1.1 Introduction

The year 2015 witnessed worldwide alarming concern over impacts and consequences of air pollution. Whole world united in a global submit held in Paris to discuss measures to control by framing effective policies to be adopted by the nations to tackle complex global issue that is air pollution. The interaction of pollutants with atmosphere results in increase of temperature leading to global warming. The 2015 Paris Climate Conference was held after 20 years of UN negotiations, aiming to arrive at a legally binding and universal agreement on climate, with the aim of keeping global warming below 2°C [1]. Government of India has been struggling hard to overcome air pollution crisis by trying to control vehicular emissions was it is one of the major contributors of air pollution [2].

According to the World Health Organization (WHO), millions of untimely deaths are occurring due to the urban air pollution created from burning of solid fuels [3]. As per WHO’s 2014 report, around seven million people were died in 2012. Of these, one in eight was due to air pollution [4]. Certain guidelines have been framed to monitor and control air quality so that health problems due to air pollution can be reduced. According to the estimations of Central Pollution Control Board (2010) of India, air around many of the Indian cities contains particulate matter (PM) far exceeds the safe limit set by the World Health Organization standards [5]. In house air pollution caused by cooking fires and outdoor air pollution due to vehicular fuel burning and industrial smoke are known to inflict more deaths in India [6]. According to the
World Bank, annually India is paying heavy price due to its environmental degradation. Estimations hint that if India achieves a reduction in PM content of 30% by 2030, it would be a lot of amount on health spending [7]. It is quoted that there are about 23 major Indian cities having more than a million population, measures air pollution which exceed WHO standards (Gupta et.al 2002) [8]. Nanoparticles (dust particles of size few nanometers) have also been claimed to affect adversely the cardiopulmonary system [9].

The material (pollutants) and energy exchange between the earth and the atmosphere is one of the most principal physical processes, which defines climatic state and patterns of atmospheric circulations [10]. All the major cities in India are undergoing urbanization at a very rapid pace. With the growing economy a lot of emphasis is given to infrastructure development. The environmental problems in these cities have escalated due to industrialization and increase in the number of vehicles. Also large number of people are migrating to cities on a daily basis which makes cities unsustainable with large population [11]. India has been growing at an average GDP growth rate between 7 and 8 per cent for the last eight years (Ministry of Finance, 2013) [11]. The urban population increased from 286.1 million in 2001 to 377.1 million in 2011, at an average annual growth rate of 2.76 per cent. Rapid urbanization has resulted in environmental degradation caused by increased pressures on the limited land available, leading to reduced open spaces, increased air and water pollution, and problems of waste disposal and its management. Various climate related changes pose additional stresses [12].

Clean air is one of the basic requirements for good human health and well-being of the humanity. Air pollution continues to be a well-known environmental problem
worldwide. It can pose a serious threat to human health if it exceeds the permissible limit (WHO, 2000; USEPA. 2008) [6]. The quality of the air is the result of complex interaction of many factors that involve the chemistry and the meteorology of the atmosphere, as well as the emissions of variety of pollutants both from natural and anthropogenic sources. Every year large quantities of toxic wastes are discharged into the environment from the ever increasing production of goods and from the burning of fossil fuels to generate the energy needed to sustain industrial and domestic activities. Sulphur dioxide, nitrogen dioxide and suspended particulate matter (SPM) are regarded as major air pollutants in India [13]. According to a study released by World Economic Forum in Davos, India has the worst air pollution in the entire world, beating China, Pakistan, Nepal and Bangladesh. Of the total 132 countries whose environmental assets were surveyed, India ranked dead last in the air ranking. The WHO estimates that about two million people die prematurely every year as a result of air pollution, while many more suffer from breathing ailments, heart disease, lung infections and even cancer [4]. Air Pollution is a complex problem as it contains so many known and unknown parameters. The pollutants are added to the environment through various known and unknown natural processes as well as anthropogenic sources viz. industrial process, auto exhaust and domestic sources. In India, pollution has become a great topic of debate at all levels and especially the air pollution because of the enhanced anthropogenic activities such as burning fossil fuels, i.e. natural gas, coal and oil-to power industrial processes and motor vehicles [14].

Not all air pollutants are gases. Particulate matter (PM) is a collective term used for very small solid and/or liquid particles found in the atmosphere. While individual particles cannot be seen with the naked eye, collectively they can appear as black
soot, dust clouds or grey hazes. Particulate matter may be generated by natural processes (e.g., pollen, bacteria, viruses, fungi, mold, yeast, salt spray, soil from erosion) or through human activities, including diesel trucks, power plants, wood stoves and industrial processes. Individual particles vary considerably in size, geometry, chemical composition and physical properties. The effect of particulates on human health and the environment varies with the physical and chemical makeup of the particulates. Particles are either emitted directly into the atmosphere or produced in the atmosphere from the physical and chemical transformation of other vaporeous or gaseous pollutants [15].

**History of Air pollution**

The origin of air pollution on the earth can be traced back to the time when man started using wood fire as a means of cooking and space heating. With increasing use of coal, the air pollution problems started to become more pronounced, and it was recognized 700 years ago in London the menace of smoke pollution that promoted King Edward - I in 1273 to make the first antipollution law to restrict people using coal for domestic heating. In the year 1300, a further act was passed banning the use of coal during the seasons of parliament.

The menace of smoke pollution continued through centuries but became severe from late eighteen century with the start of industrial revolution in the west leading to the large scale burning of coal. The air pollution problems started to further aggravate with the rise of chemical industry during the mid-eighteen century which lead to the dumping of acid fumes and other chemicals in the atmosphere. As the development and industrialization continued to take place all over the world, the rise in the atmosphere pollution also continued finally culminating in the large scale deaths and
morbidity due to air pollution disasters in 1930 in Meuse Valley, Belgium, 1948 in Donora, Pennsylvania and 1952 in London.

One more air pollution problem emerged in the beginning of twentieth century with the development of transportation system and large scale use of petrol and diesel. The problems of air pollution due to automobile exhaust are still quite serious in many cities of the developed as well as developing countries like India. In India, Air Pollution Control Act was passed in 1981 [16].

**Composition of Air**

Atmospheric air comprises certain elements in a specific ratio. According to National Aeronautics and Space Administration (NASA), 99.998% of the earth's atmosphere comprises four major gases, namely, nitrogen, oxygen, argon and carbon dioxide. Other gases are present in a very little amount and hence they are collectively known as trace gases.

The composition of air in the atmosphere remains nearly unchanged till an altitude of 10 km. The major role played by each of these components is different. For example, nitrogen is the most important plant nutrient, while oxygen is responsible for respiration and combustion. Nitrogen is also important for diluting the oxygen concentration and stabilizing the atmosphere [17]. Different elements present in the atmospheric air are listed in Table 1.1.
Table 1.1: Composition of Clean Dry Air [16].

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Component</th>
<th>Element Symbol</th>
<th>Molecular Weight</th>
<th>Percent by Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nitrogen</td>
<td>N₂</td>
<td>28.01</td>
<td>78.084%</td>
</tr>
<tr>
<td>2</td>
<td>Oxygen</td>
<td>O₂</td>
<td>32.00</td>
<td>20.947%</td>
</tr>
<tr>
<td>3</td>
<td>Argon</td>
<td>Ar</td>
<td>39.95</td>
<td>0.934%</td>
</tr>
<tr>
<td>4</td>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>44.01</td>
<td>0.033%</td>
</tr>
<tr>
<td>5</td>
<td>Neon</td>
<td>Ne</td>
<td>20.18</td>
<td>0.001818%</td>
</tr>
<tr>
<td>6</td>
<td>Helium</td>
<td>He</td>
<td>4.00</td>
<td>0.000524%</td>
</tr>
<tr>
<td>7</td>
<td>Krypton</td>
<td>Kr</td>
<td>83.80</td>
<td>0.000114%</td>
</tr>
<tr>
<td>8</td>
<td>Methane</td>
<td>CH₄</td>
<td>16.04246</td>
<td>0.0002%</td>
</tr>
<tr>
<td>9</td>
<td>Hydrogen</td>
<td>H₂</td>
<td>2.02</td>
<td>0.00005%</td>
</tr>
<tr>
<td>10</td>
<td>Nitrous Oxide</td>
<td>N₂O</td>
<td>44.01288</td>
<td>0.00003%</td>
</tr>
<tr>
<td>11</td>
<td>Xenon</td>
<td>Xe</td>
<td>131.30</td>
<td>0.0000087%</td>
</tr>
<tr>
<td>12</td>
<td>Ozone</td>
<td>O₃</td>
<td>47.9982</td>
<td>0.000007%</td>
</tr>
<tr>
<td>13</td>
<td>Nitrogen dioxide</td>
<td>NO₂</td>
<td>46.005</td>
<td>0.000002%</td>
</tr>
<tr>
<td>14</td>
<td>Iodine</td>
<td>I₂</td>
<td>253.8</td>
<td>0.000001%</td>
</tr>
<tr>
<td>15</td>
<td>Carbon monoxide</td>
<td>CO</td>
<td>28.0101</td>
<td>Trace</td>
</tr>
<tr>
<td>16</td>
<td>Ammonia</td>
<td>NH₃</td>
<td>17.03</td>
<td>Trace</td>
</tr>
</tbody>
</table>

**Importance of air pollution**

Air pollution is an important global issue because much of the pollutants travel long distances into areas far from the emission sources and also affects human health and damages ecosystems [18]. Air pollution not only affects human health but also reduces quality of land and water. One cannot escape from it. Air quality data is used for monitoring and managing the environment. Air pollution can cause death, impair
health, reduce visibility, bring about vast economic losses and contribute to the
general deterioration of both cities and country-side. It can also cause intangible
losses to historical monuments such as the Taj Mahal in India which is believed to be
badly affected by air pollution [19]. The survival of any living organism is totally
based on breathing of pure natural air and if it is polluted because of one or the other
reason, various undesirable and serious effects may occur [20].

Developmental activities for examples, industrial transportation and constructional
work cause degradation and brings drastic changes in all component of environment
namely, hydrosphere, lithosphere, atmosphere and biosphere through pollution [21].
Air pollution has emerged in the past few decades as a most challenging problem
although air pollution existed even in the prehistoric time but never in the history it
reached as menacing proportions as now. The urban population is chocked with
combined onslaught of smoke spewing industries and automobile [22].

**Industrial air pollution**

Industries are considered to be a major culprit in polluting air. This is partly because
of the utilization of enormous amounts of energy and partly due to handling of diverse
kinds of materials which themselves as their intermediates or as by-products become
air pollutants. The emission of pollutants in an industry depends on the nature of a
specific piece of equipment, materials being processed and operating procedures and
conditions. The pollutants from industry are mainly:

a) Smoke emerging from industries like power and chemical plants, other
manufacturing facilities, motor vehicles, etc.

b) Burning of wood, coal in furnaces and incinerators.

c) Gaseous pollutants from oil refining industries.
d) Dust thrown in to general atmosphere by industries such as cement plants, ore / stone crushing units, mining industries due to rock drilling & movements of mining machineries & blasting etc. [22]

Karnataka state is home to many industries, specifically in the sectors of iron and steel, cement, silk textiles, machine tools and pharmaceuticals.

Among various industrial sectors, a substantial portion of effluents containing heavy metals are generated from electroplating (nickel, zinc, copper), chemical industries. The organic pollutants are mainly generated from distilleries, sugar, pulp and paper, food processing, and pharmaceuticals industries. The main pollutants from these industries are particulate matter, oxides of sulphur and nitrogen which are emitted due to burning of fuels. Though these pollutants are also generated from vehicular sources, specific pollutants such as hydrogen sulphide, volatile organic compounds, hydrocarbons, lead, etc., are emitted from the industries like pulp and paper, refineries and lead acid battery units and shown in Table 1.2.
Table 1.2: Major air pollutants emitted by different industries [22].

<table>
<thead>
<tr>
<th>S.No</th>
<th>Industry</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminium industries</td>
<td>Particulates, fluorides, gaseous chlorides</td>
</tr>
<tr>
<td>2</td>
<td>Ammonia manufacturing</td>
<td>CO, HC, NH₃</td>
</tr>
<tr>
<td>3</td>
<td>Cement manufacturing</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>4</td>
<td>Copper smelting</td>
<td>Dust, SOₓ</td>
</tr>
<tr>
<td>5</td>
<td>Explosives making</td>
<td>SOₓ, NOₓ</td>
</tr>
<tr>
<td>6</td>
<td>Fibre glass making</td>
<td>Particulates from glass melting operations</td>
</tr>
<tr>
<td>7</td>
<td>Ferro alloys</td>
<td>CO, dust</td>
</tr>
<tr>
<td>8</td>
<td>Glass industries</td>
<td>Particulates, fluorides</td>
</tr>
<tr>
<td>9</td>
<td>Iron and Steel industry</td>
<td>Particulates, MgO, NOₓ, SO₂, Chlorine gas</td>
</tr>
<tr>
<td>10</td>
<td>Lead smelting</td>
<td>Particulates, CO, Lead oxides</td>
</tr>
<tr>
<td>11</td>
<td>Lime kilns</td>
<td>Particulates</td>
</tr>
<tr>
<td>12</td>
<td>Nitric fertilizers</td>
<td>NH₃, NO₃</td>
</tr>
<tr>
<td>13</td>
<td>Petroleum refining</td>
<td>SOₓ, NOₓ, HC, CO, Particulates and NH₃</td>
</tr>
<tr>
<td>14</td>
<td>Paint and Varnish making</td>
<td>Particulates, lost solvents as hydrocarbons</td>
</tr>
<tr>
<td>15</td>
<td>Sugar factories</td>
<td>Particulates, CO, HC, NOₓ</td>
</tr>
<tr>
<td>16</td>
<td>Sulphuric acid making</td>
<td>Acid mist</td>
</tr>
<tr>
<td>17</td>
<td>Stone quarrying</td>
<td>Dust</td>
</tr>
<tr>
<td>18</td>
<td>Synthetic fibre industry</td>
<td>Carbon disulphide, HC</td>
</tr>
<tr>
<td>19</td>
<td>Wood pulping industry</td>
<td>Odours, SO₂, CO</td>
</tr>
<tr>
<td>20</td>
<td>Zinc smelters</td>
<td>Dust, SO₂</td>
</tr>
</tbody>
</table>
**Vehicular air pollution**

All the Indian cities are also experiencing rapid urbanization and majority of the country’s population is expected to move to cities within next two decades. It has resulted in a tremendous increase in the number of motor vehicles. This increased mobility, however come with a high price [11]. The growth rate of vehicles is the backbone of economic development. In 2011, India reported 141.8 million registered motor vehicles which is shown in Table 1.3. The motorization rate in India is 26 vehicles per 1000 population, and this is lower than many of the developing countries (Brazil-222/1000 population in 2012, South Africa 153/1000 population). Over the last three decades number of motor vehicles has been doubling in India. In USA, UK and Japan annual growth rate of vehicle is within 2 to 5%.

In India, transport sector emits an estimated 261 tones of CO₂, of which 94.5% is contributed by road transport. Out of total 3,000 metric tons of pollutants bleached out every day, about 66% of it is from vehicles in Delhi. Similarly, the contribution of vehicles to urban air pollution is 52% in Bombay and nearly 33% in Calcutta. The transport sector in India consumes about 17% of total energy and is responsible for 60% production of the GHG from various activities. The pollution from vehicles is due to discharge like CO, unburnt HC, Pb, NO₂ and SO₂ and SPM [23].
Table 1.3 Registered motor vehicles in India [23].

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Vehicles in (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>72.7</td>
</tr>
<tr>
<td>2005</td>
<td>81.5</td>
</tr>
<tr>
<td>2006</td>
<td>89.6</td>
</tr>
<tr>
<td>2007</td>
<td>96.7</td>
</tr>
<tr>
<td>2008</td>
<td>105.3</td>
</tr>
<tr>
<td>2009</td>
<td>115.0</td>
</tr>
<tr>
<td>2010</td>
<td>127.7</td>
</tr>
<tr>
<td>2011</td>
<td>141.8</td>
</tr>
</tbody>
</table>

Source: road transport year book 2012

It is interesting to note that among various modes of road based passenger transport, buses occupy less road space and causes less pollution per passenger per kilometer than personalized modes of transport and tabulated in Table 1.4.
Table 1.4 Pollution rate and congestion effect of private and public transport vehicles[23].

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Average Passenger per vehicle</th>
<th>Pollution load in gm/pass.-km</th>
<th>Congestion effect in PCU/Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-stroke two-wheeler petrol engine</td>
<td>2</td>
<td>7.13</td>
<td>0.375</td>
</tr>
<tr>
<td>Four-stroke two-wheeler petrol engine</td>
<td>2</td>
<td>4.76</td>
<td>0.375</td>
</tr>
<tr>
<td>Car with catalytic converter petrol engine</td>
<td>4</td>
<td>0.93</td>
<td>0.25</td>
</tr>
<tr>
<td>Bus with diesel engine</td>
<td>40</td>
<td>10</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Note: PCU = Passenger Car Unit where 1 car = 1 PCU, 1 bus = 2.5 PCU, 1 scooter = 0.75 PCU, etc. This clearly points to a tremendous increase in the share of personal transport vehicles and shows a rapid increase in the load on air pollution.

**Road growth**

The growth of vehicular traffic on roads has been far greater than the growth in road network; as a result the main arteries face capacity saturation. Between 1951 and 2004, motor vehicle population grew at a compound annual growth rate (CAGR) of close to 11% compared to about 3.6% in the total road length with National Highway segment increasing by a mere 2.3%. There has been a step-up in the growth of the National Highway network in recent years which has grown at CAGR of about 4.5% with total vehicle population growing at 10% CAGR during 1991-2006. The average model shares of road in the country as per data collected by the MoRTH (Ministry of Road Transport & Highways) at sample stations on national highways in across India
during 2006 was 33% for cars and three wheeled vehicles, 29% for motorized two-wheelers, 29% for trucks, 7% for buses, and 2% for tractors [6]. The slow growth of road infrastructure and high growth of vehicles imply that Indian roads are reaching a saturation point in utilising the existing capacities, hence leading to congestion and further contributing to air pollution load [24].

Since the birth of automotives in the 19th century, diesel and gasoline are used as primary sources of energy for vehicles. As per CIA’s World Fact, 2008 [24] India stands 6th amongst top ten oil consuming countries of the world. Further, as per PCRA (Pollution Conservation Research Association), the transport sector alone consumes more than 50% of the total oil consumption in the country. Delhi and Mumbai have more than 100,000 commercial vehicles running on CNG. Delhi has the largest number of CNG commercial vehicles in the World. All buses in Delhi along with a majority of on-road taxis and three wheelers switched over to CNG. CNG powered vehicles emit 85% less NOx, 70% less reacts HCs and 74% less CO than similar gasoline powered vehicles. CNG has also been introduced as an automotive fuel in cities like Mumbai, Ahmedabad, Surat and Vadodra [8].

**Global air pollution**

Global air pollution is advancing day by day due to tropospheric and stratospheric ozone depletion, absorption of solar and terrestrial radiation, green-house gas warming, aerosol scattering, rain and precipitation quality, long range transport of air pollutant, heat islands effects and urban air quality. Millions of tons of variety of toxic air pollutants are released into atmosphere by various sources that gets transported to
several thousands of kilometers away through atmospheric circulation systems causing irreparable damage to the quality of air on continental and global scales [25].

**Green house effect**

Light radiation of short wavelength will lose energy on striking the earth and will be converted to heat energy of longer wavelengths. The wavelength of this terrestrial reradiation, from earth to atmosphere is in the range 4 µm -100 µm calculated using energy equation, \( E = \frac{hc}{\lambda} \), with \( \lambda \) being the wavelength increases. The prominent gas CO\(_2\) has radiation absorption bands in the range 12-18µm wavelengths. Thus CO\(_2\) present in the atmosphere allows the incoming radiation to pass through but attenuates radiation from earth to space. Similarly, gases like methane, N\(_2\)O, O\(_3\), CFCs and water vapour cause similar effects and are called as green house gases. These gas molecules absorb energy. Their temperature increases and they start radiating heat. Only a part of it escapes out into the space while remaining is radiated back to earth leading to further increase in temperature [25, 26].

### 1.2. Air pollutants

Air pollutants are added in the atmosphere from variety of sources that change the composition of air and affect the biotic environment. The concentration of air pollutants depend not only on the quantities that are emitted from air pollution sources but also on the ability of the atmosphere to either absorb or disperse these emission [27].
The air pollutants can be classified as primary or secondary pollutants. The primary air pollutants are harmful chemicals which directly enter the air due to natural events of human activities. A secondary air pollutant is a harmful chemical produced in the air due to chemical reaction between two or more components. That is primary pollutant combines with some component of the atmosphere to produce a secondary pollutant [28].

The most frequently monitored air pollutants are $SO_2$ and $NO_2$ because of their being main precursors of acid deposition, having effects on the human respiratory system and roles in the photochemical reactions. They are commonly present especially in the urban areas and emitted from various sources including vehicles, fossil fuel combustion activities, industries, etc. Also, they are subject to mixing, transport and transformation processes in the urban atmosphere [18]. The air pollutants are,

1. Sulphur dioxide ($SO_2$)
2. Nitrogen dioxide ($NO_2$)
3. Particulate matter 10 ($PM_{10}$)
4. Particulate matter 2.5 ($PM_{2.5}$)
5. Ozone ($O_3$)
6. Ammonia ($NH_3$)

**Sulphur dioxide ($SO_2$)**

Sulphur dioxide is a colourless gas with a pungent and suffocating odour. It is one of the major air pollutants discharged by various pollutant sources. Further, it reacts photochemically or catalytically with other pollutants or normal atmospheric
constituents to form sulphur trioxide, sulphuric acid and salts of sulphuric acid. Sulphur dioxide remains in the air for an average of two to four days; during this time it may be transported a distance of 1000 km before it is deposited on the ground [17].

Sources of SO\textsubscript{2}

Sulphur dioxide is formed when fuel containing sulfur is burned. Sulfur is prevalent in raw materials such as crude oil, coal and ore that contain common metals like aluminum, copper, zinc, lead etc. Erupting volcanoes can be a significant natural source of sulfur dioxide emissions. Sulfur dioxide is emitted in significant quantities from thermal power plants, smelting process of sulfide ores to produce copper, lead and zinc and also from petroleum refining processes. The diesel driven vehicles are specific source of sulfur dioxide generated during combustion process [27].

Nitrogen dioxide (NO\textsubscript{2})

Nitrogen dioxide is a reddish brown gas with pungent odour. The gas is corrosive, irritating and physiologically toxic. It reacts with water to form nitric acid, which may be a significant component of acid rain. Nitrogen Dioxide (NO\textsubscript{2}) is mainly formed from oxidization of nitrogen monoxide (NO) emitted in the process of combustion. Nitrogen Oxides or NOx (NO, NO\textsubscript{2} and NO\textsubscript{3}) are a group of highly reactive gases containing nitrogen and oxygen. NO\textsubscript{2} is also a main component of ground-level ozone and contributes to global warming [22].

Sources of NO\textsubscript{2}

The emission sources are varied but tend to result from high temperature combustion of fuel for industrial activities, commercial and residential heating and vehicle use. Industrial processes especially nitric acid production and explosive industry. Forest
fires can be a large natural source of nitrogen dioxide (NO₂). The main ambient sources of nitrogen dioxide (NO₂) include intrusion of stratospheric nitrogen oxides (NOₓ), bacterial and volcanic action and lightning [29].

**Ammonia (NH₃)**

Ammonia is a colourless gas, pungent, suffocating and highly soluble gas in water. With regard to the total production of ammonia very high percentage of 99.9% is released from the natural sources during degradation of organic matter. Life time of ammonia in the atmosphere is 6 days. It gets converted to ammonia salts [22].

**Sources of NH₃**

Ammonia is found in small quantities in the atmosphere and produced from the purification of nitrogenous animal and vegetable matter. Anthropogenic sources of ammonia include mainly the combustion of fuels in stationary and mobile sources, and incineration of wastes. It is also emitted from fertilizer plants, coke ovens and refineries. Ammonia and ammonium salts are also found in small quantities in rainwater [22].

**Particulate Matter 10 (PM₁₀)**

Total suspended particulate (TSP) refers to all particles in the atmosphere. TSP was the first indicator used to represent suspended particles in the ambient air. In July 1987, United States Environmental Protection Agency (USEPA) began using a new indicator, PM₁₀, which included only those particles with aerodynamic diameter smaller than 10µm. Ten microns is approximately one seventh the diameter of a human hair. This fraction of TSP is responsible for most of the adverse human health
effects of particulate matter because of the particles' ability to reach the lower regions of the respiratory tract. PM$_{10}$ has an aerodynamic diameter between 2.5µm and 10µm. They are formed by mechanical disruption (e.g. crushing, grinding, abrasion of surfaces), evaporation of sprays and suspension of dust. PM$_{10}$ is composed of alumino silicate and other oxides of crustal elements. PM$_{10}$ is largely insoluble and non-hygroscopic. The lifetime of PM$_{10}$ is from minutes to hours and it travels from <1 km to 10 km.

Sources of PM$_{10}$

Resuspension of industrial dust, soil tracked onto roads, suspension from disturbed soil and biological sources such as pollen, spores and bacteria and debris from forest fires, coal and oil combustion, ocean spray and volcanic dust [30].

**Particulate Matter 2.5 (PM$_{2.5}$)**

Recent data suggests that particles of size 2.5µm or smaller may pose the greater threat to human health because as they penetrate more easily deep into the lungs. USEPA is considering adopting a new standard for PM2.5 to better address the potential health problems associated with these tiny particles.

P$_{2.5}$ has an aerodynamic diameter less than 2.5µm (PM$_{2.5}$). They differ from PM$_{10}$ in origin and chemistry. These particles are formed from gas and condensation of high-temperature vapors during combustion, and they are composed of various combinations of sulfate compounds, nitrate compounds, carbon compounds, organic compounds and metals. PM$_{2.5}$ is largely soluble, hygroscopic and deliquescent. The lifetime of PM$_{2.5}$ is from days to weeks and travel distance ranging from 100m to >1000 km [30].
Sources of PM$_{2.5}$

The sources of PM$_{2.5}$ are from combustion of coal, oil, gasoline, diesel and wood. Industrial processes especially cement, iron, sugar and steel industry. The other sources are atmospheric transformation products of NO$_x$, SO$_2$ and organic compounds including biogenic species [30].

**Ozone (O$_3$)**

Ozone is a highly reactive form of oxygen, consisting of three oxygen atoms (O$_3$). It is a potent oxidant and quickly decomposes to diatomic oxygen (O$_2$), while reacting with targeted organic matter or microorganisms. Ozone is naturally generated in the stratosphere, the upper atmospheric layer that protects us from harmful radiation. Ozone is a secondary pollutant formed in the atmosphere by reaction between oxides of nitrogen and volatile organic compounds (VOCs) in the presence of sunlight [27].

Sources of O$_3$

Vehicles, industrial emissions, gasoline vapours, and chemical solvents emit oxides of nitrogen and VOCs that form ozone. Peak O$_3$ levels occur typically during the warmer times of the year sunlight [27].

**1.3 Effects of Air Pollution**

Air pollution is a serious worldwide health problem. The health impacts of air pollution have been studied extensively since the London fog in the mid 20$^{th}$ century and the subsequent series of dramatic episodes in industrialized countries [21].
Air pollution has adverse impact on human health as well as the health of other living entities and vegetation. Depending upon the lifetime of the pollutants, location of the source and prevailing air currents, receptors may be located at local, regional or global levels at time intervals from near instantaneous, to several decades. Good air quality is essential for the health of people and the environment; although significant improvements have been made in many countries over the last 2–3 decades, air quality, particularly in urban areas, remains a priority issue on most of the national environmental agendas. [31]

Exposure to ambient air pollution has been linked to a number of different health outcomes, starting from modest transient changes in the respiratory tract and impaired pulmonary function, continuing to restricted activity/reduced performance, emergency room visits and hospital admissions and to mortality. There is also increasing evidence for adverse effects of air pollution not only on the respiratory system, but also on the cardiovascular system [32]. Human beings breathe in and out approximately once every four seconds, which equates to over eight million times a year. As a consequence our lungs process around four million litres (4,000 m$^3$) of air from the earth’s atmosphere, every year. Urban air pollution is therefore one of the most important environmental issues that may be considered due to its direct effect on human health [33].

**Effects on Human Health**

The prime factors affecting human health due to air pollution depends on

- Nature of pollutants.
- Concentration of pollutants.
The major air pollutants discussed here are Sulphur dioxide, Nitrogen dioxide, Particulate Matter 10, Particulate Matter 2.5, Ozone and Ammonia. The harmful effects of these pollutants are discussed below in detail

**Effect due to Sulphur dioxide (SO$_2$)**

Health effects of SO$_2$ gas are irritation to the eyes and respiratory system, reduced pulmonary functions and aggravation to respiratory diseases such as asthma, chronic bronchitis and emphysema. Exposure to extremely high concentrations will cause permanent damage to the respiratory system. When SO$_2$ reacts with other chemicals it forms tiny sulphate particles. When they are inhaled, they get collected in lungs. These leads to respiratory symptoms and disease, difficulty in breathing and premature death [33].

The concentration of sulphur dioxide above 0.4 ppm causes an acute injury to the plants. The lower doses in the range of 0.1 and 0.4 ppm most often get oxidized inside the plant cell and may lead to chronic injury. At higher concentration of SO$_2$, majority of flower buds become stiff and hard to fall subsequently from the plants because they are unable to flower. Sulphur dioxide alters the chemical composition and quantitatively reduces the chlorophyll pigments in almost all green plants that may occur either by inhibiting the chlorophyll synthesis or by its destruction.
The effect of $\text{SO}_2$ on animals leads to lack of appetite, rapid loss in weight, decline in health, growth retardation, muscular weakness and death. The effect of $\text{SO}_2$ includes corrosion of steel, zinc, roofing slate and statues. Electrochemical deteriorations of iron, aluminum, copper, silver, building materials, leather, paper and textiles [22].

**Effect due to Nitrogen dioxide ($\text{NO}_2$)**

$\text{NO}_2$ has irritating effect on mucous membrane, eye irritation and alveoli. It gets attached to hemoglobin and reduces oxygen transport efficiency of blood. It is known that exposure to high concentrations over short periods of time is more harmful to health than long time exposure of lower concentrations. Presence of $\text{NO}_2$ in smog can irritate the eyes, nose, throat and lungs and can also cause coughing, shortness of breath and fatigue. Exposure to high levels of $\text{NO}_2$ can cause acute or chronic bronchitis and affect normal functioning of lungs [19].

$\text{NO}_2$ can ever suppress the growth of plants when exposed to the level of 0.5 ppm for several days. $\text{NO}_2$ exposure leads to leaf bleaching and suppressed growth of the plants.

The effect of $\text{NO}_2$ on animals are severe salivation, thirst and irregular pulse, rapid weight loss and decline in health leading to death.

The effects of $\text{NO}_2$ exposure on materials include corrosion of metals, white textiles turning yellow and fading of colors [22].

**Effects due to Ammonia ($\text{NH}_3$)**

Exposure to ammonia may occur by breathing or consuming food or water containing ammonia. Exposure to high levels of ammonia in air may be irritating to skin, eyes,
throat, lungs and cause coughing and burns. Lung damage and death may occur after exposure to very high concentrations of ammonia. Ammonia at higher concentrations may produce chlorotic and necrotic lesions on the margins of leaves. Ammonia in association with SO\textsubscript{2} and moisture causes damage to varnish and paints and discolors fabrics [22].

**Effects due to Particulate Matter 10 (PM\textsubscript{10})**

The increases in particulate matter have been shown to cause small and reversible decrements in lung function in normal asymptomatic children, and in those who have some form of pre-existing respiratory condition, particularly asthma. These changes were often accompanied by increase in symptoms such as chronic bronchitis or cough. Respiratory diseases such as bronchitis, asthma, emphysema, various forms of heart diseases.

Effects on plants: Necrosis at leaf tip, suppressed growth and leaf bleaching.

Effects on animals: Muscular weakness, lack of appetite, growth retardation and anemia. Effects on materials: Abrasion and corrosion of most metals, paint and textiles [22].

**Effects due to Particulate Matter 2.5 (PM\textsubscript{2.5})**

The PM\textsubscript{2.5} poses the greatest problems, because they can get deep into lungs, and some may even get into bloodstream. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including increased respiratory symptoms such as irritation of the airways, coughing or difficulty in breathing, decreased lung function, aggravated asthma, development of chronic bronchitis, irregular heartbeat, nonfatal heart attacks and premature death in people with heart or lung disease. [50]
Effects on plants: Bleaching of leaves, necrosis, suppressed growth and leaf abscission [30].

Effects on animals: Lack of appetite, muscular weakness, feeble, irregular pulse and respiration.

Effects on materials: Abrasion and corrosion of metals, alloys, paints and textiles [22].

**Effects due to Ozone (O$_3$)**

Repertory infection, lung inflammation and aggravation of asthma. Other health effects of exposure to ozone are decreases in lung function and increased respiratory symptoms such as chest pains and coughing. Long-term exposures to ozone presents the possibility of permanent changes in lung function, which could lead to premature ageing of the lungs and/or chronic respiratory illnesses [33].

Effects on plants: Ozone causes bleaching of chlorophylls within the injured cells with breakdown of leaf structure around them. Ozone can lead to a fall in ATP levels in several plants. Ozone causes a decline in leaf starch.

Effects on animals: The effects are bronchitis, emphysema, pneumonia, loss of fertility, bronchioles severely damaged in monkeys and pulmonary lesions in rats.

Effects on materials: Fading of dyes, cracking of rubber and damage to buildings [22].

### 1.4 Air Quality Index (AQI)

The air quality index is a tool used by Environmental Protection Agency (2000) and other agencies to provide public with timely and easy-to-understand information on
local air quality. The higher value (above 125) of AQI refers to a great level of air pollution [3].

1.5 Air pollution problems in India

Air pollution in India is mainly caused from vehicles, industries and domestic sources. The air pollution is mainly concentrated in following mentioned areas

**Major Cities:** The problem of air pollution is in major cities where the prominent source of air pollution is vehicles and small or medium scale industries. These cities include Delhi, Kolkata, Mumbai, Chennai, Ahmedabad, Bangalore, Hyderabad, Pune, Kanpur etc.

**Rural Areas:** The indoor air pollution exists in rural areas where the main source of air pollution is domestically used fuels. In rural areas cow dung, wood sticks are used as fuel in household. The kitchens are without any proper ventilation resulting in buildup of air pollutants in the houses.

**Reasons for high air pollution in India.**

1. Fuel of poor quality such as coal, diesel, petrol are used in India. During the past few years, various measures have been taken to improve the quality of fuel such as reduction of sulphur in diesel, unleaded petrol etc.

2. Old process technology is employed in many industries especially in small scale industries resulting in high emission of air pollutants.

3. Wrong placement of industries especially close to the residential areas results in people getting affected due to air pollution.
4. No pollution preventive steps were taken in the early stage of industrialization which has resulted in high levels of air pollutants in many areas.

5. Poor vehicle design especially 2-stroke two wheelers results in high emission of air pollutants.

6. Uncontrolled growth of vehicle population in all major cities has resulted in high levels of air pollution.

7. No pollution prevention and control system in small or medium scale industry exists resulting in high levels of air pollution.

8. Poor compliance of standard in small or medium scale industries also result in high levels of air pollution [34].

1.6 Guidelines for Monitoring Air Quality

For setting up of any ambient air quality monitoring station, the most important thing to be considered prior to the commencement of actual monitoring is to collect its background information [34].

The background information that needs to be collected includes details of sources and emissions, health status, demography, population growth and land use pattern. Such prior information will provide immense help to identify the likely effects and in particular health impacts resulting from population exposure to air pollutants.

Sources in a city include vehicles, industries etc. In an industrial area, information should be obtained on the type of industries including their number, fuel used,
composition of fuel, pollutants emitted etc. Information on number and distribution of sources should be collected. This information will help in identifying which pollutants can be expected in an area and thus should be measured. In case of industrial stacks, locations of maximum ground level concentrations should be determined by modeling. The stations should be located at locations where maximum ground level concentrations are expected. Information on type and number of vehicles should be obtained. Information on domestic fuel is used in household should be obtained. Pollution load emanating from these sources should be estimated so as to identify sources that are generating significant amount of pollution.

Health and Demographic Information

Investigations shall be carried out based on public complaints received from an area related to air pollution. If the results of such investigations reveal that the level is high that area can be considered for ambient air quality monitoring. Areas where population density is high (more than one million) can be considered for locating monitoring stations. Information on age and socio-economic status of population is also important for making a decision on initiation of ambient air quality monitoring. Location of monitoring station in such areas will help in finding exposure levels to population which can be used further in epidemiological studies to evaluate health effects of air pollutants.

Meteorological Information

Meteorological data with respect to temperature, relative humidity, wind speed and direction should be collected. Predominant wind direction plays an important role in determining location of monitoring stations. Due to effects such as land and sea
breezes, valley effects etc. it is important to collect local meteorological data specific to the site. The monitoring stations should be located in areas that are downwind from the sources. Mixing height data can be collected from Indian Meteorological Department. Information on duration of various seasons in a year is also important. Monitoring should be done in all the seasons so that all seasonal variations are included in computing annual average.

**Topographical Information**

Local winds and stability conditions are affected by topography. In river valleys there is increased tendency of developing inversions. More number of monitoring stations should be located in areas where spatial variations in concentrations are large. Mountains, hills, water bodies also affect dispersion of pollutants.

**Previous Air Quality Information**

Any previous information collected on ambient air quality can serve as a basis for selecting areas where monitoring should be conducted and previous studies may include data collected for any health studies etc. Previous studies can be used to estimate the magnitude of the problem. Once the background information is collected, the ambient air quality monitoring is to be initiated and selection of type of pollutant to be measured, number and distribution of monitoring stations etc should be made.
1.7 Air Quality Standards

Air Prevention and Control of Pollution Act 1981

Government of India enacted the Air Prevention and Control of Pollution Act 1981 to control air quality. The act provides functions for the Central Pollution Control Board (CPCB) at the control level and State Pollution Control Board (SPCB) at the state level. The main functions of the Central Pollution Control Board are as follows [34].

- To advise GOI on any matter concerning improvement of the quality of the air.
- To plan a nation-wide programme for the prevention, control and abatement of air pollution.
- To provide technical assistance to the State Pollution Control Boards.
- To carry out research related to prevention, control and abatement of air pollution.
- To compile and publish technical data concerning to air pollution.

The main functions of the State Pollution Control Board are,

- To plan a programme for prevention, control and abatement of air pollution.
- To advise the State Government on matters concerning prevention, control and abatement of air pollution.
- To provide information related to air pollution.
- To collaborate with CPCB in programmes related to prevention, control and abatement of air pollution.
- To inspect air pollution control areas and take steps for prevention, control and abatement of air pollution [34].
National Ambient Air Quality Standards (NAAQS)

The National Ambient Air Quality Standards (NAAQS) were notified by the CPCB in 1994 under the Air Act, 1981 for seven parameters i.e., Suspended Particulate Matter (SPM), Respirable Particulate Matter (RPM), Sulphur Dioxide (SO$_2$), Oxides of Nitrogen (NO$_x$), Carbon Monoxide (CO), Ammonia (NH$_3$) and Lead (Pb). The Central Government has thereafter also notified NAAQS for six parameters in the year 1996 under the Environment (Protection) Act, 1986. The review of the previous NAAQS and inclusion of new parameters was undertaken by the CPCB in association with the Indian Institute of Technology, Kanpur [34].

The objectives of air quality standards are:

- To indicate levels of air quality necessary with an adequate margin of safety to protect the public health, vegetation and property.
- To assist in establishing priorities for abatement and control of pollutant level.
- To provide uniform yardstick for assessing air quality at national level.
- To indicate the need and extent of monitoring programme.

Revised National Ambient Air Quality Standards

The Ministry of Environment and Forests (MoEF) notified the revised National Ambient Air Quality Standards on 18th November 2009. The revised ambient air quality standards provide a legal framework for the control of air pollution and the protection of public health. The citizens can approach the courts demanding better air quality. In the revised standards is that distinction between industrial and residential areas have been removed. Under these, industries have to conform to the same standards as residential areas.
As per revised NAAQS, 12 pollutants will be measured compared to six in the previous regulations to compute the level of air pollution. The pollutants added to the list include Ozone, Arsenic, Nickel, Benzene and Benzo(a)Pyrene (BaP) have been included for the first time.

Table 1.5 National Ambient Air Quality Standards 2009 [34].

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Pollutant</th>
<th>Time</th>
<th>Concentration in Ambient Air (µg/m³)</th>
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<td></td>
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<td>Industrial, Residential, Rural and other Area</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>24 hours**</td>
<td>80</td>
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<td></td>
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<td>100</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<td>Annual*</td>
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<tr>
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<td>Arsenic</td>
<td>Annual*</td>
<td>06</td>
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<tr>
<td>12</td>
<td>Nickel</td>
<td>Annual*</td>
<td>20</td>
</tr>
</tbody>
</table>

* Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.

** 24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.
1.8 Literature Survey on Air Pollution

Ramasamy Jayamurugan et al [35] reported influence of meteorological parameters such as atmospheric wind speed, wind direction, relative humidity and temperature on ambient SO$_2$, NOx, RSPM and SPM concentrations at North Chennai, a coastal city in India, during monsoon, post-monsoon, summer, and pre-monsoon seasons for 2010-11. Data was analysed by regressional method. The results of the study indicated that the influence of temperature on gaseous pollutant (SO$_2$ & NOx) is much more effective in summer than other seasons, due to higher temperature range, but in case of particulate, the correlation was found contradictory. The very weak to moderate correlations existing between the temperature and ambient pollutant concentration during all seasons indicate the influence of constant thermal variation in the coastal region. Statistically significant negative correlations were found between humidity and particulates (RSPM and SPM) in all the four seasons, but level of correlation was found moderate only during monsoon in comparison with other three seasons significant correlation was found between humidity and SO$_2$, NOx in all the seasons. It is suggested from this study that the influence of humidity is effective on subsiding particulates in the coastal region.

Madhukar R and Srikantaswamy S [3] have studied ambient air quality at eight selected stations in and around Bidadi industrial area on an 8 hourly basis in different seasons of the year 2012. Air quality was analysed with respect to the concentration of SPM, SO$_2$ and NOx and the parameters were correlated. The results revealed that the value of SO$_2$ and NOx were within permissible limits in all observed stations, whereas the value of SPM was high in all the stations.
Vineeta Shukla et al [36] report ambient air quality of Rohtak city in Haryana state was monitored using High Volume Sampler. The monitoring was done in six sites randomly selected in Rohtak city. The selected parameters to judge the quality of air were Sulphur dioxide (SO$_2$), Nitrogen dioxide (NO$_2$), Ozone (O$_3$) and suspended particulate matters (SPM) which give a fair idea of pollution load carried by the air. Sulphur dioxide was found below the permissible limits of National Ambient Air Quality Standards (NAAQS) at all the sites. Higher concentration of SO$_2$ was observed during winter in comparison to summer and monsoon seasons. Nitrogen dioxide concentration was found to be above the prescribed standards of NAAQS at four sites in winter season. Ozone concentration was found below the prescribed standards (NAAQS), but its concentration was higher in summer season than winter. Suspended particulate matter concentration was observed to be above the safety limits at all the sites in all three seasons.

Avnish Chauhan et al [9] carried out the study on air quality parameter of PM$_{10}$, SPM, SO$_2$ and NO$_x$ at four different locations in the state of Uttarakhand. The study deal with the effect of industrialization, urbanization and automobile emission on ambient air quality in Haridwar and Dehradun City. Air pollutants SO$_2$, NO$_x$, SPM and RSPM were measured with the help of RDS APM 460. The concentration of NO$_x$ was measured with standard method of Modified Jacobs- Hochheiser method (1958) [ ]. SO$_2$ was measured by Modified West and Geake method (1956) [ ], SPM and RSPM using filter paper methods. Meteorological parameters like temperature, relative humidity, wind speed and rainfall were also recorded simultaneously during the sampling period. They concluded that the concentrations of the pollutants are higher in winter than summer or the monsoon seasons. It was noticed that the SPM and PM$_{10}$ levels at all selected sites exceeds the prescribed limits as stipulated by Central
Pollution Control Board (CPCB) New Delhi, India. Apart from this, the SO\textsubscript{2} and NO\textsubscript{x} levels in residential, industrial and commercial areas remain under prescribed limits of CPCB.

Ramesh Singh \textit{et al} [37] carried out the study of assessment of ambient air quality with respect to respirable suspended particulate matter (RSPM or PM\textsubscript{10} \(\leq 10\mu\text{m}\)) and trace metals Fe, Zn, Cu, Cr, Ni, Cd, Mn and Pb concentrations at five locations of Renukoot, an industrial area of Eastern Uttar Pradesh. The data was collected June 2002. The temperature and relative humidity was recorded hourly by auto weather station (model WM 200, Envirotech, New Delhi). During their period, the daily mean of average temperature and percentage of relative humidity ranged between 28.6°C to 34.81°C and 57.8% to 91.7% respectively. Respirable dust samplers (RDS) were used for the monitoring of particulate matter at all the locations at an approximate height of 1.5 m from ground level. Monitoring was carried out for 4 weeks, and the collection was done continuously for 24 hours with RDS for RSPM. The 24 hour mean concentrations of PM\textsubscript{10} ranged between 69.3 to 118.9 \(\mu\text{g/m}^3\), which is well within the permissible limit (150 \(\mu\text{g/m}^3\)) of national ambient air quality standards (NAAQS) but found higher than the prescribed annual daily limit of US EPA (50 \(\mu\text{g/m}^3\)).

Nagappa and Sadashivaiah [38] reported on ambient air quality of Bangalore city at major traffic intersections. Air pollutants like Sulphur dioxide (SO\textsubscript{2}), Oxides of nitrogen (NO\textsubscript{x}), PM\textsubscript{10} (Particles smaller than 10 microns), and PM\textsubscript{2.5} were measured. The air pollution measurement were carried out for two weeks, starting from Feb 22, 2008 to March 1, 2008 twice a week at one location sampling as per the CPCB guideline. The studies clearly revealed high levels of air pollutants like PM\textsubscript{10}, PM\textsubscript{2.5},
at traffic intersections and SO$_2$ and NO$_x$ were below National Ambient Air Quality Standards. Fine dust PM$_{2.5}$ contained 93% to 63% organics and 6.3% to 36% metallic content and, PM$_{10}$ contained 78% to 38.95% organics and 21.1% to 61% of metallic contents. They concluded that the Bangalore city is reeling under high particulate matter concentration and suitable management options are needed to be taken.

S.Tiwari et al [39] have studied pollutants of PM$_{10}$ and PM$_{2.5}$ for two years during January 2005 to December 2006, in the central part of Delhi. They carried out sampling on the Institute’s roof-top, about 1.5 meter above the ground level. The sampling area is primarily a didactical and residential area, and no large pollutant sources exist nearby to influence the sampling site directly. Sampling of PM$_{2.5}$ was done by a Fine Particulate Sampler (APM 550; Envirotech Instruments Pvt. Ltd) and simultaneous collection of fine particles with aerodynamic diameter less than 2.5 microns was collected. The initial flow rate for this sampling was taken as 1 m$^3$/hr which reduces when the filters got chock by fine particles concentration. A 47mm quartz filter was used in each sampling. Total 92 samples of both sizes 57 of PM$_{2.5}$ and 35 of PM$_{10}$ were collected during the two years from January 2005 to December 2006. For seasonal analysis purposes, these samples are divided into four groups, i.e., for winter (December to march), pre-monsoon (April to June), monsoon (July to September) and post-monsoon (October and November). In their study periods, they got annual average mass concentrations of PM$_{2.5}$ and PM$_{10}$ were 72.37μg/m$^3$ and 173.41μg/m$^3$ respectively. PM$_{2.5}$ and PM$_{10}$ concentrations had a seasonal variation in order, winter > post monsoon > pre-monsoon > monsoon and pre-monsoon > post-monsoon > winter > monsoon.
Masitah Alias et al [8] presented measurements of air particulates namely PM$_{10}$ and TSP in TNB Research, Connaught Bridge Repair Shop, JPS Kapar, and Port Dickson Power Stations in Delhi. PM$_{10}$ and TSP were measured using mini volume sampler and dust was measured using personal dust sampler. PM$_{10}$ and TSP measured at four different areas show the values below the Malaysian Air Quality Guideline (set at 25°C and 101.13 kPa) i.e. 150 µg/m$^3$ and 260 µg/m$^3$ for PM$_{10}$ and TSP respectively, except at Kapar Repair Shop where it was higher. Measurements in Connaught Bridge Repair Shop showed PM$_{10}$ values in the range from 24.1 µg/m$^3$ to 108.3 µg/m$^3$ and TSP values in the range from 48.2 µg/m$^3$ to 216.6 µg/m$^3$. PM$_{10}$ in Port Dickson Power Station and TNB Research were in the range from 88.8 µg/m$^3$ to 103.5 µg/m$^3$ and from 41.9 µg/m$^3$ to 69.3 µg/m$^3$ respectively. TSP in Port Dickson Power Station and TNB Research were in the range from 177.6 µg/m$^3$ to 207 µg/m$^3$ and from 56.2 µg/m$^3$ to 112.1 µg/m$^3$ respectively.

D. Giri. et al [40] analysed and interpreted ambient particulate matter concentrations of PM$_{10}$ at six air monitoring stations in Kathmandu valley during 2003 through 2005. Daily average PM$_{10}$ concentrations were determined using samplers installed by Government of Nepal, Ministry of Population and Environment (MOPE) conducted at six sampling sites, within the Kathmandu valley area. A Low Volume Sampler (LVS) for PM$_{10}$ and PM$_{2.5}$ were used for monitoring. The study indicated persistently higher values of PM$_{10}$ at air sampling sites. These annual average PM$_{10}$ concentrations exceeds the standard annual average concentration prescribed by WHO and EU.

Subhankar Nag et al [41] studied relation between inhalable particulate (PM$_{10}$), fine particulate (PM$_{2.5}$) and coarse particles (PM$_{2.5-10}$). They also carried out study on meteorological parameters such as temperature, relative humidity, solar radiation and
wind speed and, data was statistically analyzed and modeled for urban area of Kolkata during winter months of 2003–2004. Ambient air quality was monitored with a sampling frequency of twenty-four hours at three monitoring sites located near traffic intersections and in an industrial area. The monitoring sites were located at 3 to 5 meters above ground near high traffic and congested areas. PM$_{10}$ and PM$_{2.5}$ samples were collected using Thermo-Andersen high volume samplers and exposed filter papers and data analysed for benzene soluble organic fraction. The particle size analysis shows that concentration of PM$_{2.5}$ was about 62% of PM$_{10}$ concentration at all the three sites.

Mukesh Sharma and Shaily Maloo [42] studied the ambient air quality of Kanpur in terms of PM$_{10}$ and PM$_{2.5}$ and chemical composition in terms of heavy metals and benzene-soluble organic fraction (BSOF) for PM$_{10}$ at three locations during October 2002–February 2003. Three sampling locations, Indian Institute of Technology (IIT), Vikas Nagar (commercial site) and Juhi Colony (residential site) were selected. Total forty-seven samples were collected for PM$_{2.5}$ and PM$_{10}$ during October 2002–February 2003 at these locations at duration of 24 hours. Instrument used for sampling PM$_{10}$ was Hi-volume sampler APM 450 and for PM$_{2.5}$ it was Wins-Anderson impactor APM 550. PM$_{10}$ (45–589 µg/m$^3$), PM$_{2.5}$ (25–200 µg/m$^3$), BSOF (1–170 µg/m$^3$) and heavy metals were highest at VN followed by JC and IIT. The study concluded that the overall air quality in the city of Kanpur was much inferior to other cities in India and abroad. Similar to PM$_{10}$ and PM$_{2.5}$, heavy metals were almost 5–10 times higher than levels in European cities.

Pulikesi M et al [43] studied on Air Quality Monitoring in Chennai, in the summer of 2005. Air pollutants like O$_3$, NO$_x$, RSPM and Total Suspended Particulate Matter
(TSPM) concentration and meteorological parameter at five different sites were measured. The mean O₃ concentration in all sites has been observed to be high. The transport of ozone rich air from the sea has been found higher on the coast than the interior. It also has been observed that surface concentration O₃ increase with increase in temperature and decrease with relative humidity. Reduction in O₃ may be due to the increase in NOₓ. The level of NOₓ was below the Indian standards. The daily mean concentration of TSPM was found to be above the NAAQS Standards. The present work has been undertaken mainly to generate new data on surface O₃ and understand the relation between O₃, NOₓ, PM and metrological parameters for Chennai city.

B. Gomisceka et al [44] carried out study on PM₁, PM₂.₅, PM₁₀ and TSP as well as the particle concentrations at four sites in Austria (3 urban and 1 rural) over one year period. The mass concentrations for PM₁, PM₂.₅ and PM₁₀ were monitored by means of TEOM devices. The mass concentrations for PM₁, PM₂.₅ and PM₁₀ were in the order of 16 µg/m³, 20 µg/m³ and 28 µg/m³ at the urban sites and lower at the rural site. The PM₁ counted for about 50–60% and PM₂.₅ for about 70% of PM₁₀. The seasonal cycle showed higher concentrations during the winter season. At the rural site no distinct seasonal cycle could be detected. The particle number concentration at the urban sites was higher during the winter months, while at the rural site no seasonal cycle could be detected.

J. D’iaz C et al [45] studied and analyzed influence of temperature and air pollution on infant mortality in Madrid. Daily values of mortality of children of less than 10 year old, maximum and minimum temperatures, and air pollutants were considered. In winter, mortality was associated with very low temperatures and high total suspended particles (TSP) concentrations. The summer mortality depended crucially on the
occurrence of high TSP and nitrogen oxides concentrations. In winter, the temperature effect was high as daily maximum temperature was lower than 6°C. This was rather different for older age groups in the same location, which showed the well-known V relationship between temperature and mortality. The association with TSP showed 2 linear branches without threshold and a strong increase in mortality for concentrations more than 100 µg/m³.

Rajnikant Sharma et al. [46] studied of seasonal variation in ambient particulate in Durg City of Chhattisgarh state, India. They identified six sampling sites, two each from residential, commercial and industrial areas to collect the respirable suspended particulate matter (RSPM), non-respirable suspended particulate matter (NRSPM) and total suspended particulate matter (TSPM), using a set of respirable dust sampler (RDS) and high volume sampler (HVS). They observed seasonal variation in ambient particulate matter during 3 seasons in the year 2000. They determined particulate matter, correlation between RSPM and SPM and air quality index. The results indicated the order of occurrences of particulate matter to be winter > summer > post-rainy. The air quality index falls under the category of poor and bad.

Mahuya Das Gupta et al [47] monitored the Suspended Particulate Matter (SPM) levels at Mandiakudar, an industrially developing area near Rourkela, for a period of three years during January 1997 to December 1999. From their analysis, it was observed that SPM values were within the permissible limits recommended by the Central Pollution Control Board (CPCB).

Dayal. H.V and Nandini.S.N.[48] studied the Ambient Air Quality for 10 congested areas in Bangalore City. In each place, they measured Suspended Particulate Matter, Oxides of Nitrogen and Sulphur dioxide. It was found that in six of the 10 congested
areas the SPM was above the limit. While both NO₂ and SO₂ were close to the WHO limit in some places. Considering Air Quality Index of all the places, it was concluded in that 1 out of 10 places the air was clean, 4 had light air pollution and in the remaining 5 places were moderately polluted.

Alam et al. [49] studied the ambient air quality at roadside in Dhaka City and estimated the Air Quality Index (AQI) at various locations of the city. They found that 70% of the locations were severely polluted and rest of the locations were highly polluted. They concluded that environmental condition had very serious implications on the health of the inhabitants of the city and it may cause eye and skin irritation, headache, breathing problems etc.

Gupta. K et al. [50] carried out a study on pollutants of SO₂, NO₂ and CO during evening peak traffic hours in Jaipur City. They collected samples at 49 stations covering 13 residential, 2 commercial, 4 sensitive and 4 industrial sites. They measured several times SO₂ and NO₂ concentrations on Sunday at 5 locations to enunciate the difference between the concentration levels on weekdays and Sunday. They carried out study only during peak traffic hours, which gave the maximum concentrations. It was inferred that even though the pollutant concentrations decreased on Sunday, ratios of NO₂ to SO₂ were constant, which also meant that the percentage contribution of sources to NO₂ and SO₂ levels remained unchanged.

Amitdyuti Sengupta et al. [51] have carried out comparative study between the ambient air quality management practices of Philadelphia and Pittsburgh. They tried to understand how these major industrial cities of the west tackled their once polluted ambient air quality. Their study also probed the strategies, planning, technologies, institutional arrangements and policies applied by Philadelphia and Pittsburgh cities
that could be possibly used to arrest the deterioration of the ambient air quality standards of Hyderabad. These studies lead to some recommendations and for reducing automobile emission and corresponding emission trends in both India and US.

1.9 Motivation for the Thesis Work

From the knowledge of literature, current issues and study on air pollution and air quality index of most of the major cities worldwide, conveys the message that air quality of those cities have crossed the nominal level of air pollution set by different investigating agencies such as WHO, EPA. In India, CPCB and NAAQS specified levels of air pollution affects human beings, animals or in total the ecosystem.

Study related to air quality index of sub metro cities like Belagavi, will establishes a base line data on concentration of air pollutants in the region. With this objective, the study was under taken by selecting five sampling locations around the city and study was carried with respect to gaseous pollutants (SO$_2$, NO$_2$ and NH$_3$) and particulate pollutants (PM$_{10}$ and PM$_{2.5}$) seasonally. Concentrations of pollutants have been determined during the study period that is from August 2013 to May 2015.

Objective of the study was

- To assess ambient air quality at the chosen sampling sites.
- To evaluate concentration of primary air pollutants at sampling sites.
- To determine the physical parameters which effect the dispersion of air pollutants.
- To carry out statistical analysis and to correlate pollutants with the physical parameters such as temperature, humidity, wind velocity and rain.
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