig.4.15. PM_{10} Source composition at KMC Attavar Site

KMC Attavar site pose the characteristics of a residential site, as the site is located at a distance of more than 500 metres from busy urban roadways and junctions. Paved and Unpaved road emissions were found to be prevailing at a higher rate of around 60% compared to other sources, since the site comprises of paved roads and unpaved roads with emissions from the suspension of particles from the shoulders of all roadways (Fig.4.15). Sand dust and construction dust are found to be second dominant as there were residential buildings construction activities taking place during the time of sampling. Diesel generators and diesel vehicle emissions showed slight contributions for PM_{10} particles size range.

4.5.1.4. Source contributions for PM_{10} particles at KMC Jyothi circle site:

Diesel vehicles emissions and paved road emissions attributed to nearly 70% of the sources emissions, as the site is located close to the most busy junction in the city with a heavy flow of vehicles throughout the day (especially heavy vehicles). Gasoline vehicle emissions were found to be the second largest contributor, since the flow of diesel vehicles in both HMV and LMV categories with diesel powered engines were considerably higher compared to gasoline powered engines. Diesel generators and tyre wear emissions are the other sources contributed to PM_{10} particles at the sampling site (Fig.4.16).

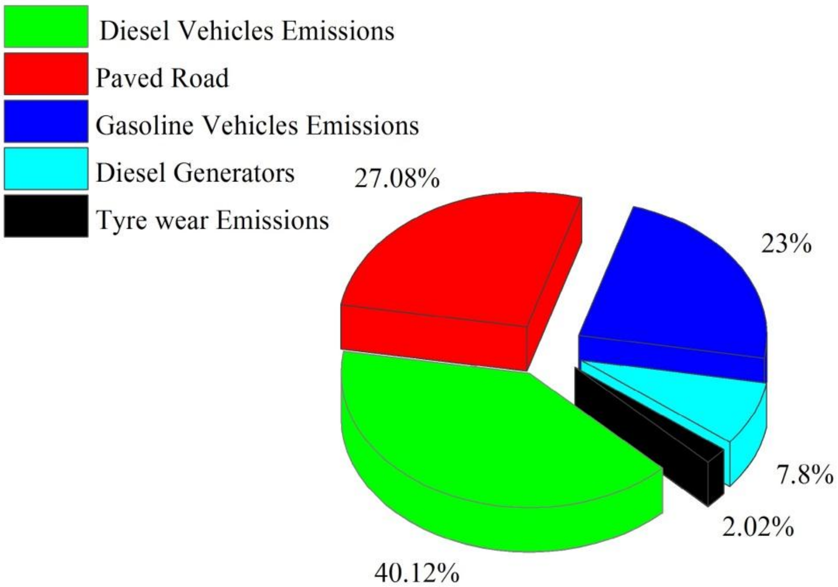


Fig.4.16. PM_{10} Source composition at KMC Jyothi Circle Site

4.5.1.5. Source contributions for PM_{10} particles at Town hall site:

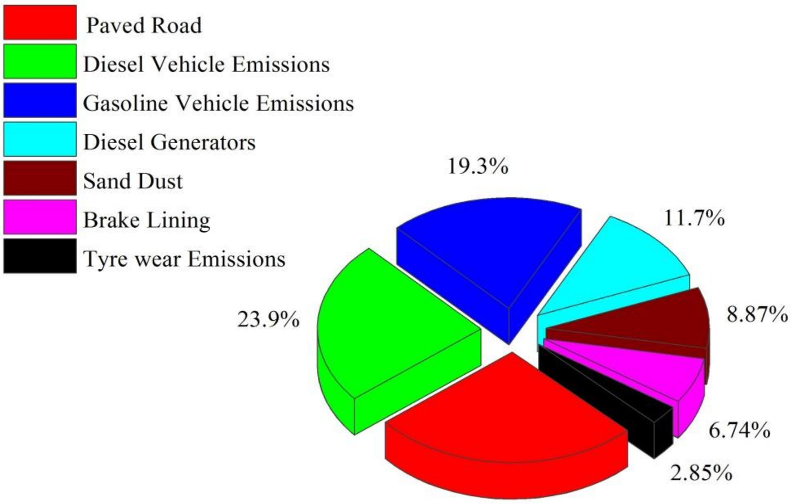


Fig.4.17. PM_{10} Source composition at Town hall site

Town hall site is characterised as traffic/commercial site surrounded by heavy traffic, major bus junctions, restaurants and various other anthropogenic activities. Paved road and diesel vehicle emissions were found to play a vital role in contributing the PM_{10} particles concentration at the sampling site (Fig.4.17). Gasoline vehicles emissions and diesel generator emissions were found to be the next highest contributors of PM_{10} particles due to emissions from the gasoline vehicles and generator usages from restaurants and hotels present in the close vicinity of the sampling site. Other sources such as sand dust, brake lining and tyre wear emissions have been contributed from the resuspension of road dust and vehicles abrasions.

4.5.1.6. Source contributions for PM_{10} particles at KSPCB site:

KSPCB is categorized as an industrial site and the unpaved road emission prevails in higher contributions among other sources. The roads have been damaged by continuous transport of heavy vehicles and trucks with tons of loads on them. Thus, the emissions from these unpaved roads contribute to a higher amount of emissions from PM_{10} particles (Fig.4.18). Secondly paved road dust and sand dust emissions were found to be higher with respect to the resuspension of sand dust and vehicle abrasions on the paved road surface in the sampling site. Also, diesel vehicle emissions and diesel generators emissions are found to be at a considerable concentration with the effect of diesel emissions from vehicles transport and use of generators at industries due to power cuts and shut downs

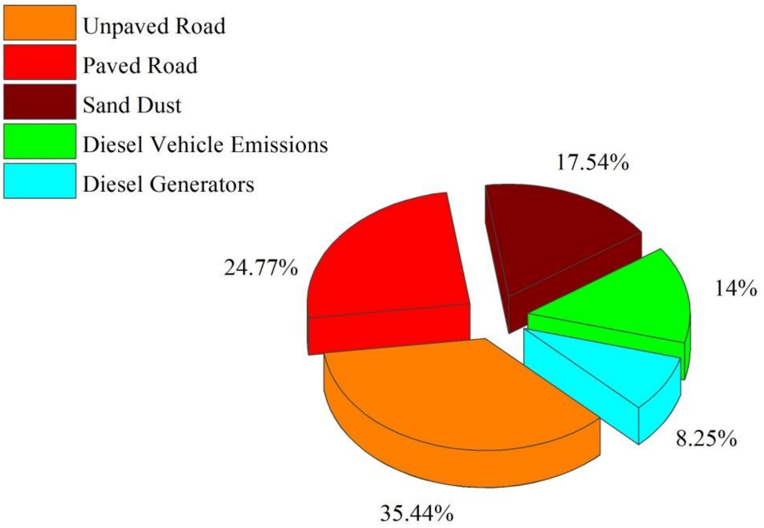


Fig.4.18. PM_{10} Source composition at KSPCB Site

4.5.2. Source contributions for $PM_{2.5}$ particles at various sites in Mangalore:

4.5.2.1. Source contributions for $PM_{2.5}$ particles at Lady hill site:

At Lady hill site the emissions from two wheelers were found to be contributing at a higher proportion amounting to nearly 40% compare to other estimated sources (Fig.4.19). The site is located in a major junction adjacent to a residential area with a higher volume of two wheeler usage by the population resulting in a higher contribution of $PM_{2.5}$ particles. Four wheeler emissions from diesel powered vehicles was found to be the second dominant source as the population usage of two wheelers is higher compared to four wheelers in the vicinity of the sampling site, hence the contribution from four wheelers was found to be lower compared to two wheeler emissions. Subsequently, with more or less equal amount of contribution from heavy vehicles' emission have been observed due to the fact that the sampling site was located close to the vicinity of Lady Hill junction. Paved road dust contributes with a slight concentration of 8% in $PM_{2.5}$ particle size range.

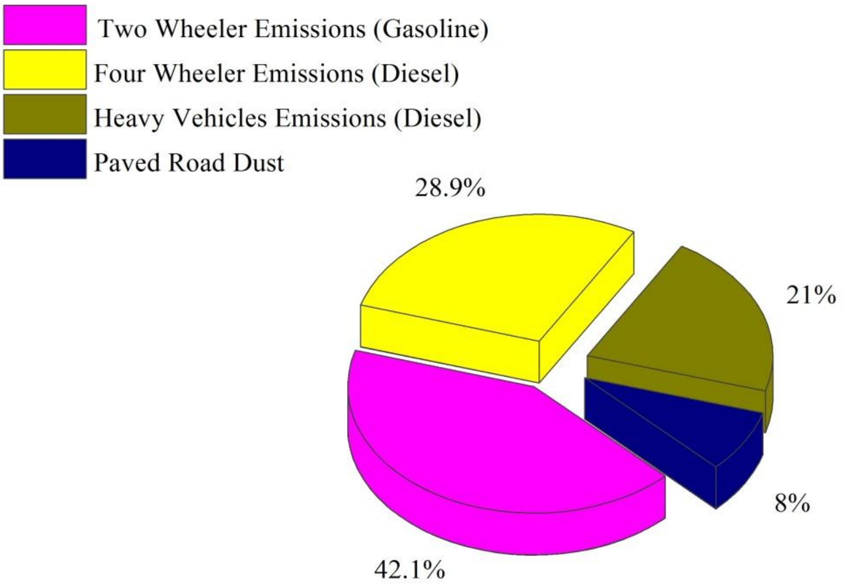


Fig.4.19. $PM_{2.5}$ Source composition at Lady Hill Site

4.5.2.2. Source contributions for $PM_{2.5}$ particles at City center site:

City center site was found to possess a considerably higher amount of sources contributing to $PM_{2.5}$ particles comparatively. The site possess a hierarchy of emissions from Two wheeler emissions, Four wheeler emissions (Diesel), Heavy vehicles emissions (Diesel), Three wheeler emissions (Diesel), Paved road dust and LPG Stove emissions (Fig.4.20).

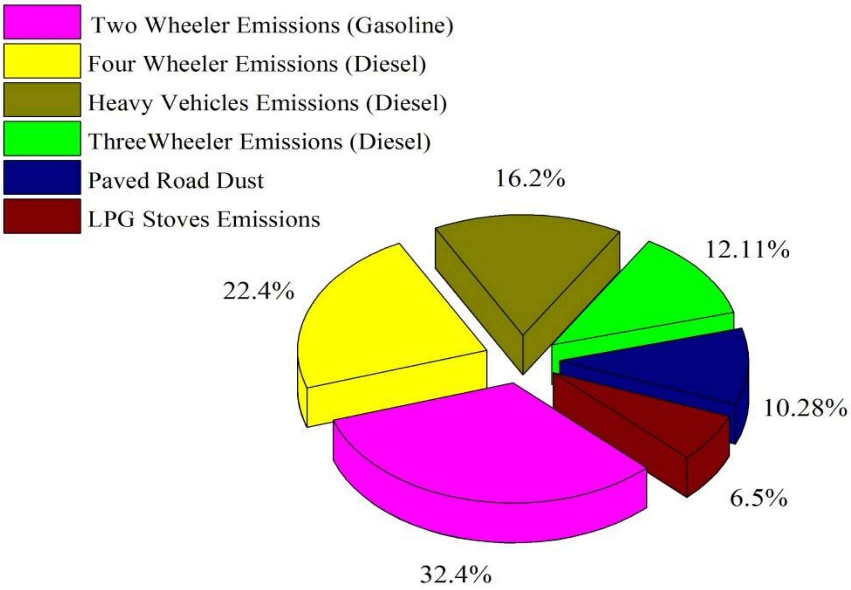


Fig.4.20. $PM_{2.5}$ Source composition at City Center Site

The site is located in a close vicinity to K S Rao road which is one of the busiest roads in the city. The two wheeler emission was found to be subsidizing a higher contribution in emissions compared to four wheeler and heavy vehicles emissions. Three wheeler emissions show some significant contribution compared to paved road dust and LPG stove emissions. The restaurants in and around the site would have contributed to the LPG stove emissions in $PM_{2.5}$ particle size range.

4.5.2.3. Source contributions for $PM_{2.5}$ particles at KMC Attavar Site:

KMC Attavar is a residential site with higher amount of emissions from two wheelers emissions with four wheeler emissions (diesel) as the second highest contributor of $PM_{2.5}$ particles (Fig.4.21). The contributions from kerosene stove emissions and LPG stove emissions were found to be having a significant contribution from the residential buildings, KMC hospital canteen and cafeteria cooking activities. Paved and unpaved road dusts were other type of sources which could have contributed through road abrasions and resuspension of particles.

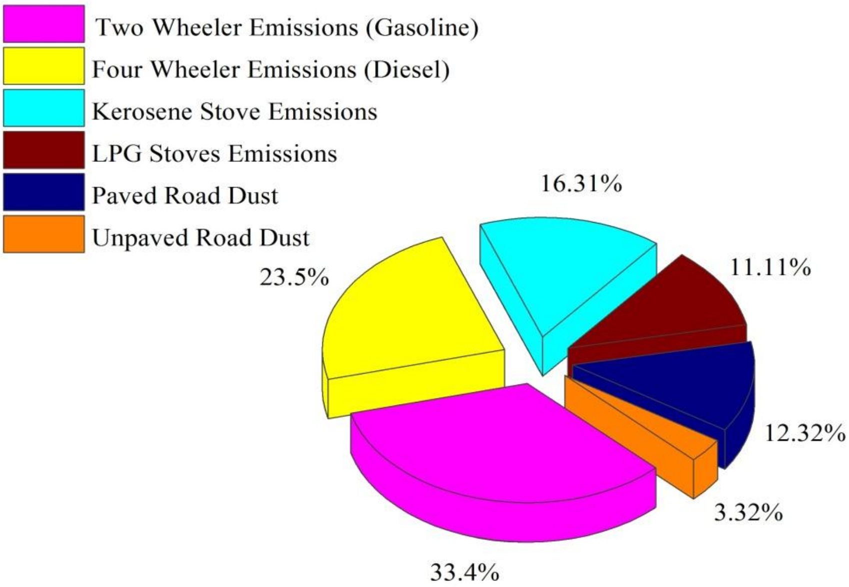


Fig.4.21. PM$_{2.5}$ Source composition at KMC Attavar Site

4.5.2.4. Source contributions for PM$_{2.5}$ particles at KMC Jyothi Site:

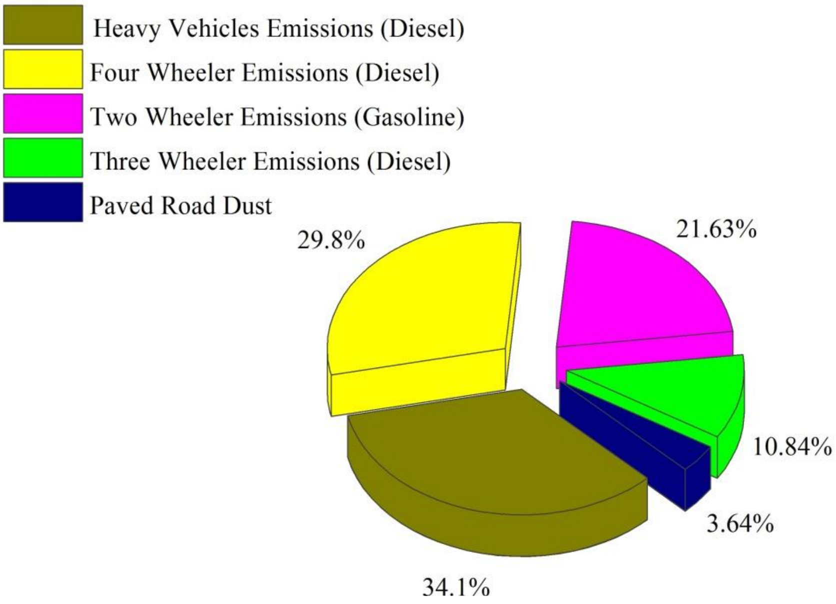


Fig.4.22. PM$_{2.5}$ Source composition at KMC Jyothi Site

KMC Jothi site is one of the busy junctions flooded with vehicles of all size ranges. However, the heavy vehicles emissions contribution was found to be higher since the site acts as a major junction for both city and mofussil buses as this junction connects the roads to many schools, colleges, hospitals and commercial complexes located in various parts of Mangalore (Fig.4.22). Four wheeler vehicles' emissions were found to be the second dominant source followed by two wheelers' and three wheeler emissions where, the last contribute towards paved road dusts.

4.5.2.5. Source contributions for $PM_{2.5}$ particles at Town hall Site:

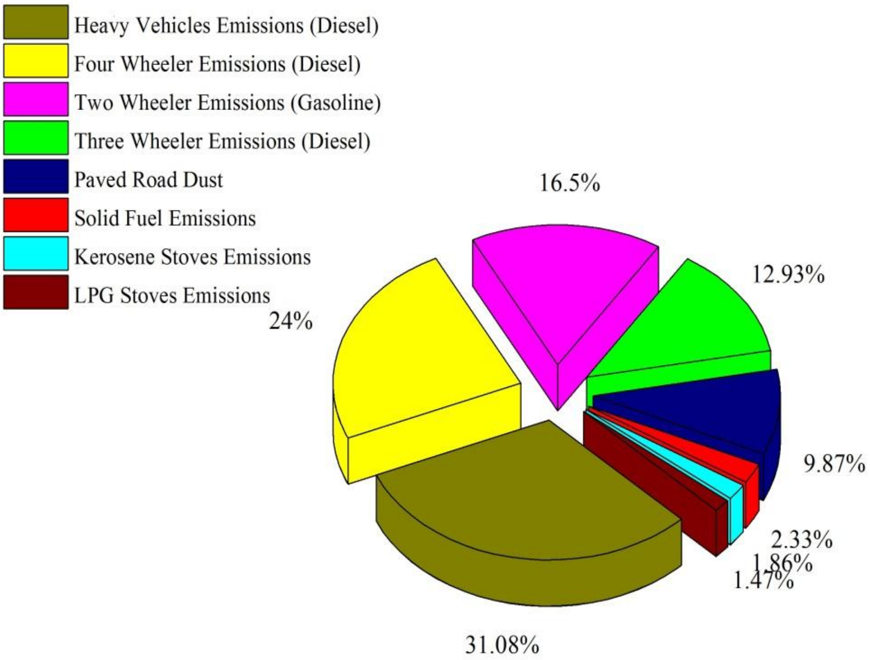


Fig.4.23. $PM_{2.5}$ Source composition at Town Hall Site

Town hall is the busiest junction compared to all the sites taken in our study. The site is categorized as a traffic/commercial site with contributions from nearly 8 sources with a considerable contribution of $PM_{2.5}$ particles. Among all the 8 sources heavy vehicle emissions contribution was found to be higher, as the site is located in a close vicinity to bus stations of local buses connecting to various parts of the city and moffusil buses connecting to the nearby Dakshina Kannada districts. The busy traffic at the junction will lead to these heavy vehicles to idle resulting in a higher emission of pollutants from these vehicles compared to four wheeler, two wheeler and three wheeler emissions. The paved road dust contributes next to the vehicles emissions as these vehicles causes abrasions and these abrasions in turn resuspend the particles into the ambient atmosphere (Fig.4.23). The solid fuel emissions, kerosene stove and LPG stove emissions contributes faintly revealing the fact that these emissions are from the road side restaurants, barbecues using charcoal, bakeries and restaurants located in the sampling site neighbourhood.

4.5.2.6. Source contributions for $PM_{2.5}$ particles at KSPCB Site:

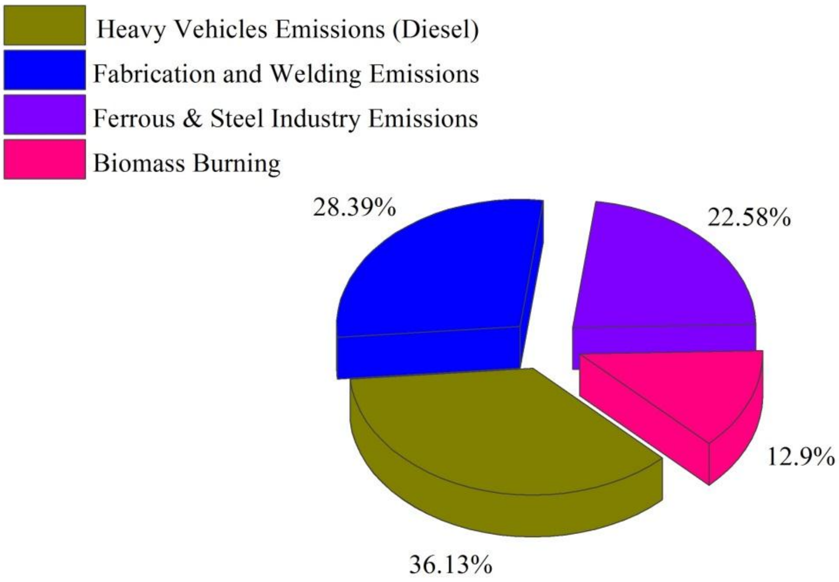


Fig.4.24. $PM_{2.5}$ Source composition at KSPCB Site

KSPCB is an industrial site with a higher amount contribution of emissions from heavy vehicles, as the trucks with loads are being in a higher population for raw materials transportation compared to other vehicular emissions. The fabrication and welding industrial activities stands next to the heavy vehicle emissions followed by ferrous and steel industries emissions (Fig.4.24). The emissions from burning of biomass in the industrial area such as burning of shredded leaves and wood burning for cooking in a nearby marriage hall has contributed slightly to the $PM_{2.5}$ particles in the atmosphere of the sampling site.

4.5.3. Source contributions of PAHs at various sites in Mangalore:

The collected samples were then ultrasonicated and extracted for estimating the PAHs present in them. The samples subjected to fluorescence spectrophotometer exhibited seven PAHs namely Fluorene (Flu), Acenaphthene (Ace), Chrysene (Chr), Benz(a)anthracene (B(a)A), Benzo(a)pyrene (B(a)P), Benzo(b)fluoranthene (B(b)F), Indeno (1,2,3-c,d) pyrene. The obtained concentrations of these PAHs has been further being used to carry out receptor modeling studies to estimate the sources contributing the emission of PAHs at the selected sampling sites in the ambient atmosphere of Mangalore. However, the sources of PAHs in any atmosphere would have been contributed majorly from vehicular emissions, wood combustion and bio mass burning. The following pie charts discuss in detail about the sources of PAHs contribution at the sampling sites in Mangalore.

4.5.3.1. Source contributions of PAHs at Lady Hill Site:

Lady Hill site as discussed in the earlier sections is one of the major junction in the city with a residential area in the nearest vicinity of the study area. Two wheeler emissions was found to contribute nearly 40% of the sources contributing to PAHs, with more or less equal contribution from heavy vehicles and diesel powered passenger car emissions respectively (Fig.4.25). However, gasoline powered passenger cars contributes to a notable amount of PAHs at the sampling site. This above arrangement of sources clearly depicts that the vehicular emissions altogether contributes to the emissions of PAHs in the lady hill sampling site.

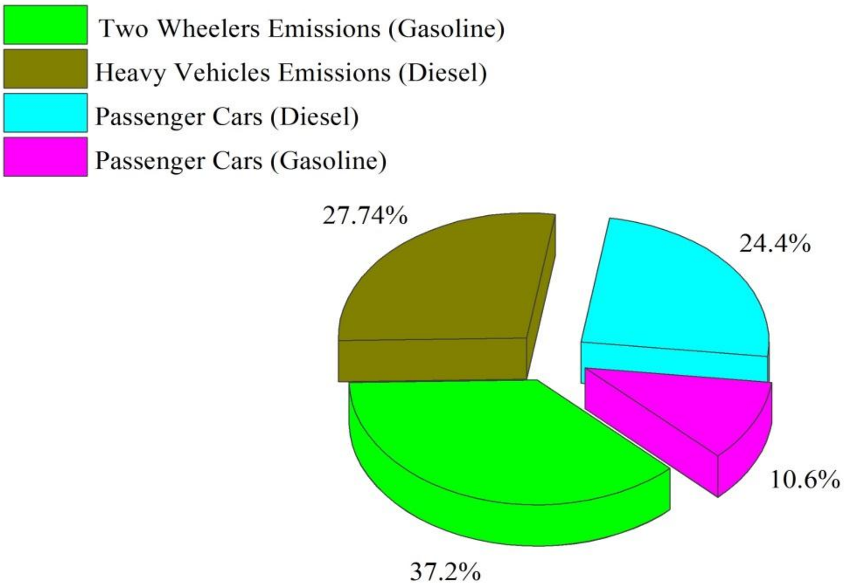


Fig.4.25. PAHs Source composition at Lady Hill Site

4.5.3.2. Source contributions of PAHs at City center Site:

City center site, located at one of the major urban roadway with a constant flow of vehicles of all categories. The source contribution estimated by the receptor model reveals that diesel powered passenger cars emissions are found to contribute a higher proportion of PAHs compared to heavy vehicles and three wheeler emissions, since the flow of diesel powered passenger cars were found to be higher and the sampling was carried out near city center mall where the cars would be in idling stage at the uphill for parking purposes. The idling process at the uphill may lead to a higher amount of exhaust emissions from the cars leading to a higher contribution from these vehicles. Furthermore, the contribution of emissions from gasoline powered cars and two wheelers were in a considerable range at the sampling site (Fig.4.26).

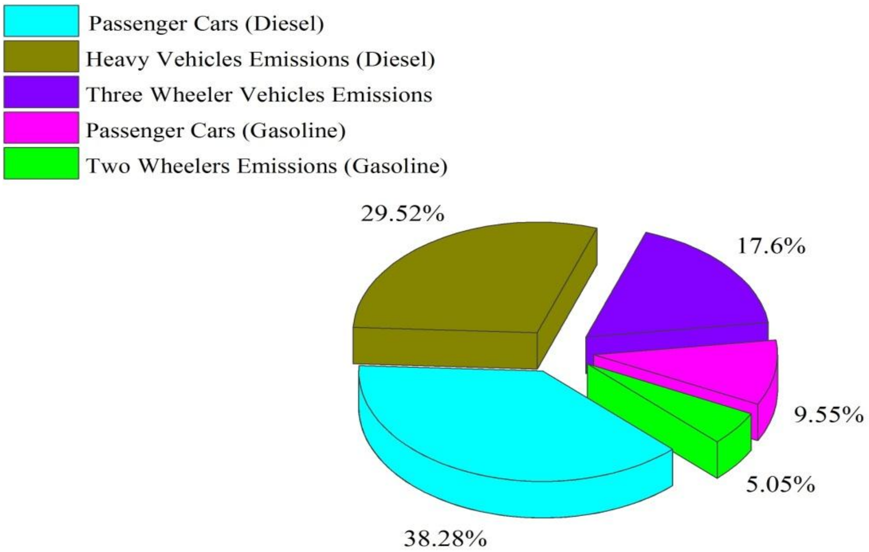


Fig.4.26. PAHs Source composition at City Center site

4.5.3.3. Source contributions of PAHsat KMC Attavar Site:

KMC Attavar site, located close to a residential area and at a considerable distance from the busy urban roadways resulted with four sources contributing to $PM_{2.5}$ particles. Among which diesel powered passenger cars were found to be contributing majorly compared with gasoline powered two wheelers and passenger cars (Fig.4.27).

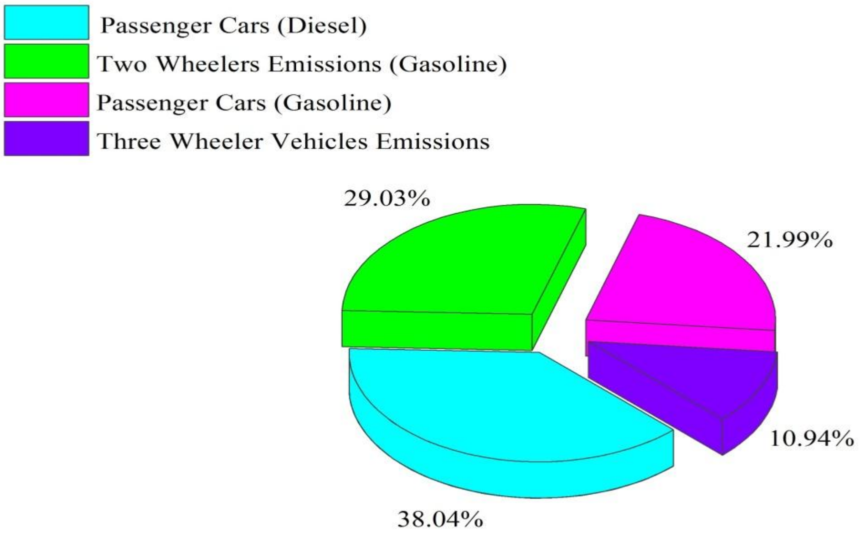


Fig.4.27. PAHs Source composition at KMC Attavar Site

The emissions from two wheelers and passenger cars were found at a roughly equal contribution range at KMC Attavar site with a considerable range of emissions from three wheelers. The emission from heavy vehicles does not contribute at a considerable range.

4.5.3.4. Source contributions of PAHs at KMC Jyothi Site:

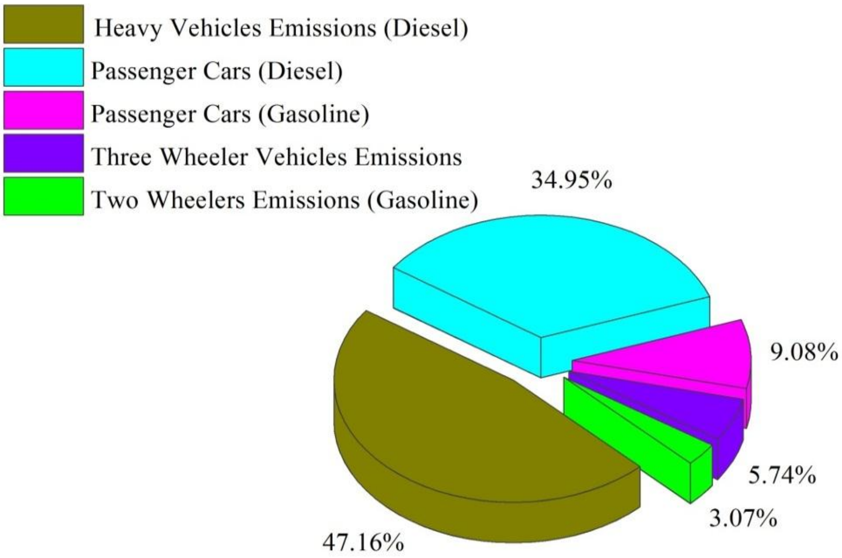


Fig.4.28. PAHs Source composition at KMC Jyothi Site

KMC Jyothi, One of the busy junctions in the city shows that the heavy vehicle emissions serve as the major source contributing to nearly 50% followed by diesel powered passenger cars with nearly 35%, Thus the heavy vehicles and diesel powered passenger cars serve as the major source in contributing PAHs formation in the busy junction followed by slight contribution of 15% altogether from gasoline powered passenger car emissions, three wheeler emissions and two wheeler emissions (Fig.4.28).

4.5.3.5. Source contributions of PAHs at Town hall Site:

Town hall, the site is categorized as traffic / commercial site of Mangalore and emissions from heavy vehicles was found to be contributing at a higher range followed by diesel powered passenger cars (Fig.4.29). The emission from diesel powered vehicles has been found to be contributing at a higher range at all the sites in the urban area of Mangalore. However, there is a significant amount of contribution from wood combustion which have been carried out at all the road side restaurants, barbecue joints and bakeries where the wood will be used as a primary fuel for cooking activities. Likewise, emissions from three wheelers, gasoline powered cars and two wheelers were found to participate with a slight contribution in the formation of PAHs.

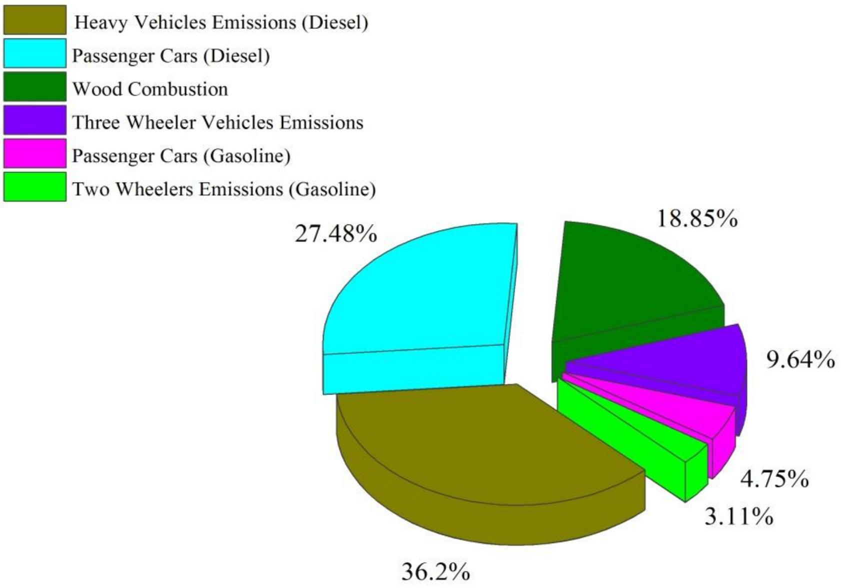


Fig.4.29. PAHs Source composition at Town Hall Site

4.5.3.6. Source contributions of PAHs at KSPCB Site:

KSPCB is an industrial site with varied industrial activities, where a higher contribution of PAHs was found from ferrous and steel industries emissions. In most of the industrial activities the feedstock (coal) will be used as the primary fuel for processing any raw material, thus the KSPCB site has the second highest contribution of PAHs from feedstock emissions followed by wood combustion emissions.

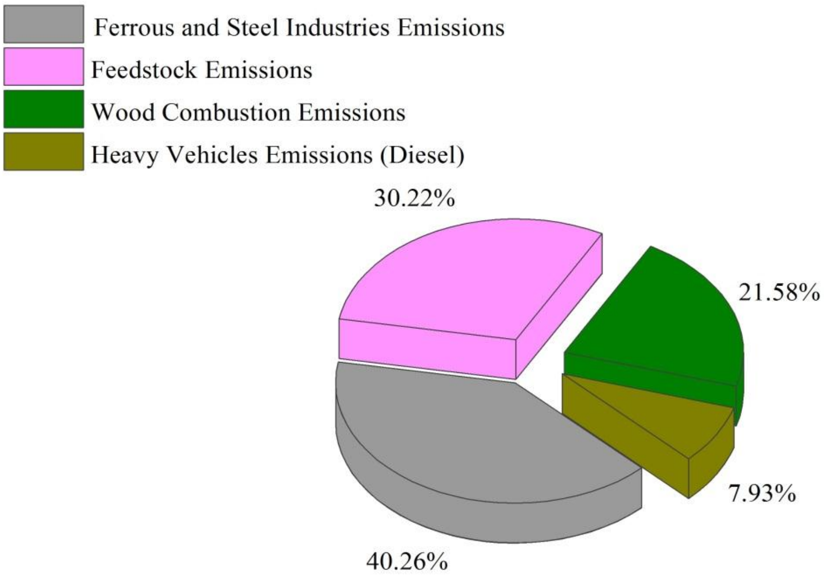


Fig.4.30. PAHs Source composition at KSPCB Site

However, emissions from heavy vehicles were also found to contribute to the PAHs formation which shows that the vehicular transportation plays a moderate role in deteriorating the ambient air of an industrial site.

Table 4.11. Sources of PM_{10} at different sampling sites

Sampling Site	Sources of PM_{10} particles								
	PRD	**UPRD**	**DG**	**TE**	**BL**	**SD**	**GE**	**DE**	**CD**
Lady hill	34%	10%	5%	-	3%	28%	-	19%	-
City Center	47%	-	5%	-	2%	-	14%	33%	-
KMC Attavar	35%	24%	6%	-	-	17%	-	6%	12%
KMC Jyothi	28%	-	8%	2%	-	-	23%	40%	-
Town hall	27%	-	12%	3%	7%	9%	19%	24%	-
KSPCB	25%	35%	8%	-	-	18%	-	14%	-

PRD – Paved road dust; UPRD – Unpaved road dust; DG – Diesel generators; TE – Tyre wear emissions; BL – Brake lining emissions; SD – Sand dust; GE – Gasoline vehicles emissions; DE – Diesel vehicle emissions; CD – Construction dust.

Table.4.12. Sources of $PM_{2.5}$ particles at different sampling sites

Sampling Site	Sources of $PM_{2.5}$ particles											
	PRD	UPRD	TRE	HVE	FE	TWE	LE	KE	SFE	FWE	FSI	BB
Lady hill	8%	-	-	21%	29%	42%	-	-	-	-	-	-
City Center	10%	-	12%	16%	22%	32%	7%	-	-	-	-	-
KMC Attavar	12%	3%	-		24%	33%	11%	16%	-	-	-	-
KMC Jyothi	4%	-	11%	34%	30%	22%	-	-	-	-	-	-
Town hall	10%	-	13%	31%	24%	17%	2%	2%	2%	-	-	-
KSPCB	-	-	-	36%	-	-	-	-	-	28%	23%	13%

BB - Biomass Burning; FSI – Ferrous and steel industries emissions; FWE – Fabrication and welding emissions; SFE – Solid fuel emissions; UPRD – Unpaved road dust; KE – Kerosene stove emissions; LE – LPG stove emissions; PRD – Paved road dust; TRE – Three wheeler emissions; HVE – Heavy vehicles emissions; FE – Four wheeler emissions; TWE – Two wheeler emissions.

Table.4.13. Sources of PAHs at different sampling sites

Sampling Site	Sources of PAHs							
	TW (G)	HE (D)	PC (G)	PC (D)	TRE	WC	FSE	FSI
Lady hill	37%	28%	10%	24%	-	-	-	-
City Center	5%	30%	10%	37%	18%	-	-	-
KMC Attavar	29%	-	22%	38%	11%	-	-	-
KMC Jyothi	3%	47%	9%	35%	6%	-	-	-
Town hall	3%	36%	5%	27%	10%	19%	-	-
KSPCB	-	8%	-	-	-	22%	30%	40%

TW (G) – Two wheeler emissions; HE (D) – Heavy vehicles emissions (Diesel); PC (G) – Passenger cars (Gasoline); PC (D) – Passenger cars (Diesel); TRE - Three wheeler emissions; WC - Wood combustion; FSE – Feed stock emissions; FSI – Ferrous and steel industries emissions.

Table.4.14. Statistics of CMB performance for PM_{10} particles at all the sites

Sampling Site	R^2	χ^2	%mass	Degrees of Freedom
Lady Hill	0.89	3.05	83.2	6
City Center	0.97	1.87	92.3	9
KMC Attavar	0.91	3.31	96.4	11
KMC Jothi Circle	0.95	1.08	110.9	8
Town Hall	0.92	1.79	103.2	10
KSPCB	0.90	1.52	110.8	12

Table.4.15. Statistics of CMB performance for $PM_{2.5}$ particles at all the sites

Sampling Site	R^2	χ^2	%mass	Degrees of Freedom
Lady Hill	0.86	3.68	96.4	10
City Center	0.98	1.28	93.7	8
KMC Attavar	0.92	1.02	98.2	14
KMC Jothi Circle	0.94	3.44	92.9	9
Town Hall	0.91	1.78	97.9	13
KSPCB	0.96	1.66	98.1	7

Table.4.16. Statistics of CMB performance for PAHs at all the sampling sites

Sampling Site	R^2	χ^2	%mass	Degrees of Freedom
Lady Hill	0.96	1.21	96.5	12
City Center	0.88	2.01	87.3	9
KMC Attavar	0.98	1.71	97.5	14
KMC Jothi Circle	0.92	1.55	94.9	10
Town Hall	0.89	0.91	89.9	15
KSPCB	0.9	1.96	89.3	8

4.5.4. Sources contributing to $PM_{2.5}$ concentrations in schools located near urban roadways:

The concentrations of the elements and ions obtained from the indoor air samples of urban schools viz. LHV and BEM subjected for receptor modelling using USEPA CMB8.2 to identify the sources that contribute to the elements and ions in the samples. The LHV School has a considerably higher percentage mass of 119.6% with an R^2 of

0.96 and Chi square of 1.08. The $PM_{2.5}$ particles are contributed by five sources, such as Paved Road Dust (PRD) (13.7%), Soil Dust (4.08%), Gasoline Vehicle Emissions (7.01%), Diesel Vehicle Emissions (70.78%) and Marine Sources (4.43%) respectively (Fig.4.32). It is well evident that emissions from diesel vehicles contribute a higher percentage of $PM_{2.5}$ particles, since the receptor site is located very close to a busy urban roadway which encompasses diesel vehicles especially local buses and diesel cars. Whereas the CMB analysis for BEM School acquiesce well with sources with a percentage mass of 119.1% with a R^2 value of 0.96 and Chi square value of 1.04 with 10 Degrees of Freedom. The sources contributing to the school premises are unpaved road dust (10.99%), Paved Road dust (3.26%), Soil Dust (4.09%), Diesel Vehicle Emissions (80.52%) and Fuel oil Combustion (1.14%) (Fig.4.33). Due to the road construction work near the sampling site it is evident that there is a significant increase in contribution of unpaved road dust compared to paved road dust. Since it is a busy commercial street there is a slight amount of contribution of $PM_{2.5}$ particles from the small scale fabrication industries which uses fuel oil (engine oil or light diesel oil) for mechanical parts fabrication in the vicinity of the sampling site. The diesel vehicle combustion plays a major rule in contributing the particulate matter in BEM High School as it is located in a busy commercial area with vehicular traffic leading to particle contribution higher than Lady Hill Victoria Girls High School.

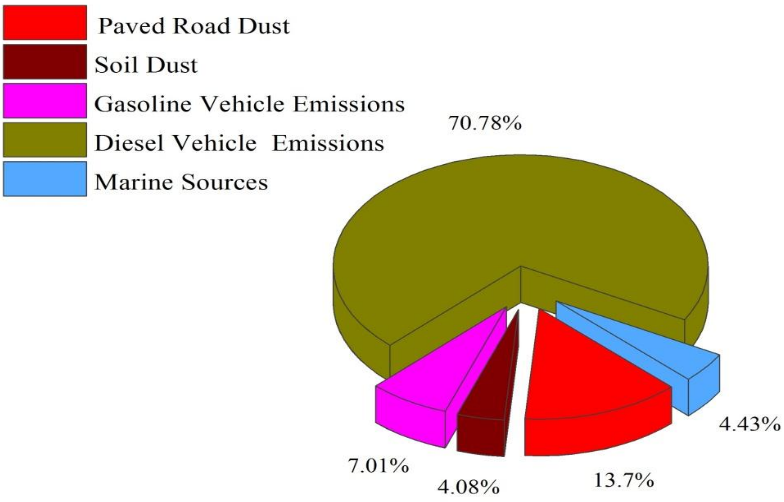


Fig.4.31. $PM_{2.5}$ Source composition at LHV School

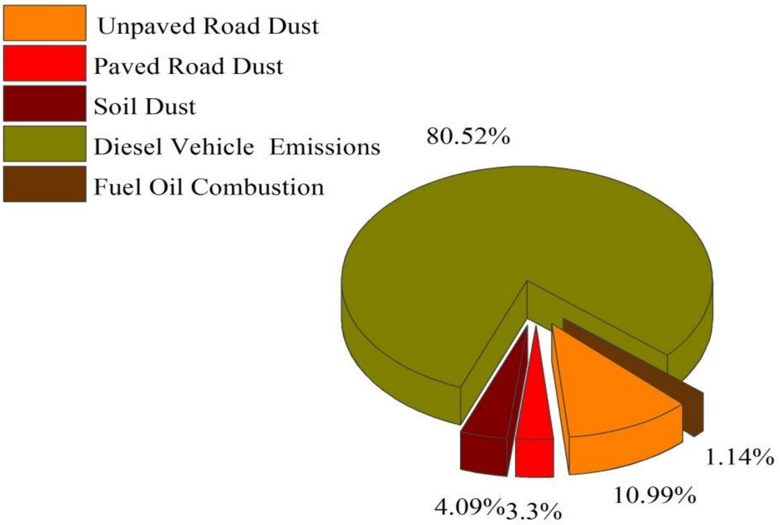


Fig.4.32. PM2.5 Source composition at BEM School

4.5.5. Sources contributing to PM2.5 concentrations in schools located near sub-urban highways:

The obtained concentration of elements and ions from the schools in sub urban area is also subjected for receptor modelling to estimate the source contributions of $PM_{2.5}$ particles in those schools. The KMS School which is located very close to the highway (NH 66) yielded a percentage mass of 106.3% with a R^2 of 0.98 and a Chi square of 0.81 with 8 Degrees of Freedom. The sources contributing to $PM_{2.5}$ particles in this school are Open Burning (2.34%) Paved Road Dust (20.78%), Soil Dust (2.30%), Gasoline Vehicle Emissions (2.61%) Diesel Vehicle Emissions (59.61%) and Marine Sources (12.36%) (Fig.4.34) The diesel vehicle contribution is lesser than the schools located at the urban areas since there is a greater chance of particles to drift away with the wind speed as the density of buildings in a suburban area is lesser as that of an urban area and also the idling time of the vehicles is lesser compared to urban areas. Also there is a considerable contribution from Marine Sources since the sampling site is located close to the shores of Arabian Sea. Likewise Paved Road Dust also plays a considerable role since the resuspension of paved Road Dust will be higher than urban areas due to the movement of heavy vehicles at a higher rate in a highway compared to any urban roadway. Likewise, the receptor modelling is applied for EMS School which is located 100 meters away from the NH66 obtained a percentage mass of 86.6% with a R^2 of 0.93 and Chi square of 1.02 with 12 Degrees of Freedom. The major sources contributing to this sampling site are Paved Road Dust (3.15%), Soil Dust (55.2%), Gasoline Vehicle Emissions (19.36%) and

Marine Sources (22.3%) (Fig.4.35). Since the school is located close to a playground there is a higher amount of contribution from soil dust and the fall in Paved Road Dust emission is due to the fact that the resuspension is lower in the roads running through the campus. Given the fact that the sampling site is located in a university campus and 100 meters away from the highway and the Gasoline Vehicles usage is higher than the Diesel Vehicles leads to a higher contribution of $PM_{2.5}$ particles from Gasoline vehicle Emissions as that of emissions from Diesel Vehicles. It is clearly evident that the indoor environment of schools located close to the urban roadways and highways contribute $PM_{2.5}$ with heavy elements from vehicular and combustion activities compared to the school located 100 meters away from any vehicular activity compared to the other sampling sites.

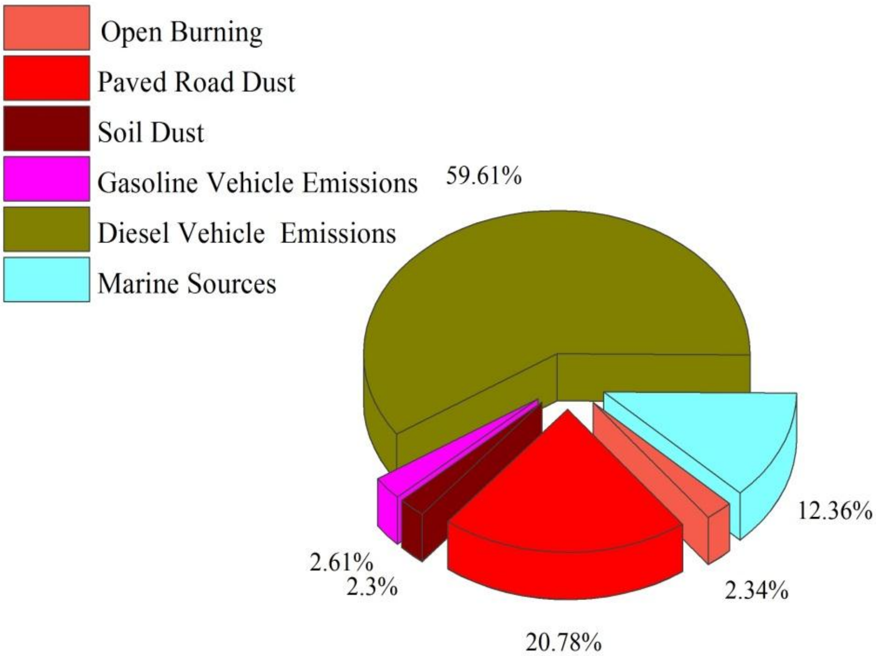


Fig.4.33. $PM_{2.5}$ Source composition at KMS School

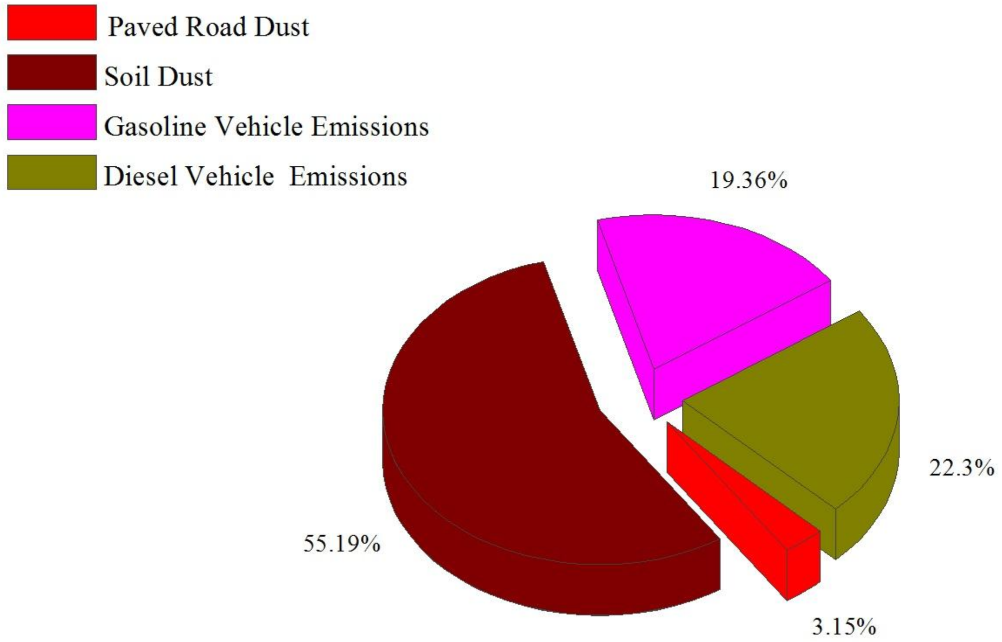


Fig.4.34. $PM_{2.5}$ Source composition at EMS School

Table.4.17. Statistics of CMB performance at school indoors

Particle Size	R^2	χ^2	%mass	Degrees of Freedom
LHV School	0.96	1.08	119.6	10
BEM School	0.96	1.04	119.1	10
NITK Kannada Medium School	0.98	0.81	106.3	8
NITK English Medium School	0.93	1.02	86.6	12

4.6. Dispersion modeling results using AERMOD simulations:

4.6.1. Observed and predicted $PM_{2.5}$ concentration:

The $PM_{2.5}$ concentration have found for four different seasons and for 3 different sites by sampling and modelling. Model was run for complex terrain using Cartesian grid point receptor. From the grid points, the $PM_{2.5}$ concentration has found out exactly in the place where the pollutants have observed. The Observed pollutants concentrations were compared with the predicted concentrations. The 8 hour average and 24 hour average concentration of $PM_{2.5}$ by sampling and modelling for four seasons and for different sites are given in Table 4.18, 4.19 and 4.20.

In Lady Hill School, the PM concentration varying from 4.51 to 94.27 for 8 hour average and 12.66 to 54.14 for 24 hour average. Out of total samples in Lady Hill Circle, the maximum 8 hour average and maximum 24 hour average concentration have found in Post Monsoon and followed by winter season. There is maximum concentration in post monsoon and winter season because of low mixing height, low wind speed and low temperature in post monsoon and winter than other seasons, so this makes the unfavorable conditions for the pollutants to disperse easily in atmosphere. Wind direction is also one of factors influences the pollutants dispersion. In post monsoon, season the wind pattern was from west to east and the Lady Hill School is located in the east side of the road. So, this also might be the responsible for higher concentration in Lady Hill School. However the 8 hour average concentration exceeded among other in one time period of Monsoon. Actually, the pollutants concentration is very low in Monsoon season since the dilution of pollutants because of precipitation. However, in monsoon season, if there is no precipitation that also makes the pollutants to accumulate in ambient environment. So this might be the reason for high concentration in particular 8 hour time period.

In Jyothi Circle, the PM concentration varying from 5.32 to 111.35 for 8 hour average and 20.39 to 64.12 for 24 hour average. The maximum 8 hour average and maximum 24 hour average concentration have found in Post Monsoon and followed by winter season. This is because of climatic conditions i.e. low wind speed, low mixing height and low temperature than other seasons. However, the 8 hour average and 24 hour average concentration exceeded in one time period of summer season.

This might be the influence of wind direction in summer season. The sampling location is in south direction to the road and the wind direction was north to south. So, this could make the pollutants to transverse towards the sampling location.

In KMC Attavar, this is considered as Residential Area, the 8 hour average PM concentration varying from 21.56 to 72.15 and the 24 hour average PM concentration varying from 32.62 to 58.48. The maximum PM concentration have found in Monsoon season and Post Monsoon. In case of summer season, there is high concentration of 8 hr average and 24 hour average. Since it is the residential area, there is possibility for pollutants could have come from any other sources like diesel generators. Therefore this might be the reason for higher concentration in particular period. Over all, there is high $PM_{2.5}$ concentration in both Post Monsoon and winter seasons because of climatic conditions. Also we can observe that the 8 hour average concentration in the time period of 2 PM to 10 PM is high followed by 6 AM to 2 PM than other time period (6 AM to 2 PM and) of one day. This is because of high vehicular movements during that period and also other activities which generate the fine particles like diesel generators and wood burning. So this could make the more fine particles generation in the period of 2 PM to 10 PM.

Table.4.18. Observed and predicted $PM_{2.5}$ Concentration for Lady Hill Circle

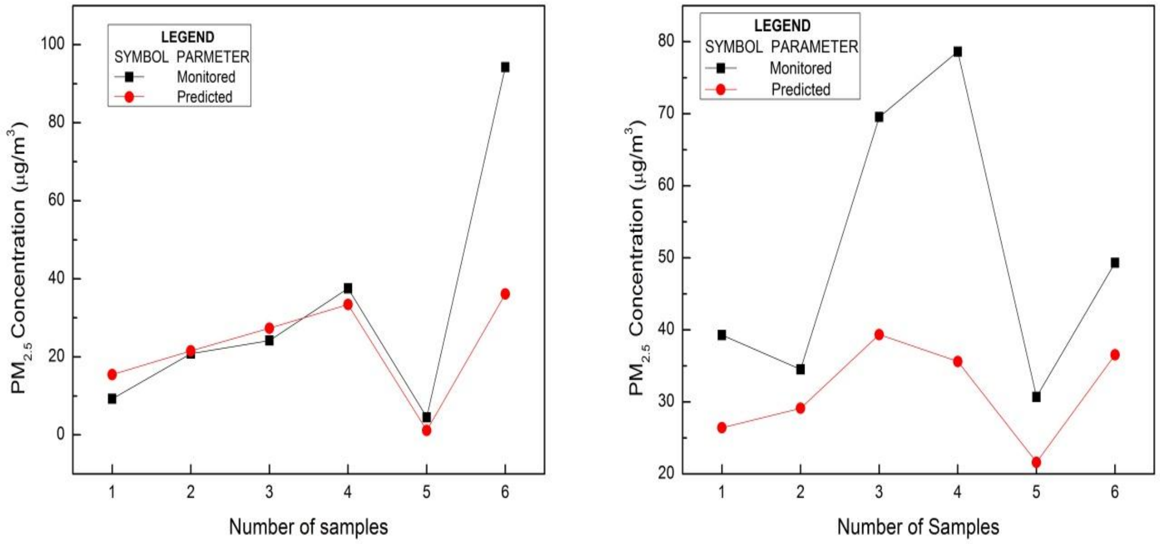
Seasons (For LH Circle)	**6 AM to 2 PM (8 hr average)**		**2 PM to 10 PM (8 hr average)**		**10 PM to 6 AM (8 hr average)**		**6 AM to next day 6 AM 24 hour average**	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
Monsoon	9.27	15.48	24.21	27.35	4.51	1.16	12.66	14.67
	20.85	21.54	37.55	33.42	94.27	36.11	50.89	30.36
Post Monsoon	39.27	26.42	69.54	39.35	30.69	21.62	46.50	29.13
	34.51	29.12	78.62	35.62	49.31	36.54	54.14	33.76
Winter	39.27	32.65	62.35	34.12	41.51	36.25	47.71	34.34
	24.51	21.54	81.52	95.62	39.27	36.11	48.43	51.09
Summer	28.51	26.63	57.45	32.63	42.23	31.74	42.73	30.33
	31.95	29.81	46.92	33.56	48.82	38.24	42.56	33.87

Table.4.19. Observed and predicted $PM_{2.5}$ Concentration for Jyothi Circle

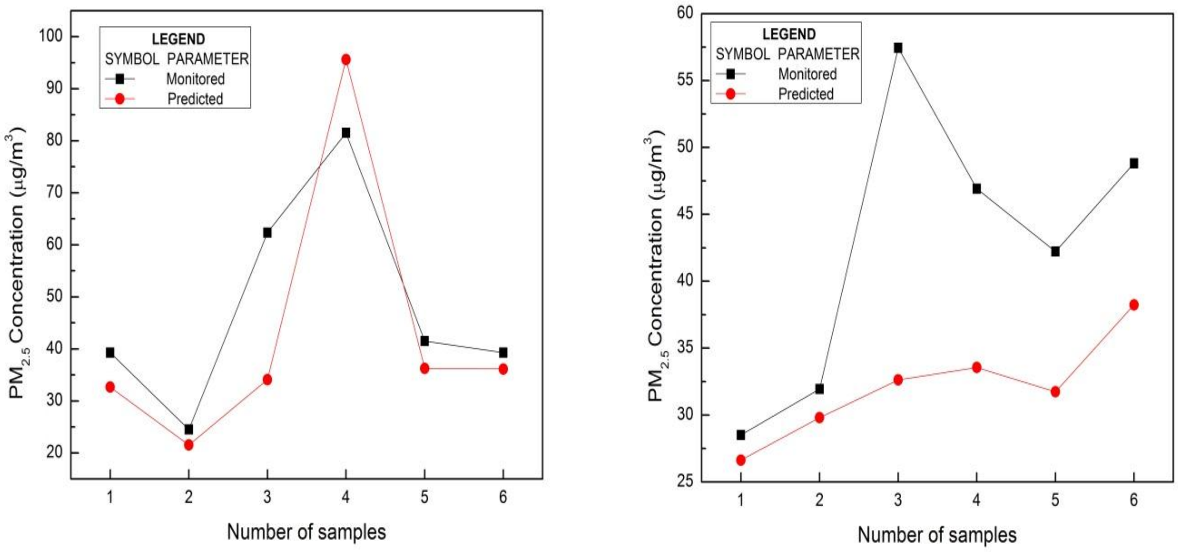
Seasons (For Jyothi Circle)	6 AM to 2 PM (8 hr average)		2 PM to 10 PM (8 hr average)		10 PM to 6 AM (8 hr average)		6 AM to next day 6 AM 24 hour	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Monsoon	14.32	20.48	5.32	7.62	41.52	31.06	20.39	19.72
	24.15	13.25	17.35	12.08	23.24	13.81	21.58	13.05
Post Monsoon	38.94	31.26	111.35	35.26	42.06	32.15	64.12	32.89
	32.12	22.26	94.36	41.25	36.89	26.35	54.47	29.95
Winter	41.62	31.64	61.25	40.26	33.15	22.35	45.34	31.42
	16.32	5.02	69.32	46.21	53.15	29.31	46.26	26.85
Summer	31.26	26.35	102.36	36.15	36.32	22.36	56.65	28.29
	55.36	38.65	48.36	25.16	15.32	17.23	39.69	27.06

Table.4.20. Observed and predicted $PM_{2.5}$ Concentration for KMC Attavar

Seasons (For KMC Attavar)	6 AM to 2 PM (8 hr average)		2 PM to 10 PM (8 hr average)		10 PM to 6 AM (8 hr average)		6 AM to next day 6 AM 24 hour	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
Monsoon	21.56	6.15	43.15	14.36	33.15	15.18	32.62	11.90
	35.16	10.25	45.23	21.15	35.16	14.32	38.52	15.24
Post Monsoon	40.35	18.34	31.62	14.61	55.36	17.28	42.44	16.74
	56.35	21.35	72.15	21.43	26.35	11.05	51.62	17.92
Winter	40.27	7.25	70.15	19.62	61.25	14.26	57.22	13.71
	62.15	17.34	38.23	9.15	51.26	19.26	50.55	15.25
Summer	41.25	12.64	55.26	18.94	42.15	16.29	46.22	15.96
	31.25	9.34	65.25	16.84	78.95	19.27	58.48	15.15

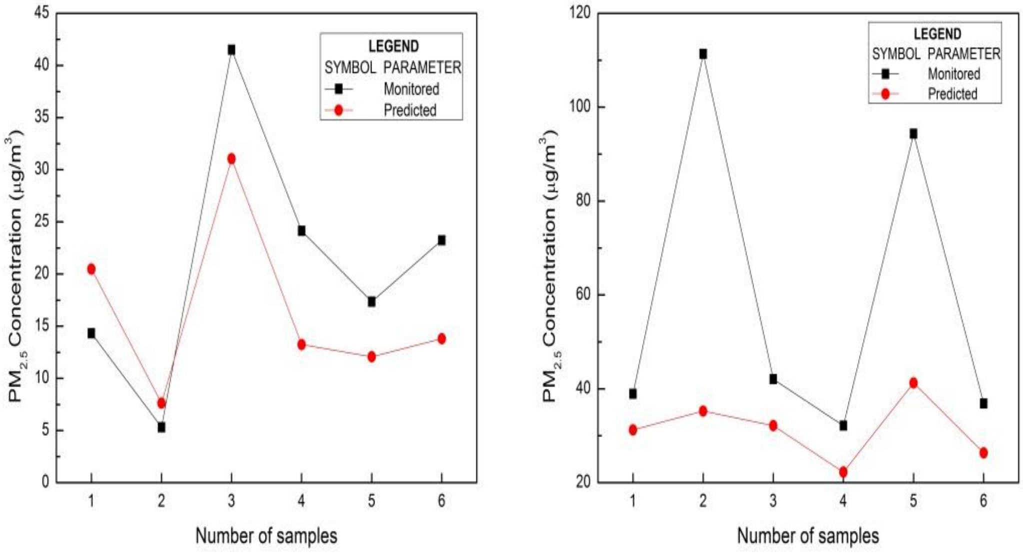


(a) Monsoon (b) Post Monsoon



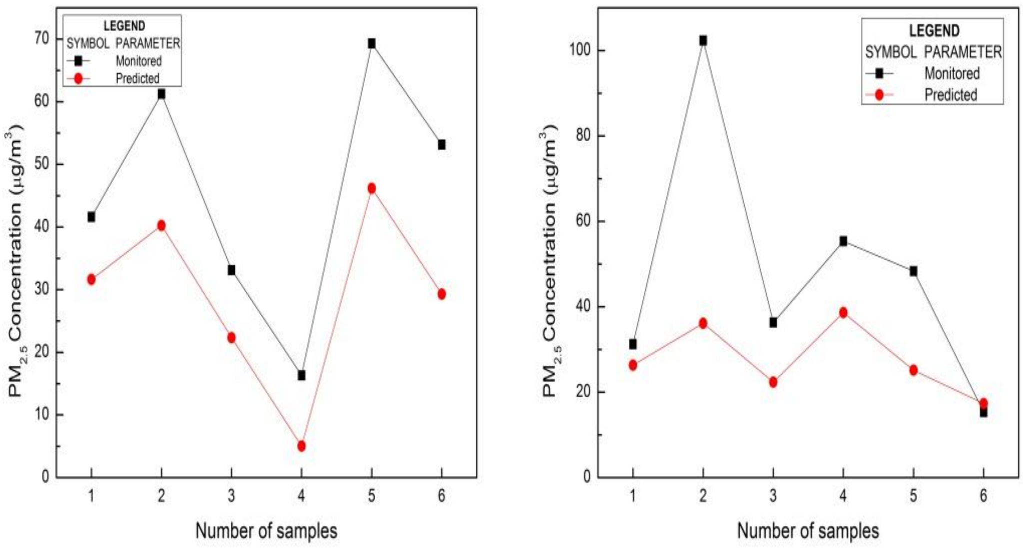
(c) Winter (d) Summer

Fig.4.35. Comparison of Observed and predicted PM$_{2.5}$ in Lady Hill School



(a) Monsoon

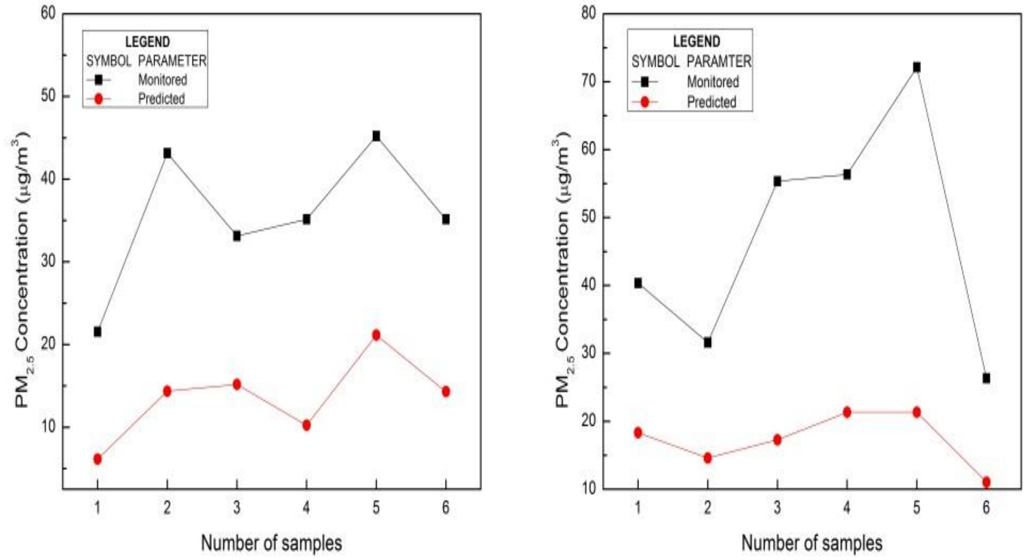
(b) Post Monsoon



(c) Winter

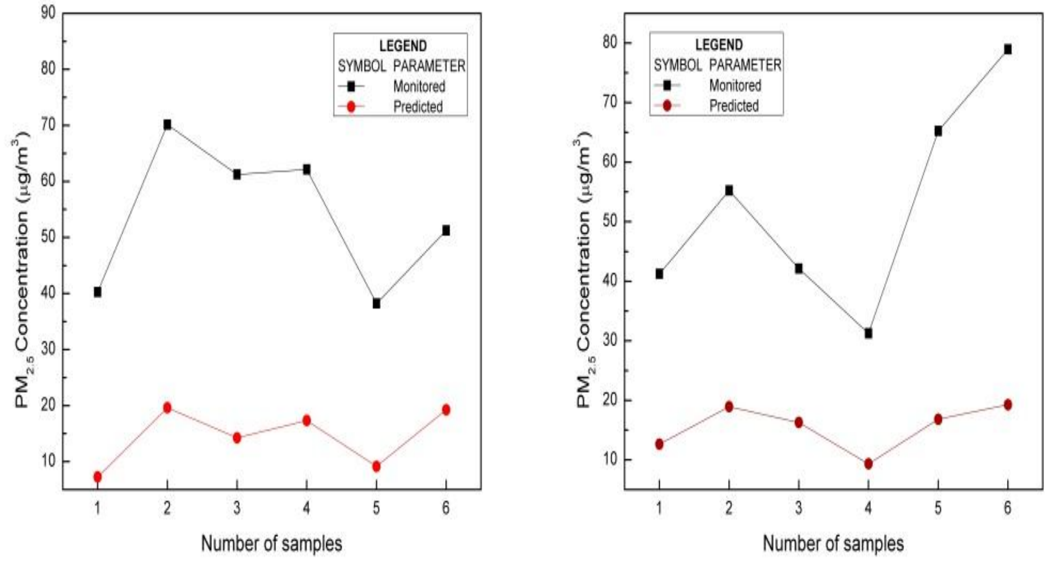
(d) Summer

Fig.4.36. Comparison of Observed and predicted $PM_{2.5}$in KMC Jyothi Circle



(a) Monsoon

(b) Post Monsoon



(c) Winter

(d) Summer

Fig.4.37. Comparison of Observed and predicted PM$_{2.5}$ at KMC Attavar

4.6.2. Model evaluation:

The model is evaluated by comparing predicted PM2.5 concentration with observed PM2.5concentration values. Statistical parameters, correlation coefficient (r2), index of agreement (d), Normalized mean square error (NMSE), Fractional Bias (FB), have used to evaluate the model performance. The results show that all statistical parameters are within the acceptable limit according to (Kumar et al. 2006a). These statistical parameters values are given in table 4.18 for different places with different seasons.

The index of agreement (d), given in table 4.18, shows that the values are higher for Lady Hill School and Jyothi circle than the KMC Attavar. This might be because of other activities which generate PM2.5. Normalized Mean Square Error (NMSE) and Fractional bias (FB) also show that prediction error is less for Lady Hill School and Jyothi circle than KMC Attavar.

Table.4.21. Statistical parameters for different sampling places

Statistical Parameters	LADY HILL CIRCLE	JOTHI CIRCLE	KMC ATTAVAR (Residential)
R^2	0.45	0.61	0.48
d	0.75	0.63	0.44
NMSE	0.26	0.61	1.63
FB	0.29	0.49	1.02

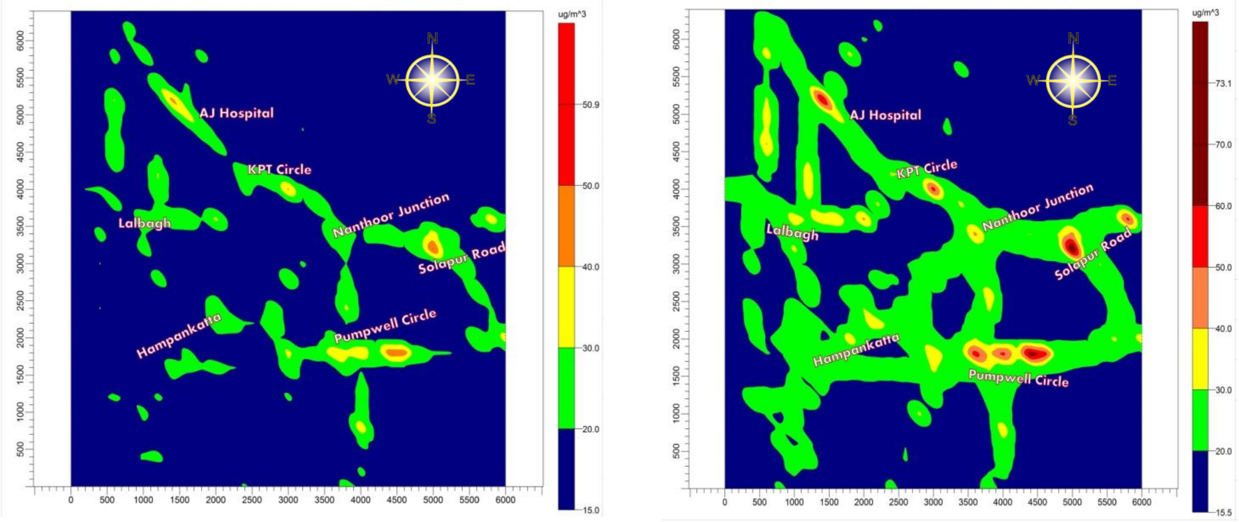
It is found that the time periods i.e. 6 AM to 2 PM, 2 PM to 10 PM and 10 PM to 6 PM also influence the prediction performance. The Statistical parameters for different time periods have given in table 4.22. The prediction performance at the time period of 6 AM to 2 PM than others two for all three places. The prediction performance at the time period of 2 PM to 10 PM is less, i.e. the accuracy will be less. This is because of many other activities which generate fine particles in the day time. Actually, in most of the places many activities start at morning 10 AM only and these activities could contribute the fine particles to the receptor at the time period of 2 PM to 10 PM due to transverse of pollutant. So, this might be the reason for predicting with accuracy at the time period of 2 PM to 10 PM.

Table.4.22. Statistical parameters for different time periods

Statistical Parameters	LADY HILL CIRCLE			JYOTHI CIRCLE			KMC ATTAVAR		
	6 AM to 2 PM	**2 PM to 10 PM**	**10 PM to 6 AM**	**6 AM to 2 PM**	**2 PM to 10 PM**	**10 PM to 6 AM**	**6 AM to 2 PM**	**2 PM to 10 PM**	**10 PM to 6 AM**
R^2	0.81	0.24	0.43	0.73	0.60	0.67	0.57	0.33	0.42
d	0.97	0.85	0.83	0.91	0.63	0.83	0.01	-0.219	-0.106
NMSE	0.05	0.24	0.37	0.14	0.93	0.19	1.65	1.58	1.62
FB	0.12	0.32	0.38	0.29	0.70	0.36	1.04	1.02	1.01

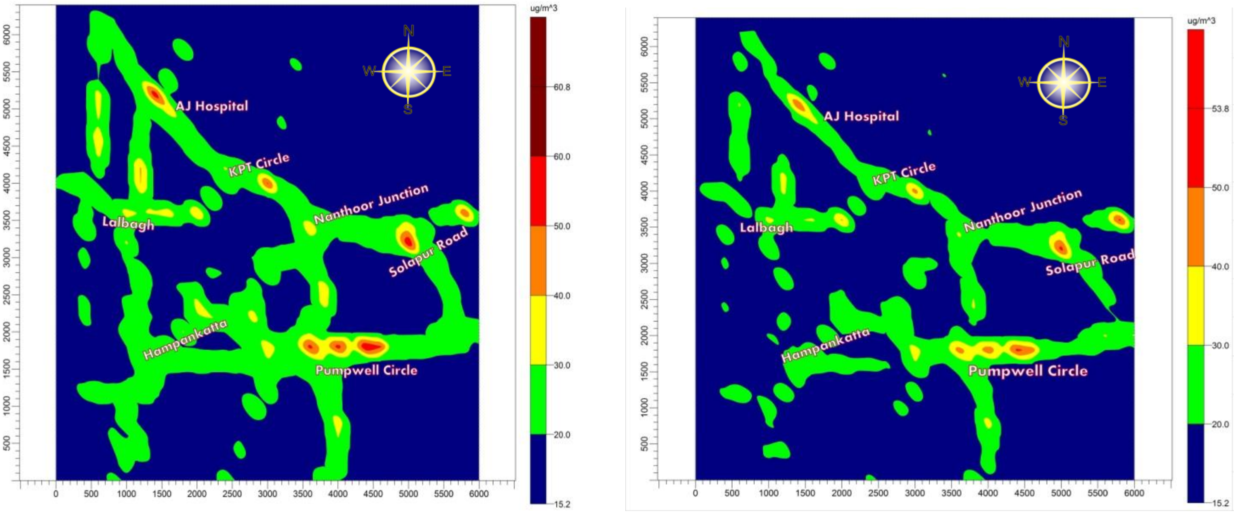
4.6.3. Dispersion of ambient PM for urban Mangalore:

AERMOD model was run and ambient $PM_{2.5}$ pollutant dispersion was simulated under existing scenario using emission inventory developed in this study. $PM_{2.5}$ emissions from vehicles are modelled for different seasons using current existing scenario and 24 hour average concentrations were calculated. The dispersion of $PM_{2.5}$ for four different seasons has shown in figure 4.39. Sources from vehicles only are considered in modelling. Among the four seasons (Monsoon, Post monsoon, winter and summer), the 24 hour average maximum $PM_{2.5}$ concentrations were found in post monsoon season followed by winter season. The hotspots for $PM_{2.5}$ have been found to be Pump well circle, Solapur-Mangalore highway, KPT Circle and AJ Hospital. These four hotspots have been identified in east side of Mangalore. During post monsoon and winter season, the $PM_{2.5}$ concentration in these hotspots is higher than during monsoon and summer season. This is because of high occurrence of stagnation in Post monsoon, winter season than in monsoon and summer (Chithra and Nagendra 2014). The $PM_{2.5}$ concentration in interior of Mangalore city is high dense during post monsoon and winter season. Low wind speed and low mixing height in post monsoon and winter season, due to more stable atmospheric conditions, reduce dispersion of $PM_{2.5}$ and high density of $PM_{2.5}$ observed over the city. However if the pollutants disperse, it will move towards city only from High way vehicles sources, outer skirt of Mangalore, since the winds are predominantly blowing from east south east direction in post monsoon and from east south east as well as north direction in winter season. This could make pollutants to disperse into the city. Since the impact of wind direction, predominantly blowing from West North West in monsoon and summer season, and presence of precipitation in monsoon, there is much less dense of $PM_{2.5}$ in interior of the city as well as there is reduction in maximum $PM_{2.5}$ concentration in National Highway.



(a) Monsoon

(b) Post Monsoon



(c) Winter

(d) Summer

Fig.4.38. PM Distribution for different seasons

In summer, the $PM_{2.5}$ concentration is lower due to better dispersion conditions. Frequent changes in wind speed and direction increased the atmospheric turbulence during summer months, thereby increasing the dispersion of $PM_{2.5}$ pollutant. The relatively high frequency of recirculation during the summer season was the direct consequence of the land-sea breeze circulations (Chithra and Nagendra 2014). We have observed that the ambient air quality is worst in post-monsoon season, particularly in November month. This results of air dispersion modelling show that meteorology has an important factor on the air quality (Sharma and Chandra 2008). The particulate matter concentration varies considerably with time, location and depending on meteorological conditions and source emissions rate (Elminir 2005).

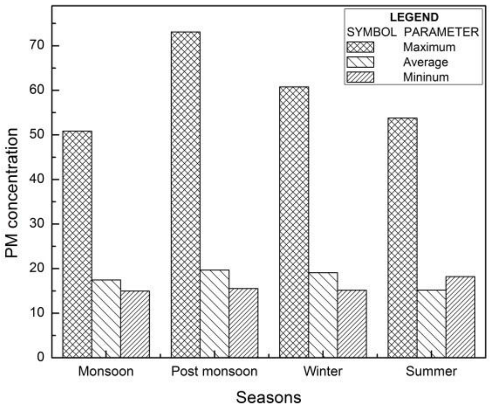


Fig.4.39. $PM_{2.5}$ concentration for four seasons

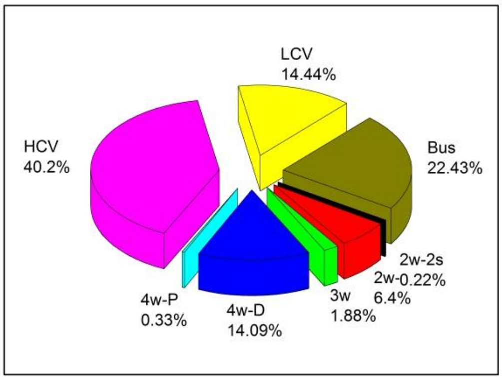
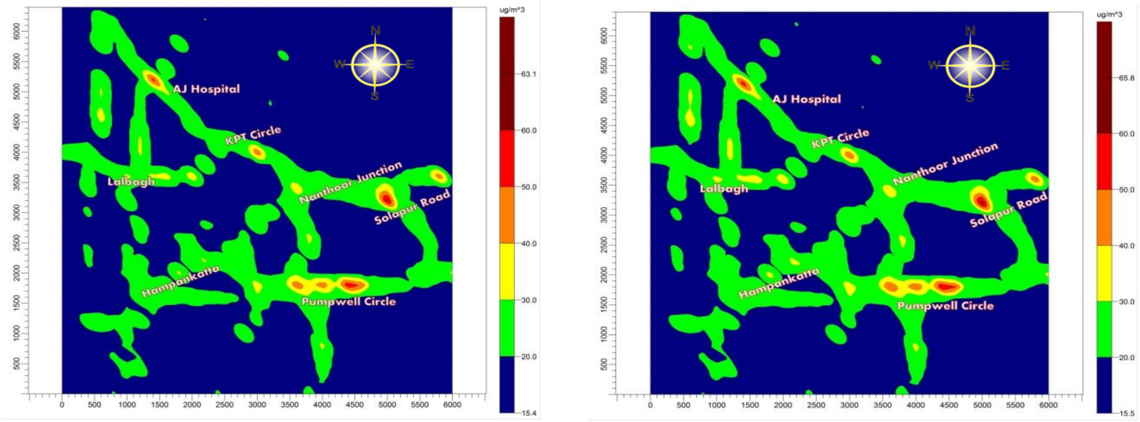


Fig.4.40. $PM_{2.5}$ contribution from vehicles

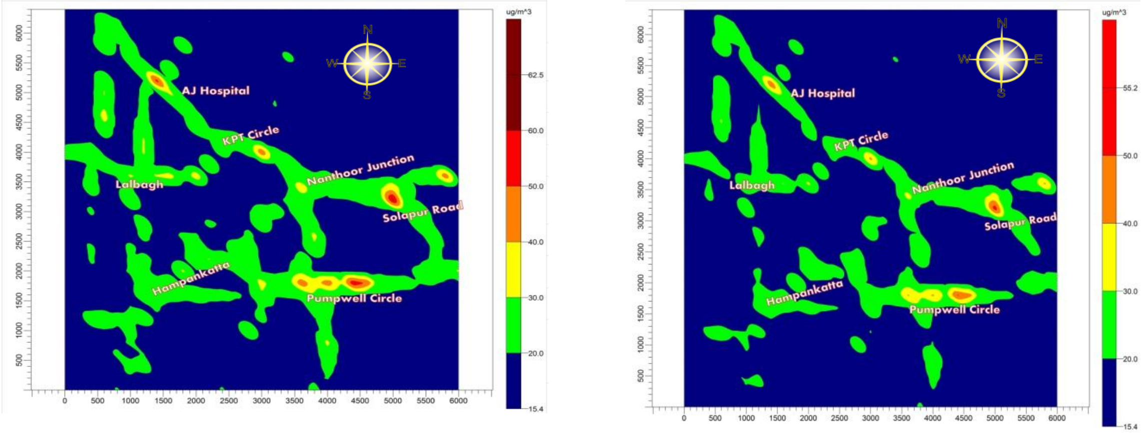
4.6.4. Air quality for future control scenario:

The AERMOD has been applied for various control scenarios to estimate change in air quality level for air quality management. Control scenarios are based on vehicular restriction and cleaner engine fuel. In the case of vehicular restriction, the 24 hour maximum $PM_{2.5}$ concentration has decreased by 14% from the existing scenario. Still the concentration was found to be exceeding the NAAQS limits. Also there is a controversy on ban of 10 years old vehicles in Delhi. So this scenario may not be possible for all over India. Therefore, the scenario based on using of cleaner engine fuel has selected to check the impact on ambient air quality. The 24 hour maximum $PM_{2.5}$ concentration has decreased in both case of CF1 and CF2. The concentration under CF2 scenario has decreased more than the concentration under CF1 scenario. Even in these two cases, the concentration was found to be exceeding the NAAQS limits slightly. The control scenario CF3 has applied to check the impact of PM concentration. Since this is the combination of two scenarios both CF1 and CF2, there was quite decrease in maximum $PM_{2.5}$ concentration and this is within NAAQS limits. We observed that CF3 scenario is better than other scenarios, since the maximum reduction of about 23 % of $PM_{2.5}$ concentration was found. PM emissions were found to be reduced significantly under both scenarios by using CNG fuel. Also, PM emissions from buses will be reduced significantly under CNG bus scenario since diesel buses emits more fine particles.



(a) Vehicular Restriction

(b) CNG car



(c) CNG bus

(d) Both CNG car and CNG bus

Fig.4.41. PM Dispersion in Mangalore city for future control scenario

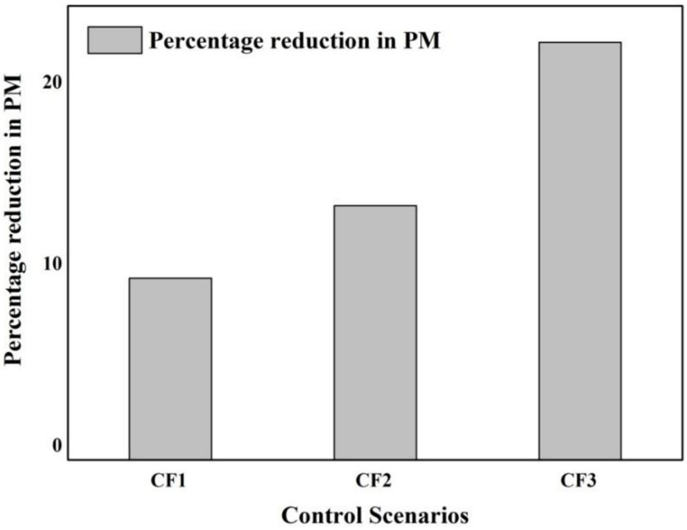


Fig.4.42. Percentage reduction of PM for all proposed scenarios

From the figure (Fig.4.41), we observed that diesel buses emit more particles than petrol and diesel cars. PM emissions are reduced significantly under both scenarios by using CNG fuel (Assessment of air quality after the implementation of compressed natural gas (CNG) as fuel in public transport in Delhi, India) and (Air Quality Assessment in Delhi: Before and After CNG as Fuel). This depends on emissions as well as number of buses and cars plying on the roads. In most cases, the density of cars will be higher than number of buses in all the cities. Nowadays, petrol and diesel cars are equally plying on the road. In this study, we have noticed 55% of diesel driven car and 45% petrol driven car (almost equal percentage). Since approximately half of the total car is petrol driven, the PM emission in existing scenario will be lower leading to a considerable reduction of PM concentration in the case of CNG car scenario. PM emissions from buses will be reduced significantly under CNG bus scenario since diesel buses emits more fine particles.

CHAPTER 5

CONCLUSIONS

The largest coastal industrial city of Karnataka, Mangalore with its speedy progress in the commercial, educational and industrial sector together deteriorates the ambient environment of air by releasing serious hazardous pollutants making the air less suitable for breathing. The burgeoning demand for addressing this issue had led us to carry out the present study by following the proposed guidelines framed by the Govt. Regulatory body, Central Pollution Control Board (CPCB). The study reveals that, particulate matter (PM_{10} and $PM_{2.5}$) a type of serious air pollutant is pertaining above the proposed limits for the ambient air of Mangalore. In addition to that, source apportionment study results depicts that vehicular emissions were found to be contributing nearly 70% of PM to the ambient atmosphere of Mangalore. Also, the dispersion study portrays the dispersion of particles from the outskirts of Mangalore to the urban area. A detailed explanation and conclusion on these studies have been discussed and some future regulations have been recommended to increase the quality of air in urban Mangalore.

5.1. Ambient air quality of Mangalore:

Source apportionment studies on particulate matter (PM_{10}& $PM_{2.5}$) using the USEPA proposed receptor model CMBv8.2 have been carried out for the coastal industrial city Mangalore. The PM mass concentrations of both particles were found to be higher during post monsoon season compared to monsoon and summer seasons due to the decreased mixing height and temperature inversion leading to the reduction in particle dispersion. The PM_{10} and $PM_{2.5}$ concentration of all the six sampling sites were found to be exceeding the NAAQS limits.Among all the sites, Town Hall recorded the highest concentration of 231 µg/m^3 for PM_{10} particles and 120.3 µg/m^3at KMC Attavar site for $PM_{2.5}$ particles. The PM_{10} particles were found to be contributed mainly from paved road dust and diesel vehicles emissions in urban Mangalore. Also, two wheeler emissions (Gasoline), heavy vehicle emissions (Diesel) and four wheeler emissions (Diesel) were found to contribute around 70% of the sources responsible for $PM_{2.5}$ particles emissions. Thus, the receptor modeling study on Mangalore region reveals that vehicular emissions (especially heavy vehicles emissions from diesel vehicles) plays a viable part in deteriorating the ambient air of urban Mangalore. The particle generation in urban Mangalore is found to be emitted majorly from vehicles due to incomplete combustion of fuels, which is a result of irregular throttle in the vehicles, improper and unsafe driving of diesel powered vehicles in Mangalore. In future, some strict driving regulations have to be formulated in the city with regular monitoring of speed violations in the urban and sub-urban areas of Mangalore. Similarly, optimal mitigation techniques and strategies are needed to abate PM non-exhaust emissions from road traffic.

5.2. Influence of outdoor PM in schools premises:

The Influence of $PM_{2.5}$ particles in school premises located close to urban and suburban roadways was investigated. The concentration of $PM_{2.5}$ particles was found using Dust Trak aerosol monitor. $PM_{2.5}$ samples were collected using high volume samplers and the exposed filters are subjected to further analyse for their elemental and ionic composition. The obtained data was then used to apportion the sources contributing to the indoor environment of the schools by using a receptor modelling technique Chemical Mass Balance (CMB). The modelling results indicate that the major sources in schools located near an urban roadway were Paved Road dust, Soil dust, Gasoline vehicles, Diesel Vehicle Emissions and Marine sources with a higher contribution of particles from diesel vehicle emissions. Whereas the sources contributing to the schools located close to sub urban highways were Paved Road dust, Soil dust, Gasoline Vehicle Emissions, Diesel Vehicle Emissions and Marine Source Emissions. The diesel vehicle contribution was found to be less in suburban highways compared to urban roadways due to the less traffic congestion and less vehicular population in a sub urban highway and the marine source contribution is considerably higher in sub urban schools since those schools are located in a close vicinity to the coastal line of Mangalore. The vehicular emissions are higher in the schools located near to any roadway than the school located 100 meters away from the roadway. This scenario clearly depicts that the indoor environment of schools located near to any urban roadway or sub urban highway is highly affected by the outdoor air pollutants (particularly in the size range of $PM_{2.5}$ particles) compared to the schools located far from the roadways. Prolonged exposure of school children to these particles implanted with the heavy elements can be subtle and it is not easy to recognize the health impacts of these particles on to the wellbeing of school children.

5.3. Ambient PAHs:

The seven PAHs compounds obtained from all the six sampling sites were found to possess significant concentrations in urban Mangalore, with a higher TPAHs concentration observed at Town Hall site. Among the PAHs, Acenapthene (Ace) stands with a higher concentration of 42.53 ng/m^{3}at KMC Jyothi site.The receptor modeling results clearly depicts that the vehicular emissions (around 75% from diesel powered passenger cars and heavy vehicles combustion) contributes majorly to PAHs into the ambient air of Mangalore.

5.4. Dispersion modeling:

The concentration of PM$_{2.5}$ particles were found for different climatic conditions viz. monsoon, post monsoon, winter and summer and found to be higher during post monsoon season compared to the rest as the precipitation in monsoon scrubs the PM and atmospheric turbulence during the summer drifts and dilutes them. Dispersion modeling study using AERMOD v 9.1, revealed that a significant quantities of PM getting accumulated in some parts of the city reaching levels above the NAAQS limits. The statistical parameters like correlation coefficient (R^2), index of agreement (d), Normalized mean square error (NMSE) and Fractional Bias (FB) for the observed and predicted values were found to be in agreement with the set values. Thus the ambient air quality of entire Mangalore city was assessed and four hotspots (Pump well circle, Solapur-Mangalore highway, KPT Circle and AJ Hospital) were identified. Future control scenarios were applied in prediction of PM$_{2.5}$ for Mangalore city based on Vehicular restriction (VR) and cleaner engine fuel (CF1and CF2). The scenarios showed a remarkable decrease in PM concentration with CF2 posing as a good and viable scenario with 23% of PM concentration reduction in ambient atmosphere of Mangalore.

Significant findings and Suggestions:

- The PM$_{10}$ concentration of all the six sampling sites were found to be exceeding the NAAQS limits, with Town Hall recorded with the highest concentration of 231 µg/m^3. The PM$_{10}$ particles were found to be contributed mainly from paved road dust and diesel vehicles emissions in Mangalore region.

- The concentration of PM$_{2.5}$ was found to be exceeding the NAAQS limits, by recording a higher concentration of 120.3 µg/m^{3}at KMC Attavar site, which is a residential site possessing numerous combustion sources especially from cooking activities.

- Two wheeler emissions (Gasoline), heavy vehicle emissions (Diesel) and four wheeler emissions (Diesel) were found to contribute around 70% of the sources responsible for $PM_{2.5}$ particles emissions.
- The seven PAHs compounds obtained from all the six sampling sites were found to possess significant concentrations in Mangalore, with a higher TPAHs concentration observed at Town Hall site. Among the PAHs, Acenapthene (Ace) stands with a higher concentration of 42.53 ng/m^3at KMC Jyothi site.
- The receptor modeling results clearly depicts that the vehicular emissions (around 75% from diesel powered passenger cars and heavy vehicles combustion) contributes majorly to PAHs into the ambient air of Mangalore.
- Studies carried out on the influence of outdoor particles in school premises showed some valuable insights and the results pose that a higher concentration of 90.63 µg/m^3 was observed at NITK Kannada Medium School (KMS) in the close vicinity of NH66.
- The model outputs and performance evaluation shows that the emissions from diesel vehicles were contributing around 60% compared to other sources, except in NITK English Medium School (EMS), since it is located at a distance of more than 100 metres from the roadways.
- Dispersion modeling study using AERMOD v 9.1, showed significant results, with the statistical parameters evaluation and the observed and predicted values were found to be satisfactory.
- The dispersion of particles from out skirts of Mangalore has been found to contribute to the air quality of Mangalore city and their dispersion during different seasons pose that the particle concentration is always higher during post monsoon and winter seasons compared to other seasons.
- The scenarios proposed showed remarkable decrease of about 23% PM concentration in ambient atmosphere of Mangalore.

Hence the study on PM for urban Mangalore reveals that the emissions from vehicle exhaust plays a vital role in deteriorating the ambient air and it has to be addressed quickly as it is the need of the hour for the rapidly growing coastal industrial city Mangalore. The measures targeted at reducing tyre, brake and road wear emissions are generally unexplored and offer much scope for future research. The possible strategies to reduce non-exhaust emissions can be categorized as those aimed at minimizing the sources by (i) improving wear properties of materials and (ii) reducing the wear potential of traffic (e.g. studded tyres) and those aimed at minimizing suspension to air by (i) removing / immobilizing dust from road surface (road cleaning), (ii) binding dust to road surface and (iii) adjusting traffic (less traffic, lower speed, less heavy vehicles). Although more research is needed, recent studies suggest that beside the wear resistance of rock materials used for road pavement, other factors can reduce road wear emission potential: larger gravel size, lower texture depth, road pavement construction type (e.g. rubber mixed asphalt, porous asphalt) and good operation and maintenance. The lack of research focusing on preventive measures that has directed interest towards mitigating measures, aimed at minimizing suspension to air. Road cleaning activities were found to reduce road dust re-suspension only when water was used, due to the increase of road moisture content (rather than actual removal of dust).

The overhauling of vehicles, restricting older vehicles and controlling traffic are some valuable suggestions to be followed for improving the quality of ambient air in urban Mangalore.

SCOPE FOR FUTURE WORK

- The present work can be extended by carrying out source apportionment studies on Volatile Organic Compounds (VOCs) and Secondary Organic Aerosols as Mangalore comprises of one of the largest refineries in the country.

- Source apportionment studies can be done using various other available multivariate methods such as Positive Matrix Factorization (PMF)

- Dispersion studies can be carried out using CALINE model for SOx, NOx and VOCs to study the dispersion of these particles into the urban Mangalore.

- Environmental chamber studies can be carried out to study the behaviour of SOA in accordance with the meteorological conditions of urban Mangalore.

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LIST OF PUBLICATIONS:

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3. Kalaiarasan. G., Balakrishnan, R. M., Adarsh M., Krupadam R J., Characterization and Source identification of Polycyclic Aromatic Hydrocarbons (PAHs) for coastal industrial city Mangalore, India. MATTER: *International Journal of Science and Technology, 3(1), 01-15,*[*https://dx.doi.org/10.20319/Mijst.2017.31.0115*](https://dx.doi.org/10.20319/Mijst.2017.31.0115).

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