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Original Article
Analyzing Air Quality Data Using Response Surface Methodology
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Abstract
Air pollution is the major problem of concern in today’s scenario which is a result of increasing traffic, industrialization and rapid economic development. Unplanned urban and industrial development and increase in population are the prime factors that had led to air pollution problems. The measurements of wind speed and direction, temperature, humidity, and rainfall are important parameters used in the study of air quality monitoring and to further understand the chemical reactions that occur in the atmosphere. Meteorological monitoring is used to predict air pollution events such as inversions and high pollutant concentration days. The objective of this paper is to analyse the air quality data with Response Surface Methodology (RSM) in order to find the influence of meteorological parameters on the air pollution concentration. Air quality data was collected from 25 stations in and around Coimbatore city. Analysis has been done to establish the effect of the meteorological parameters with the concentration of air pollutants. The high-volume sampler was used for sampling and monitoring.

KEY WORDS: Particulate matter, Nitrogen oxide, Sulphur dioxide, Meteorological parameters, Vehicular emission.

1. INTRODUCTION
Though emissions from industries and incineration of waste contribute to the air pollution, the major source of air pollution is vehicular emission. This is one of the ground level sources and has the maximum impact on the general population. Road transport contributes, on an average, more than half of the nitrogen oxides emissions, particulate matter, and about 35 percent of volatile organic compounds (VOC) emissions. Air pollution is a phenomenon by which particles (solid or liquid) and gases contaminate the environment. Such contamination can result in health effects on population, which might be either chronic (arising from long-term exposure), or acute (due to accidents). Other effects of pollution include damage to buildings (e.g., the marble statues on the Parthenon in Athens and Taj Mahal in Agra are corroded as a result of air pollution), agricultural damage (such as reduced crop yields and tree growth), impairment of visibility (tiny particles scatter light very efficiently), and even climate change (certain gases absorb energy emitted by the earth, leading to global warming).

Apart from Carbon dioxide (CO2) emissions, significant quantities of carbon monoxide (CO), hydro carbons (HC), oxides of nitrogen (NOx), sulphur dioxide (SO2) suspended particulate matter (SPM) and other air toxins are emitted from the motor vehicles into the atmosphere, causing serious environmental and health impacts. Like many other parts of the world, air pollution from motor vehicles is one of the most serious and rapidly growing problems in urban centers of India (CRRI, 1998). The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India and vehicular emissions have been identified as one of the major contributors in the deteriorating air quality in these urban centers (CPCB, 1999). Although, recently, improvement in air quality with reference to the criteria pollutants (viz., NOx, SO2, CO and HC) have been reported for some of the cities, the air pollution situation in most of the cities is still far from satisfactory (CPCB, 2000). The problem has further been compounded by the concentration of large number of vehicles and comparatively high motor vehicles to population ratios in these cities (CRRI, 1998). In India, the number of motor vehicles has grown from 0.3 million in 1951 to approximately 50 million in 2000, of which, two wheelers accounts for 70 percent of the total vehicular population. Two wheelers, combined with cars account for approximately four fifth of the total vehicular population. Vehicles in major metropolitan cities are estimated to account for 70 percent of CO, 50 percent of HC, 30-40 percent of NOx, 30 percent of SPM and 10 percent of SO2 of the total pollution load of these cities, of which two third is contributed by two wheelers alone. These high level of pollutants are mainly responsible for respiratory and other air pollution related ailments including lung cancer, asthma etc., (CPCB, 2002).

Milind (2007) used spectral methods to analyze changes in
air quality at a single monitoring site in Delhi. Power spectral density calculations of daily concentration data for particulate matter (PM10), carbon monoxide (CO), oxides of nitrogen (NOx) and oxides of sulfur (SOx) revealed the presence of trends and periodic oscillations for all the pollutants. Singular Spectrum Analysis (SSA) was used to decompose daily data into statistically significant nonlinear trends, seasonal cycles and other oscillations. Indrani and Rakesh (2006) used a set of time series analysis methods viz. t-test adjusted for seasonality, Seasonal Kendall test and Intervention analysis to identify and estimate the trend in PM10 and total suspended particles (TSP) levels in India. Vulnerable analysis (VA) was carried out by Mrinal et al, (2004) to evaluate the air pollution stress at different locations in Kolkata.

Evaluation of traffic pollution in streets requires basically information on three main factors: traffic emissions, the meteorological conditions and the street surroundings. Examining the relationships between model predictions and measurements with respect to the meteorological conditions and inter-relationships between different pollution components allowed quantitative evaluation of the traffic emissions. This methodology was adopted by Berkowicz et al, (2006) using the Danish Operational Street Pollution Model OSPM, and time series of traffic related pollutants.

Street level concentrations of NOx and CO were calculated using OSPM as the dispersion model and emission data estimated by the widely used COPERT (European methodology). Meenakshi and Saseetharan, (2003) analysed the seasonal variations of suspended particulate matter and oxides of nitrogen concentrations in five stations in Coimbatore city. Francesca et al (2006) assessed nitrogen oxides (NO2 and NOx), sulphur dioxide (SO2), and benzene, toluene, xylene (BTX) in ambient air by diffusive sampling technique, through three measurement campaigns at 100 locations in the Chinese city of Suzhou. Calori et al, (2006) used SPRAY Lagrangian particle model, coupled with the MINERVE diagnostic wind field code, to reconstruct the model, taking into account CO and NOx.

2. STUDY AREA CHARACTERISTICS

Coimbatore is the second largest city in Tamilnadu. The city has six major arterial roads and three National Highways. Most of the textile industries are situated in Coimbatore. There are about 40,000 small, medium and large scale industries in the city. Due to industrialization and urbanization Coimbatore’s air quality is worsening. The ambient air quality of Coimbatore has deteriorated with an increase in the number of vehicles and industrial pollution. Hence this paper attempts to reveal the air quality status of the city.

![Figure 1 Locations of monitoring stations](image)

3. METHODOLOGY

The study was carried out throughout the year 2010. About 25 monitoring stations as shown in Figure 1, were selected and the sampling duration was 8 hours. One station was monitored each day. Periodic sampling was taken in each station in a cyclic manner. About 8 to 9 readings were taken in each station. High volume sampler (Model APM 460 NL) was used in this study for collecting the air samples. The collected air samples were analyzed in the laboratory. The sampling time was from 8am to 4pm covering peak hours and moderate traffic flow hours. Method of estimation of respirable particulate matter (RPM) and Total suspended particulate matter (TSPM) was done by Gravimetric Method. Method of estimation of Sulphur dioxide (SO2) was carried out by improved West and Gaekw method. Method of estimation of Nitrogen oxides (NOx) was done by Jacob-Hocheiser (modified Na-Arsenite) method (Anil 2001). The meteorological data like
Temperature, relative humidity, wind speed and direction were collected. Any study of air pollution should include a study of the weather patterns (meteorology) of the local area because the air pollutants are influenced by the movements and characteristics of the air mass into which they are emitted. If the air is calm and pollutants cannot disperse then the concentration of these pollutants will build up. Conversely, if a strong, turbulent wind is blowing any pollution generated will be rapidly dispersed into the atmosphere and will result in lower concentrations near the pollution source.

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analyzing applications where the response of interest is affected by several variables. In RSM problems, the form of relationship between the response and the independent variables can be fitted by a polynomial model of first, second or third order as appropriate to the problem under investigation. To obtain a reasonably more accurate optimized value, the second order model, which has curvature due to the polynomial terms as given below, is selected.

\[ y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ij} x_i^2 + \sum_{i<j} b_{ij} x_i x_j \]  

where, \( x_i \) (\( i = 1, 2, ..., k \)) are quantitative variables and \( b_0, b_i \) are the least square estimates of the regression coefficients.

Designs for fitting second order model are called composite designs (Montgomery 2005). These designs are modified by adding central points and axial points along with factorial points to get a central composite design. In order to provide equal precision of estimates in all directions, a central composite design with rotatability or equal precision is selected. The parameter distance to the axial points (\( \alpha \)) from the design centre depends on the factorial points and can be calculated as \( (n_f)^{1/4} \) for rotatable design where \( n_f \) is the number of points used in the factorial portion of the design. Response Surface Methodology (RSM) using (SAS Release 8.02) has been used, in which the response surfaces built include the curvature due to the presence of polynomial function in the predicted model (Montgomery 2005). The influences of meteorological parameters on the concentration of the air pollutants were analyzed and the response surface was drawn.

The meteorological data was collected from the Surface and Ground water Department at Taramani, Chennai. The wind rose diagram is shown in Figure 2.

4. RESULTS AND DISCUSSION

The observed air pollutant concentrations recorded using the high volume sampler are shown in Figures 3 to 5. The concentration of all pollutants recorded at Gandhipuram was the highest. Since it is commercial area traffic congestion occurs resulting in higher concentration. Moreover parking of vehicles is not planned correctly in this area leading to traffic hindrances. Selvapuram and Ramanuja nagar which are the residential areas have recorded lower TSPM concentration (Figure 3).

Selvapuram and GCT have recorded the lowest RPM concentration. Lowest concentration of \( \text{SO}_2 \) was recorded in TVS Nagar and Ramanuja Nagar. Apart from Gandhipuram, Ukkadam and intersection near PSG college has recorded maximum concentration of NOx. Selvapuram and Singanallur have recorded the minimum concentration of NOx (Figure 4). Highest concentration of CO was recorded in Gandhipuram and Tatabad, while GCT and Selvapuram recorded the lowest concentration (Figure 5).
The concentration of NO\textsubscript{x} also increases as the temperature and relative humidity increases (Figure 12). NO\textsubscript{x} are produced during the combustion processes at high temperature for oxidation of the nitrogen in air and in the fuel and the first by-product is NO (primary pollutant), while NO\textsubscript{2} can be formed only when the oxygen is enough to let the further oxidation of NO to NO\textsubscript{2} (secondary pollutant); thus, high NO\textsubscript{2} emissions can be measured in urban areas only in processes involving high excess of air (low load diesel engines) or areas far from the primary sources of NO. Also, the amount of air pollutants generated has an influence on the diurnal variation. The primary factor of diurnal variation is the operational pattern of factories and usage pattern of automobiles. It is also related with the life pattern of the people. The diurnal variation of automotive traffic is maximum at morning and evening period and the concentration increases significantly when stable, low wind speed weather condition prevails.

Concentration of CO increases as the temperature and relative humidity increases (Figure 14). CO is generated by incomplete combustion of fuels, and could be possibly released from industries such as gas work, steel mill and carbonyl compounds manufacturing. The degree of atmospheric diffusion is greatly affected by the vertical variation of air temperature. The situation of temperature variation that affects the diffusion of air pollutants most is the temperature inversion layer. This is a condition where the temperature of the lower layer is below that of the upper layer. As the air pollutants are trapped in the temperature inversion layer and would not diffuse, the concentration of air pollutants is increased. The radiation inversion and the subsidence inversion are known as two major causes of the temperature inversion. Particularly, the radiation inversion which often appears in a clear night of winter season is the major factor for the generation and sustenance of a high concentration of air pollution. On the other hand, in the daytime of a fine weather, the ground is heated by sunlight to generate a thermal convection, and the vertical mixing of air is enhanced. This atmospheric layer is called the mixing layer.

The influence of the meteorological parameters on the concentration of pollutants is presented in Figures 6 to 15. Increase in vehicle count obviously increases the concentration of pollutants. Other than that the meteorological parameters play a vital role in dispersion of pollutants. As there is increase in temperature the concentration of TSPM and RPM increased (Figure 6 and 8). This is attributed to the dusts generated by the road side due to traffic movement. When the velocity of wind is more the dispersion of this road dust is quicker. At certain times the dust would prevail in the air until the speed of the wind is sufficient enough to disperse these dust particles. The concentration of SO\textsubscript{2} also increases as the temperature increases (Figure 10). Sulphur existing in crude oils as organic polymer compounds of sulphur is largely transferred to heavy oil during the oil refinery process and desulfurized by hydrogenation technique. Some sulphur will remain in heavy oil and oxidized to SO\textsubscript{2} in the flame of combustion facilities. A part of it will be oxidized to anhydrous sulphuric acid and both will enter into the exhaust gas and will be released into the atmosphere. Also, sulphur exists in coal as sulphides of iron, organic sulphur compounds or gypsum and when they burn it gets converted to SO\textsubscript{2}. Since some places in Coimbatore are industrial areas the concentration of SO\textsubscript{2} is attributed both due to traffic emission and from industries. But as the wind speed increases the concentration gets reduced due to oxidation of these pollutants (Figures 7, 9, 11,13 and 15). The weather and the chemical reaction give the largest effect on the diurnal variation of air pollutant concentration. Among the weather factors, the wind and stability have quite a large influence.

The “Prob > F” value of less than 0.05 shows significant. The adjusted R\textsuperscript{2} squared values and the F values are highly significant. Table 1 shows that the predicted models are significant.

![Figure 5](image.png)  
*Figure 5: Observed concentration of SO\textsubscript{2} and NO\textsubscript{x}*

It is observed that, the adjusted R\textsuperscript{2} squared values were very closer to the R\textsupersquared values and the F-values are highly significant. The “Prob > F” value of less than 0.05 shows that the predicted models are significant.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>R\textsupersquared</th>
<th>Adjusted R\textsupersquared</th>
<th>F Value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSPM</td>
<td>0.79</td>
<td>0.62</td>
<td>4.58</td>
<td>0.0057</td>
</tr>
<tr>
<td>RPM</td>
<td>0.86</td>
<td>0.66</td>
<td>4.44</td>
<td>0.0113</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>0.90</td>
<td>0.76</td>
<td>6.50</td>
<td>0.0026</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>0.73</td>
<td>0.63</td>
<td>2.07</td>
<td>0.0057</td>
</tr>
<tr>
<td>CO</td>
<td>0.94</td>
<td>0.86</td>
<td>11.8</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

![Table 1](image.png)  
*Table 1: Regression model statistics for Pollutants*

![Figure 6](image.png)  
*Figure 6: Response surface of TSPM for Temperature and RH*
Figure 7 Response surface of TSPM for wind data

Figure 8 Response surface of RPM for Temperature and RH

Figure 9 Response surface of RPM for wind data

Figure 10 Response surface of SO₂ for Temperature and RH

Figure 11 Response surface of SO₂ for wind data

Figure 12 Response surface of NOₓ for Temperature and RH
5. CONCLUSION
The concentrations of all pollutants recorded in commercial areas were high due to traffic congestion. Moreover parking of vehicles is not planned correctly in this area leading to traffic hindrances. In all the stations the pollutant concentrations were higher in December than that was collected in June. The air pollution concentration in Coimbatore city in the winter season was found to be higher than in the summer season due to the formation of the inversion layer leading to accumulation of pollutants as the efficiency of dispersion is reduced. During summer the radiation of sun breaks up the cloud and causes the pollutants to disperse faster resulting in lower pollution concentration.

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