CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

With the background of the literature reviewed, consolidated framework were arrived for assessing nexus between the Particulate matter climate and health to achieve the proposed objectives of the research. The methodology includes both quantitative and qualitative methods adopted in this endeavor, where both primary and secondary sources where thoughtfully tailored. The study carefully considered the generic principles and guidelines of exposure and vulnerability assessment.

As shown in Figure 3.1 the conceptual methodological frame work were adopted in the study to fulfill the scope and objective of the present work. The prime focus of the methodology is to enumerate the influence of particulate matter on temperature and health in urban Chennai, India.

The description of the methodology applied in the present research work was dealt under each of the four objectives. The first objective was framed to estimate the change in trend at the surface and the temperatures at the standard pressure levels, and to enumerate the association of aerosol optical depth on the temperature trends using various statistical methods. Following the temperature analysis, the second objective is framed such a way to estimate the concentration of coarse and fine pollutant at the source based locations.
Figure 3.1 Overall methodology of the research

To the further depth, the particulate matter samples were characterized to identify the source markers using various analytical methods. These data were subjected to identify the statistical relationship with the pollution markers.
The third objective aims to enumerate the population exposed at the various concentration of particulate matter based on the WHO guidelines using GIS. Based on the exposure assessment, the vulnerable groups were selected for lung function test based on their nature of work, total work experience and total daily working hours at the exposure environment. Modified version of American Thoracic Society (ATS) questioner survey was used to collect medical history of the respondent and finally by incorporating all the analysis, the forth objective prioritized the mitigation strategies to control the particulate matter were proposed using correlation matrix.

3.2 CLIMATE ANALYSIS

As an indispensable foundation for climate change research, the determination of the change trend of the surface and upper-air temperature has quickly become one of the most important directions of climate-change research in recent years (Mears and Wentz 2005; Seidel et al 2004; Chen et al 2015). The present objective makes an attempt to understand the changes in mean, decal and seasonal variability and their association with AOD.

The detection, estimation and prediction of trends and associated statistical and physical significance are important aspects of climate research (Zwiers and Storch 2004). The data collection and methods adopted to evaluate the past climate variability and characteristics of variability were presented below.

3.2.1 Data Collection

To study the variability of surface, upper air temperature along with aerosol optical depth for Chennai city, the data were obtained from the various global climate data repositories maintained by organizations involved in climate research.
The upper air temperature data was taken from the radiosonde observations. Daily radiosonde flights are being made by the India Meteorological Department (IMD) at several locations over the country. These balloon flights are made twice a day at 00 and 12 GMT. An international inter-comparison measurement by WMO 2011 (Nash et al. 2005) revealed that the data quality of the Indian radiosonde is comparable with global standards. Forty one years of radiosonde data for the 1973-2014 were collected from the University of Wyoming climate data repository (www.weather.uwyo.edu). As a part of data sharing agreement IMD shares radiosonde data to Wyoming university data repository and it is widely used by various researchers to examine long term trends in tropopause height and upper air temperatures (Mallik and Lal et al. 2011; Ganguly and Iyer 2009; Chakrabarty et al. 2001).

The daily data, filtered for 00 GMT values, are averaged into monthly values for standard pressure levels of 1000, 850, 700, 500, 250, 150, 100 hPa. Over India, 00 GMT corresponds to a local time of 5.30 a.m., which is pre-sunrise time and the effect of warming of sensors due to solar radiation is minimum (Sherwood et al. 2005).

The corresponding daily average surface air temperature for Chennai international airport for the above said study period was obtained from global summary of the day (GSOD) data maintained at National Climate Data Center (NCDC – NOAA) repository. Climatologically analysis for a 30 year period is of sufficient duration to reflect natural climate variability on a multi decadal time scale, which is important in considering long term impacts of climate change (Rathore et al. 2013).
3.2.1.1 AOD data over Chennai city

The AOD is a measure of the extinction of the solar beam by dust and haze. In other words, particles in the atmosphere (dust, smoke, pollution) can block sunlight by absorbing or by scattering light. AOD tells us how much direct sunlight is prevented from reaching the ground by these aerosol particles (Chu et al 2003). It is a dimensionless number that is related to the amount of aerosol in the vertical column of atmosphere over the observed location. A value of 0.01 corresponds to an extremely clean atmosphere, and a value of 0.4 would correspond to a very hazy condition. Moderate resolution Imaging Spectro Radiometer (MODIS) is a remote sensor that measures aerosol optical depth at 550 nm. MODIS onboard the two EOS Terra and Aqua satellites, has been providing AOD retrievals for more than 11 years, twice daily (under cloud free conditions) on a near–global basis with high spatial resolution (10 km²) with good accuracy over dark vegetated surfaces (Suman et al 2014; Chu et al 2014; Chelani et al 2015). These two satellites are sun synchronous which crosses near polar at 10:30 a.m. descending node (Terra) and 1:30 p.m. ascending node (Aqua). The study area is divided into the grids of 10 × 10, and the average of the 7 grids, ranged between latitude 12.5-13.5, longitude 79.5- 80.5, facilitates data-retrieval of the entire study location.

The Terra and Aqua satellites operate at an altitude of 705 km. The MODIS data used in this study are Level 3 Collection 5 data with a spatial resolution of 1° * 1°, downloaded from NASA GIOVANNI website (http://disc.sci.gsfc.nasa.gov/giovanni). The MODIS AOD has a uncertainty of ±0.05 ± 0.15 × (AOD) over land (Kishcha et al 2011; Remer et al 2005; Safarpour et al 2014) it has been widely used in various air quality and climate research globally (Gupta et al 2013; Ramachandran et al 2012; Kumar et al 2007; Mao et al 2014). MODIS land aerosol algorithm makes use of the
dark target approach (Levy et. al., 2010). Since MODIS started its global mission to monitor AOD initiated from 2003 onwards. Monthly AOD data starting from 2003 – 2014 for the study area were used in this study.

This retrieval algorithm is known to have some uncertainties when the underlying surface is not dark enough (Kaufman et al 2002; Gupta et al 2013).

3.2.1.2 Analysis

The data were segregated to represent annual and seasonal pattern of the study area. The climatological calendar for the study area has four seasons, winter (January(J) to February(F)), summer (March to May), South west monsoon (pre monsoon) (June – September), North east monsoon (October to November). Before subjecting the data to statistical analysis, the values lying outside the 3-sigma range have been removed to eliminate errors and enhance quality using control chart function at XL stat 2015. Mean and standard deviation were estimated for all the segregated data sets. Then the data was subjected to long term trend analysis for annual and seasonal basis. Trend analysis is most commonly used fundamental statistics techniques for detect the climatic changes on global and local basis (Kruger and Shongwe 2004; Jaswal et al 2015). The linear regression method was used to analyze the behavior of the mean annual temperature.

3.2.1.3 Regression analysis

Temporal changes in monthly annual values were analyzed by significance of the trends has been computed with a parametric student’s t-test with a null hypothesis of no trend. Parametric or non-parametric tests are useful to detect whether there is statistically significant trend in the data. The t-test is employed to determine whether the slope of the trend line differs
significantly from zero (Sonali and Kumar 2013). These regression methods
determine whether there is a significant linear relationship between an
independent variable x and a dependent variable y (Ahmed et al 2014).

Regression analysis methods are ones in which the mean of a
response (or dependent) variable is described in terms of a simple function of
one or more predictors (or independent variables). The models are said to be
linear because they are linear in their unknown parameters. It is thus
postulated that the conditional mean of a response variable Y depends linearly
upon a random factor X. Suppose that we have n pairs of observations \{(x_i, y_i): i = 1,\ldots,n\} representing the realizations of a corresponding random
variable pair (X_i, Y_i), all pairs being independent and identically bi-variate
normally distributed. The hypothesized relationship between the two variables
is given by the Equation (3.2).

\[ y_i = \alpha + \beta(x_i) + \varepsilon \]  

(3.1)

where

- \( y_i \) – dependant or the endogenous variable
- \( x_i \) – independent or explanatory or exogenous variable
- \( \alpha \) – a constant amount
- \( \beta \) – an unknown vector or scalar factor
- \( \varepsilon \) – the noise term reflecting other factors

The nature of simple regression analysis is to produce an estimate
of the two unknown parameters \( \alpha \) and \( \beta \) (\( \varepsilon \), may or may not be observed in
certain situation). The simple regression equation is the equation for a line—a
line with an “intercept” of \( \alpha \) on the vertical axis and a “slope” of \( \beta \). Thus we
consider a scatter plot the hypothesized relationship thus implies that
somewhere on the diagram may be found a line with the equation above
Equation (3.1). The task of estimating \( \alpha \) and \( \beta \) is equivalent to the task of
estimating where this line is located. Decadal temperature has been estimated at each standard pressure levels of atmosphere using the linear regression analysis. This will help in detecting the signals of warming or cooling trends from surface to upper pressure levels. This method has been widely used in different fields of research for detection of signal change in linear trend series (Dilip and Dimacha 2012; Arora et al 2005).

3.2.2 Correlation Analysis

Once knowing that there is a significant temperature trend, the basic assertion for estimating the relationship between two parameters were assessed statistically using simple correlation analysis. Karl Pearson’s correlation was applied for the temperature and AOD relationship. In statistics, the Pearson product-moment correlation coefficient ($r$) is a common measure of the correlation between two variables $X$ and $Y$. Pearson’s correlation reflects the degree of linear relationship between two variables. It ranges from +1 to -1. A correlation of +1 meant that there is a perfect positive linear relationship between variables. A correlation of -1 means that there is a perfect negative linear relationship between variables. A correlation of 0 means there is no linear relationship between the two variables. The mathematical formula for calculating the Pearson’s correlation is given in Equation (3.2).

$$ r = \frac{N \sum xy - (\sum x)(\sum y)}{\sqrt{[N \sum x^2 - (\sum x)^2][N \sum y^2 - (\sum y)^2]}} $$  \hspace{1cm} (3.2)

where $N = \text{number of pairs}$

$\sum xy = \text{sum of the product of paired scores}$

$\sum x = \text{sum of the x scores}$

$\sum y = \text{sum of the y scores}$
The linear correlation coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson. Statistical level of \( p \leq 0.01 \) or \( p \leq 0.05 \) was considered to be significant.

3.3 SOURCES SEGREGATION OF PARTICULATE MATTER

Before starting any environmental monitoring study, one should have basic information about the available pollution sources and their locations, existing environmental problems, demographic details around the pollution source, distance from the source to receptor location, health status, land use pattern, metrological pattern like wind speed and direction, distance from the coast if is coastal city etc (CPCB 2003). Such prior information will provide immense help to identify the likely effects and in particular health impacts resulting from population exposure to air pollutants. Further more, micro level information like location of schools and hospitals around the pollution source also needed.

3.3.1 Selection of Sampling Sites

The sampling sites for monitoring coarse and fine particulate matter in Chennai were identified after a detailed survey of above said parameters and previous air pollution assessment reports. Totally 12 sampling locations were identified based on the stationary sources (industries, thermal power plants, brick kilns, diesel power generators and municipal solid waste dump sites) and line sources (traffic locations) in urban Chennai. The monitoring locations are listed below in Table 3.1 and segregated based on the nature of the location, like residential, industrial site etc... Figure 3.2 shows the
sampling locations in Chennai city. The samples were collected during May 2012- March 2013.

**Figure 3.2 Sampling Locations**

**Table 3.1 Sampling sites at Chennai**

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Description of site</th>
<th>Land use type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1     Anna University</td>
<td>Back ground area</td>
<td>Institution, dense vegetation</td>
</tr>
<tr>
<td>2     Velacherry</td>
<td>Kerbsite</td>
<td>Commercial Major road, Residential</td>
</tr>
<tr>
<td>3     Perungudi</td>
<td>Residential / Dumpsite</td>
<td>Municipal solid waste dumping site</td>
</tr>
<tr>
<td>4     Manali</td>
<td>Industrial</td>
<td>Petro chemical industries &amp; major road</td>
</tr>
</tbody>
</table>
Table 3.1 (Continued)

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Description of site</th>
<th>Land use type</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Ennore</td>
<td>Thermal power plant</td>
<td>Thermal power plant / Major road</td>
</tr>
<tr>
<td>6 Pakkam</td>
<td>Industrial</td>
<td>Brick kilns</td>
</tr>
<tr>
<td>7 Royapuram</td>
<td>Kerbsite</td>
<td>Major road, port, residential</td>
</tr>
<tr>
<td>8 Triplicane</td>
<td>Residential</td>
<td>Residential, minor road, commercial</td>
</tr>
<tr>
<td>9 Central</td>
<td>Kerbsite</td>
<td>Major road, commercial, rail way terminus, general hospital zone</td>
</tr>
<tr>
<td>10 Kodungaiyur</td>
<td>Residential / Dump site</td>
<td>Solid waste dump site, residential</td>
</tr>
<tr>
<td>11 T.Nagar</td>
<td>Commercial/Traffic location</td>
<td>Major road, commercial / residential</td>
</tr>
<tr>
<td>12 Mint</td>
<td>Kerbsite</td>
<td>Major road, commercial, residential</td>
</tr>
</tbody>
</table>

3.3.1.2 Sample collection

The coarse and the fine samples were collected at season wise at the above said sampling locations. The sampling procedures were carried out as per the CPCB prescribed methodology (CPCB 2011). The sampler were kept at above 3 meters from the ground level. The instrument specification and operation procedures are listed out in the Table 3.2. The empty filters were preweighed to estimate the mass difference after sampling, the PM$_{10}$ samples were transported to and from the field in sealed polyethylene bags and were desiccated for 48h before and after use. PM$_{10}$ loads were determined gravimetrically by weighing the filters twice in a microbalance after proper conditioning. Filters were stored in a refrigerator (4°C) until
The concentration of PM$_{10}$ in the designated size range was calculated by dividing the weight gain of the filter by the volume of air sampled.

**Table 3.2 Instrument speciation and sampling method for particulate matter**

<table>
<thead>
<tr>
<th>Particulate matter</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling Instrument</strong></td>
<td>High volume respirable dust sampler (APM 460 BL Envirotech sampler)</td>
<td>Fine particulate dust sampler (APM 550, Envirotech sampler)</td>
</tr>
<tr>
<td><strong>Sampling principle</strong></td>
<td>Filtration of aerodynamic sizes cut by improved cyclone with sharper cutoff</td>
<td>Filtration of aerodynamic size cut by portable Wins Anderson impactor</td>
</tr>
<tr>
<td><strong>Flow rate</strong></td>
<td>1.0 m$^3$/min</td>
<td>16.7 LPM</td>
</tr>
<tr>
<td><strong>Sampling duration (h)</strong></td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td><strong>Analytical instrument</strong></td>
<td>Electronic microbalance with 0.01 mg resolution (Model GR202, A&amp;D Company Ltd., Japan)</td>
<td>Electronic microbalance with 0.01 mg resolution (Model GR202, A&amp;D Company Ltd., Japan)</td>
</tr>
<tr>
<td><strong>Analytical method</strong></td>
<td>Gravimetric</td>
<td>Gravimetric</td>
</tr>
<tr>
<td><strong>Filters</strong></td>
<td>Whatmann 8*10 quartz filters, EPM 2000 Glass fiber filters</td>
<td>Teflon filters were Whatman Teflon Microfibre filter papers (47 mm diameter, 2 µm pore size); Whatman Quartz fibre filter (47 mm diameter, 2.5 µm pore size)</td>
</tr>
</tbody>
</table>
The PM$_{2.5}$ samples collected at the 47 mm diameter Teflon and quartz filter were transported safely by keeping the filters in the filter cassettes and kept at relative humidity of 50% and temperature of 25°C for 24 hours to remove the moisture content. Gravimetric determination of the collected mass was carried out using an electronic microbalance. Each filter was weighed before and after sample collection to determine the net gain due to the particulate matter. The mass concentration in the ambient air was computed as the total mass of collected particles in the PM$_{2.5}$ size ranges divided by the actual volume of air sampled. Both the PM$_{10}$ and PM$_{2.5}$ is expressed in μg/m$^3$. To maintain the quality purpose both the samplers were calibrated periodically to nullify the pressure difference in the samplers. The samples collected at Whatmann glass fiber filters were analyzed for ions present in PM. Quartz based filters were specially used for carbon measurements. Totally 156 samples of both PM$_{10}$ and PM$_{2.5}$ were collected from the entire study area in Chennai (at the interval of summer 36, pre monsoon – 48, monsoon – 24, winter 48).

3.3.1.3 Sample preparation and analytical procedures

About a circular portion of 4 cm were cut at the middle of the equally distributed PM$_{10}$ sample collected at the glass fiber filters using a stainless steel punch were digested with 10 mL HNO$_3$. Similarly the PM$_{2.5}$ samples collected at the Teflon fibers were prepared for ion analysis, with a punch of 16.5 mm diameter from the sampled quartz filters and the acid digestion were carried out similarly as mentioned in coarse sample. Milli-Q water (purified and deionized water) was used for dilution and other preparatory work throughout the study. The sample was subjected to microwave digestion at 150°C for complete digestion under the influence of high pressure. Sample was allowed to cool and after subsequent filtration (Whatman No. 42) and volume made up to 25 ml with high purity deionized
water. The extracted solutions were transferred to polypropylene bottles and refrigerated until analysis. Extraction and analysis of metallic elements is carried out as per the U.S. EPA Compendium Methods (US EPA 1999a, 1999b).

The samples were analyzed with the inductive coupled plasma with atomic emission spectroscopy (make: Perkin Elmer Optima 5300) at sophisticated analytical instrument facility at IIT Madras. The method detection limit (MDL in ng/m$^3$) values for various elements analyzed are reproduced here: As = 2.12, Ca = 0.11, Cd = 1.33, Cr = 4.13, Cu = 10.42, Fe = 6.25, K = 0.11, Mg = 0.1, Mn = 2.08, Na = 0.11, Ni = 2.08, Pb = 22.93, Se = 2.08, Ti = 2.08, V = 2.08, Zn = 2.08, respectively (Chakraborty and Gupta 2010; Gupta and Mandariya 2013).

For water-soluble ion determination, one portion of the filter was extracted with distilled deionized water by mechanical shaking and filtered through a pre-washed Whatman 42 filter. The water extraction of particulate samples were followed from the standard operating procedures (SOP) given by CPCB, New Delhi. The anion’s and cations were analyzed at the department of chemical engineering, IIT Madras (Make : 761 Compact IC, Metrohm, Switzerland). MDL (in ng/m$^3$) values for various ions analyzed are reproduced here Cl$^-$ = 3.0, NO$_3^-$ = 8.7, SO$_4^{2-}$ = 12.0, NH$_4^+$ = 17.0 (Chakraborty and Gupta 2010; Gupta and Mandariya 2013).

The surface morphology of aerosols was studied by using scanning electron microscope. The samples collected were punched in 1 mm$^2$ from the centre of each sample. All the samples were mounted on plastic stubs for gold coating. A very thin film of gold (Au) was deposited on the surface of each sample using vacuum coating unit called Gold Sputter Coater (SPI-MODULE) which can prepare 6 samples at a time. The fine coating of gold
makes the samples electrically conductive. The samples were placed in the corner of SEMEDX chamber. Seen under microscope (JSM-5800 LV) at 15 kV (to restrict the beam penetration to more than 0.99 mm) with band width of 16 mm equipped with energy dispersive X-ray system (Oxford 6841). It was assume that sample collected on the filter paper was uniform and small disc was cut to analyse samples on SEM machine. Disc portion was selected randomly but 4 different areas in the same disc was analyzed for metal.

Table 3.3 List of analytical methods for the sample

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Method of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cations : Na(^+), NH(_4)(^+), K(^+), Ca(^{2+}), Mg(^{2+})</td>
<td>Ion Chromatography (Make : 761 Compact IC, Metrohm, Switzerland).</td>
</tr>
<tr>
<td>Anions : Cl(^-), NO(_2)(^-), NO(_3)(^-), SO(_4)(^{2-})</td>
<td></td>
</tr>
<tr>
<td>Metallic elements: Al, Si,Ti, Fe, Ca, Na, Cl, Zn, Br, Mg, V, Ni,Mn, Fe,Cr,As, Co,K, Pb</td>
<td>1. Inductive coupled plasma with atomic emission spectroscope (Make : Perkin Elmer Optima 5300)</td>
</tr>
<tr>
<td></td>
<td>2. Scanning electron microscope with X ray diffraction facility (Make: JSM-5800 LV with energy dispersive X-ray system(Oxford 6841).</td>
</tr>
<tr>
<td>Total Carbon</td>
<td>CHNS elemental analyzer ( Thermo Scientific Flash 2000)</td>
</tr>
</tbody>
</table>

Blank filters were stored and processed as per the methodology above to compare the results. Table 3.3 shows the analytical methods involved in the characterization of particulate matter. The analytical methods
are listed based on the procedure given in standard methods of air sampling and analysis (APHA 1977).

3.3.1.4 **Principle component analysis / Multi Linear Regression (PCA – MLR)**

The potential source categories of the PM$_{10}$ and PM$_{2.5}$ ambient samples in Chennai were analyzed by the principal component analysis/multiple linear regression (PCA-MLR) model (Thurston & Splenger 1985). The PCA-MLR model is a receptor model, which is a useful tool for identifying potential source categories and estimating source contributions (Harrison et al 1997; Watson et al 2008; Vallius et al 2008). The PCA-MLR model can extract certain factors from an ambient dataset. The factors can be identified as the actual source categories according to the source markers (Thurston et al 2011).

The general receptor model can be described as all $m$ chemical species in the $n$ samples are contributions from $p$ independent sources:

$$x_{ik} = \sum_{j=1}^{p} g_{jp} f_{pk} + e_{ik}$$  \hspace{1cm} (3.3)\]

where $x_{ik}$ is the $i$th species concentration measured in the $k$th sample; $f_{pk}$ is the contribution of the $p$th source to the $k$th sample; $g_{ip}$ concentration of the $i$th species from the $p$th source; and $e_{ik}$ is the error. This function was framed by Paatero and Hopke 2003.

The factor loading can be obtained by PCA-MLR. The source profile and contribution matrix can be calculated from the factor loading and score matrices. The detailed methods of PCA-MLR were widely used for PM source segregation studies (Wang et al 2012; Khillare and Sarkar 2012;...
Kulshrestha et al 2009). In the present study eigen values > 1 and the factor with cumulative % greater than 10 were considered for the selecting the factors.

3.4 HUMAN EXPOSURE ASSESSMENT

After analyzing the current status of coarse and fine particulate matter, it is necessary to analyze the exposure of the system. For this, primary components that define the exposure, which were analyzed and evaluated here include coarse and fine particulate matter limits, vulnerable zones, demographic status, vulnerable groups that are exposed more to the pollutants are considered.

3.4.1 Coarse and Fine Particulate Matter Exposure Limits

The evidence on airborne PM and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations. As thresholds have not been identified, and given that there is substantial inter-individual variability in exposure and in the response in a given exposure, it is unlikely that any standard or guideline value will lead to complete protection for every individual against all possible adverse health effects of particulate matter. Since this study is focused more on the short term health effects, it is recommended to use WHO interim target guidelines based on 24 hour average. Meeting the guideline values for the 24-hour mean will however protect against peaks of pollution that would otherwise lead to substantial excess morbidity or mortality. It is recommended that cities with areas not meeting the 24-hour guideline values undertake immediate action to achieve these levels in the shortest possible time. WHO has estimated the risk coefficients for short term mortality, based on the exposure under interim target guidelines. The prescribed limits for coarse and
fine particulate matter were already discussed in the previous chapter (Section 2.5).

3.4.2 Demographic Analysis

Population is the primary component and play pivotal role in the exposure assessment studies. In a complex urban environment the population settlements were located closely in the proximity of the pollution source, this increase the probability of exposure to the pollutant. Gridded population data projections from the year 2015 from gridded population estimates of the world (GPW V3) were used. Population count gridded data at 2.5' resolution derived from the SEDAC (Socioeconomic and Applications Center). This data was prepared based on the country level UN population estimates. It is the gridded data product that renders global population data on the scale and extent required to demonstrate the spatial relationship of human population and the environment across the globe. With the aid of Arc Gis 9.3 the population data was segregated for study area from the global data set based on the administrative shape file provided by the Chennai corporation. Population data were converted to points and spatially interpolated, to attain the high spatial resolution (0.01° × 0.01°) which can be used population weighted exposure function estimates (Mahmud et al 2012).

Gridded population of the World version 3 has been extensively used in various environmental assessment studies (Donkelaar 2015; Yao et al 2014; Kishtawal et al 2010; Sun et al 2013).

3.4.2.1 Calculation of Population Exposure to PM Based on AQG

The coarse and fine PM monitoring locations were fed in the GIS based on their geo coordinates. The average concentration of the PM for each monitoring location was entered at the designated data points. To cover the
entire spatial extent of the study area for exposure assessment additionally five more locations (Kundrathur, Ponthamalle, Adyar, Sholinganallur, Perungalathur) were selected for the study, apart from the 12 regular monitoring points. These additional monitors were operated for short duration only during winter season (10 samples). The data from these additional monitoring were used for estimating the PM concentration alone. they were not subjected for chemical characterization. Although the 17 sampling locations were selected to represent the whole spatial extent of Chennai, spatial interpolation technique in GIS platform were used to surface data over the entire area. Since there are numerous spatial interpolation methods, this study used the Kriging method, originated by Matheron 1963. Kriging and universal kriging methods have been used in epidemiologic studies, providing both a concentration estimate and an uncertainty estimate (Ivy et al 2008).

Using the GIS, the interpolated pollution data were classified into four classes according to the WHO interim target (IT) guidelines (24 hour average). The pollution layers pertaining to each class were converted into polygon features, which were overlaid to analyze population exposure levels in various concentration ranges. The vulnerability map for Chennai has been generated based on the WHO based air quality guidelines.

### 3.4.2.2 Calculation of Population Weighted Exposure Level

The interpolated population and the pollution layers were converted into data points. These gridded points were extracted zone wise using Chennai metropolitan area which comprises of 15 zones and sub urban area. The PWEL function were separately estimated for both coarse and fine PM.

The PWEL of the given grid i, is calculated based on the exposure equation is as follows:
\[
PWEL = \frac{\sum (P_i \cdot C_i)}{\sum P_i}
\]  
(3.5)

where \(P_i\) is the population in the grid \(i\), and \(C_i\) is its average \(\text{PM}_{10,2.5}\) concentration.

### 3.4.3 Identification of Vulnerable Groups based on Reduced Lung Function

Based on the vulnerability mapping and PWE for the study area, the locations prone to risk for particulate matter were identified. Since vulnerability is depended on the total duration of exposure to the pollutant in the outdoor environment. Cohort groups were identified from vulnerable location who exposed more to the particulate pollution based on their nature of work, total working hours in the exposure environment. by considering the above conditions cohort groups from brick klin workers, traffic police men, auto drivers were subjected for lung function test. Study subjects were selected within the age group of 20 – 50, apart from this a modified version of American thoracic society – Division of Lung Disease (DLD) 78 questionnaire based survey for adults were conducted. questions related to past respiratory health problems, family history for cardiac related issues. Information pertaining to total years of work experience, annual income, and behavior changes like smoking/ passive smoking, alcohol usage were included in the survey. The questionnaire were typed in English and the regional language, Tamil. A group of control subjects who stay from air pollution source were selected for estimating the odds ratio. confounding parameters like working hours, experience, smoking / passive smoking. A confounding variable is causally associated with the outcome of interest, and non-causally or causally associated with the exposure, but is not an intermediate variable in the causal pathway between exposure and outcome (Szklo & Nieto 2007). The study was conducted repeatedly to the above said groups during the winter 2014. The average coarse and fine particulate matter
for location was considered for particulate matter mediated lung function assessment.

3.4.3.1 Lung function assessment using spirometer

Lung function test for the vulnerable group were estimated using battery operated super Spiro spirometer (Micro medical, UK). Parameters like Peak expiratory flow rate (PEFR), forced expiratory volume in the first second (FEV1) were measures as per the recommendations of the ATS. PEFR is the maximum velocity with which air is forced out of the lungs. The subjects were asked to inhale and exhale out to the full capacity from the mouth on the mouth piece in the spirometer. FEV1 is the volume of air that can be forced out in one second after taking a deep breath, an important measure of pulmonary function. The persons handling the spirometers were given training under expert supervision to minimize the error during sampling. We make sure that the respondent didn’t smoke or drink/ eat in the past half an hour before sampling to minimize the bias during interpretation of results. Prior to spirometry the respondents were subjected for questioner survey and they height and weight were measured to separately. They were given individual mouth pieces to avoid infection. Before conducting the test they were asked to take deep breath and repeated demo were shown how to undertake the test. The test was repeated till we get the average of best blow from the subjects. The interpretation of lung function was carried out using the predicted reference equations for Indians (Udwadia et al 1986).

3.4.3.2 Statistical analysis

Student’s t–test was used to compare the mean values of age, height, weight, Body Mass Index (BMI), age, height, weight, FEV1 and PEF among the test and control groups. The odds ratio and 95% Confidence Interval (95% CI) were identified with the study groups. Step wise
hierarchical regression was used to estimate the relationship between the lung functions, PM and confounding parameters (Kesavachandran et al 2015).

(i) **ODDS ratio**

An ODDS Ratio (OR) is a measure of association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. Odds ratios are most commonly used in case-control studies, however they can also be used in cross-sectional and cohort study designs as well (Szumilas et al 2010).

\[
OR = \frac{\text{odds that an exposed person develops the disease}}{\text{odds that a non exposed person develops the disease}}
\] (3.6)

The odds ratio can also be used to determine whether a particular exposure is a risk factor for a particular outcome, and to compare the magnitude of various risk factors for that outcome.

- OR=1 Exposure does not affect odds of outcome
- OR>1 Exposure associated with higher odds of outcome
- OR<1 Exposure associated with lower odds of outcome

(ii) **Confidence Interval**

The 95% confidence interval (CI) was used to estimate the precision of the OR, A large CI indicates a low level of precision of the OR, whereas a small CI indicates a higher precision of the OR. It is important to note however, that unlike the p value, the 95% CI does not report a measure’s statistical significance. In practice, the 95% CI is often used as a proxy for the presence of statistical significance if it does not overlap the null value.
Nevertheless, it would be inappropriate to interpret an OR with 95% CI that spans the null value as indicating evidence for lack of association between the exposure and outcome.

3.5 IDENTIFYING AND PRIORITIZING MITIGATION OPTIONS

Various mitigation strategies were identified to reduce the particulate pollution for the prominent sources identified from the above methodologies. Mitigation of strategies that were implemented for various urban cities were listed out from the through literature review. The pair wise ranking method is employed to prioritize the recommended mitigation options (Pretty 1995). Pair wise (or preference) ranking is often used by social scientists, and increasingly by community development workers, as a means of prioritizing or ranking lists prepared by related communities, other groups or individuals. The application of pair wise ranking for prioritizing mitigation and adaptation strategies in the climate change field has been used in various studies (Ramachandran et al 2015).