CHAPTER 4

DATA AND METHODOLOGY

Data

The present study is based on the urban ambient air quality data published by the Central Pollution Control Board of India and the State Pollution Control Boards belonging to Indian states. These data are in the form of monthly average values, monthly maximum values, monthly minimum values, and annual average values for sulfur dioxide (SO₂), oxides of nitrogen (NOₓ) and suspended particulate matter (SPM) in micrograms per cubic metre (μg/m³). Data used in this study are for 72 recording stations located in 28 Indian cities for the period extending from 1988 to 1994. Monitoring of ambient air pollutants is conducted by respective State Pollution Control Boards under the guidance and supervision of the Central Pollution Control Board. The monitoring is done for SO₂, NOₓ, and SPM. The sampling duration for monitoring is 24 hours and it is done twice every week.

The set of instruments called High Volume Sampler are used by the Pollution Control Boards to monitor ambient air quality and pollution levels. Similar instruments are in widespread use all over the world to measure air pollution levels (Instruction Manual, High Volume Sampler, Envirotech APM 410-411).

Measurement of SPM¹

The Pollution Control Boards use the air pollution monitoring instruments developed by ENVIROTECH, a team of technical entrepreneurs engaged in developing indigenous technology for pollution monitoring. In these samplers, the airborne particulates are measured by passing air at a high flow rate of 1 to 1.3 cubic metre per minute through a high-efficiency filter paper which retains the particles. The instrument

¹ This and the next sections are based on the information and techniques discussed in Instruction Manual, High Volume Sampler, Envirotech APM 410-411.
measures the volume of air sampled, while the amount of particulates collected is
determined by measuring the change in the weight of the filter paper as a consequence of
air passage at a high rate.

The ENVIROTECH’s APM 410 High Volume Sampler is used by the Pollution
Control Boards to measure the concentration of SPM in the air. The mass concentration
of SPM in the ambient air, expressed in micrograms per cubic metre (μg/m³), is
determined by measuring the mass of collected particulates in the volume of air sampled.

In the APM 410, the flow rate of air passing through the filter is monitored by
measuring the pressure drop across an orifice plate placed between the filter holder and
the blower. The scale of the manometer used to measure the pressure drop is calibrated in
air flow units of cubic metres per minute. A time totaliser records the time in hours/
minutes for which the system has sampled the air. Hence the volume of air sampled is
known. The mass of particulates collected is measured gravimetrically, using a balance
capable of reliable measurement to the nearest milligram. For the identification of trace
quantities of specific elements or compounds, the collected dust may be analysed using
standard methods using electron microscopes, atomic-absorption infra-red spectroscope
etc. Only particulate matter such as wood, smoke or photochemical smog may block the
filter and cause a rapid decrease in air flow at a non-uniform rate. Even fog or high
humidity can severely reduce the air flow through the filter. The glass fibre filters used are
sensitive to changes in relative humidity, but some of the collected particulates may be
hygroscopic and may lead to partial blocking of filters. To avoid these complications the
filter mediums are carefully cleaned and conditioned both before and after sampling.

After the sampling is done the filters are removed carefully and weighed. The
concentration of SPM is then determined as:

\[
W_{\text{SPM}} = W_2 - W_1 \quad \text{(1)}
\]

where: 

\[
W_2 = \text{weight of the filter paper after sampling (grams)} \quad \text{and}
W_1 = \text{weight of fresh filter paper (grams)}.
\]
Volume of air sampled (in cubic metres), $V = Q_{SR} \times T$. 

(2)

where: 

$Q_{SR}$ = average sampling rate in cubic meters per minute and 

$T$ = sampling time (minutes).

The value of $Q_{SR}$ is found from the following -

$Q_{SR} = (Q_1 + Q_2) / 2$

where:

$Q_1$ = initial sampling rate indicated by the orifice meter at the start of the sampling and 

$Q_2$ = final sampling rate indicated by the orifice meter just before the end of sampling.

From (1) and (2) the concentration of suspended particulate matter in grams per cubic metre, $SPM = \frac{W_{SPM}}{V}$.

**Measurement of Gaseous Pollutants**

The ENVIROTECH's APM 411 gaseous sampler attachment is used for the measurement of gaseous pollutants. The two units, viz. APM 410 and APM 411, operate independent of each other. In the APM 411 gaseous sampler wet chemical method is used for the absorption and detection of gaseous pollutants. Atmospheric air passes through the absorbers containing suitable reagents which would absorb relevant gases like SO$_2$, NO$_x$, etc. The absorbing reagent is analysed in a laboratory to work out the quantity of gases absorbed.

The method for the measurement of SO$_2$ is called hydrogen peroxide method. When a measured volume of air is drawn through a dilute solution of H$_2$O$_2$ (hydrogen peroxide) at about pH = 5, SO$_2$ in the air is absorbed and oxidised to H$_2$SO$_4$. The resultant increase in acidity of the solution is determined by a simple titration using an indicator or a pH meter.

When SO$_2$ from the air stream is absorbed in a sodium tetrachloromercurate solution it forms a stable dichlorosulphitomercurate. The amount of SO$_2$ is then estimated by the colour produced when prosaniline hydrochloride is added to the solution. The
colour is estimated by a reading from an absorptimeter or spectrophotometer for which a calibration curve has already been prepared.

The oxides of nitrogen (NOx) are collected by bubbling air through a sodium hydroxide solution to form a stable solution of sodium nitrate. The nitrate ions produced during sampling are determined calorimetrically by reacting the exposed reagent with phosphoric acid, sulphanilamide, and N(1-napthyl) ethylenediamine dihydrochloride.

The High Volume Sampler is usually operated at ground level. In normal usage it is never operated more than 15 m above the ground level. In order to obtain a representative sample, the sampler should not be positioned near a wall or other obstruction that would prevent free air flow. In excessively turbulent conditions or in the presence of strong surface winds or otherwise inclement weather, the sampling rate is likely to decrease rapidly and perhaps in a non-linear fashion due to filter choking. If the sampler is operating in the vicinity of a source, day-to-day variations in the measurement are expected due to varying meteorological conditions and changing atmospheric phenomena, like wind speed and direction, dispersal, diffusion etc.

Glass microfibre filters having low resistance to airflow, a low affinity for moisture and a 98 % collection efficiency for particles of 0.5 micron or larger size are suitable. Prior to use each filter is exposed to a light source and inspected for pinholes, particles and other imperfections and then the filter is weighed. The monitoring of SO2, NOx and SPM is conducted at eight-hourly intervals for 24 hour periods on a two-times a week basis.

Methodology

Determination of Temporal Trend

The ambient air quality data published by the Central Pollution Control Board for the recording stations spread over the country have been represented as line graphs in order to visualise the past trend of the data (Appendix). Time on such graphs is
represented on the horizontal axis (independent variable) and the level of pollutant concentration is shown on the vertical axis (dependent variable). By observing the data over a period of time one can easily understand the trend over the period of analysis. Seasonal cyclical variations and irregular variations were analysed by calculating three-monthly, six-monthly, and annual averages of the ambient air quality data and the causes of these variations are suggested. Monthly values (mean, maximum and minimum) are then plotted (Appendix). The overall trend is determined by fitting a least-square regression line to the monthly average values by calculating the regression of time on pollutant concentrations. This is shown in Appendix. An analysis of correlation between the pollutant concentration and time has also been done. The values of the Karl Pearson’s coefficient of correlation ($r$), the coefficient of determination ($r^2$), and the coefficient of alienation ($\sqrt{1-r^2}$) have been used to determine time-dependence of the pollutant concentration. It has been suggested by Ferguson (1981) that “.the correlation coefficient squared, $r^2$, is the proportion of variance in $Y$ [the dependent variable] that can be predicted from $X$ [the independent variable]....” This coefficient which has been called the coefficient of determination, therefore, in the present study, would denote the proportion of variance in pollutant concentration that can be predicted or explained from time variable. While talking about the coefficient of alienation, Ferguson (1981) observes that “$\sqrt{1-r^2}$ is the obverse of the correlation coefficient. The correlation coefficient describes the degree of association between two variables. The quantity $\sqrt{1-r^2}$ describes the degree of lack of association, or alienation, between two variables”. In the present case this coefficient will describe the degree to which the pollutant concentration is time-independent. The values of $r$, $r^2$, and $\sqrt{1-r^2}$ for the data for all recording stations analysed are shown on diagrams in the Appendix.

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**Determination of Spatial Trend**

For the purpose of determining the spatial trend in the values of pollutant concentration, the values recorded at different recording stations within each city were averaged to give a mean value for that particular city. These city pollutant level values were plotted on a map of India and an isoline map showing urban pollutant concentration level was generated. The same data were also represented in the form of block diagrams. These maps and diagrams gave a visual representation of the urban pollutant levels of the country. This analysis has been done for monthly, three-monthly, six-monthly, and annual values of SO$_2$, NO$_x$, and SPM concentrations and spatial trends for different time periods were determined. A set of monthly, three-monthly, six-monthly, and annual maps (Figures 10 to 36) for the whole period shows how the spatial distribution of different urban pollutants has varied over time. When there are a large number of recording stations within a city (6 stations in Delhi, for example), the spatial trend of pollutant concentration within the city can be visualised using isoline mapping outlined above. Recording stations are located on a city map, pollutant concentration values are plotted on this map, and then isoline map and block diagram are generated using SURFER software as is done above. Such an analysis has been done only for Delhi (Figures 37 to 43) as all other cities have not more than 4 recording stations, and also because the city maps for many of them were not available.

**Ambient Air Quality Standards**

The Central Pollution Control Board of India has set national standards or limits for the concentration of different ambient air quality measures for residential, industrial and sensitive recording stations. These air quality standards have been developed under the statutory powers of the Air (Prevention and Control) Act, 1981 which was approved and notified by the Government of India, Ministry of Environment and Forests under Section 25 of the Environmental (Protection) Act, 1986 (Central Pollution Control Board,

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1 For drawing isoline maps and block diagrams on the basis of the city-wise pollutant data, these data were plotted on a map of India, x and y coordinates of the cities were determined, and a software called SURFER, version 6.03, Surface Mapping System of the Golden Software Inc. was used.
June 1997). These standards (Table 31) have been set keeping in view the different health- and environment-related effects of air pollutants. Three classes of recording stations, viz. residential, industrial, and sensitive, have been identified. Standards for sensitive areas are the lowest; those for the residential areas are intermediary; and those for the industrial areas are the highest. Such standards have earlier been set by the United States Environmental Protection Agency (EPA) and the World Health Organisation (WHO), but they were not applied in the present study to the data recorded by the Central Pollution Control Board of India because of some technical differences. The data of the Central Pollution Control Board of India are, therefore, compared to the standards set by the Central Pollution Control Board of India only using the methodology outlined in the following section.

**Comparing Recorded Data with Standards**

The data values for ambient air quality measures (concentration of SO$_2$, NO$_x$, and SPM) are compared with the Central Pollution Control Board standards in the same manner as raw scores in an array of data are compared with the mean of the array by calculating the standard deviation ($s$) and standard scores ($z$). The raw values of the ambient air quality measures are compared with the standards (limit set by Central Pollution Control Board of India) for the class in which the station falls instead of comparing them with the means. If the standard for a particular class of station is $M$, then:

1. Deviation scores from $M = DSM = (X, - M)$;
2. Standardised deviation from $M = SM = (\sum (X, - M)) / \sqrt{N}$; and
3. Standardised score in terms of $M = Z_{Mi} = (X, - M) / SM$.

Where: $X, = i^{th}$ raw score; and $N = \text{number of values in the data array}$.

$Z_{Mi}$ values indicate the comparison of the raw values of ambient air quality measures with the predetermined standard value. A negative $Z_{Mi}$ value is for a raw score that is less than
Table 31
National (Indian) Ambient Air Quality Standards
(For Annual Averages)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Standard Concentration in Ambient Air ($\mu g/m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitive Areas</td>
</tr>
<tr>
<td>Sulfur Dioxide ($SO_2$)</td>
<td>15</td>
</tr>
<tr>
<td>Oxides of nitrogen (as $NO_2$)</td>
<td>15</td>
</tr>
<tr>
<td>Suspended Particulate Matter (SPM)</td>
<td>70</td>
</tr>
</tbody>
</table>

Source: Central Pollution Control Board, Delhi, June 1997.
and a positive $Z_{M_i}$ is for a raw score that is greater than $M$. Magnitude of these values is indicative of the departure from the respective $M$. This can be shown graphically. If the data pertains to spatial units then $Z_{M_i}$ values can be mapped and areas with different $Z_{M_i}$ values be demarcated to specify the magnitude of the problem being analysed. Before the $Z_{M_i}$ values are represented graphically or mapped on city-wise basis, the values for multi-station cities are averaged. In such cases the values for all stations within a city are summed algebraically and this sum is then divided by the number of stations. These $Z_{M_i}$ values are now plotted (Figures 44 to 50) in order to visualise the spatial distribution of air pollution.