A preliminary assessment of PM_{10} and TSP concentrations in Tuticorin, India

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Abstract The respirable particulate matter (RPM; PM_{10}) and total suspended particulate matter (TSP) concentrations in ambient air in Tuticorin, India, were preliminarily estimated. Statistical analyses on so-generated database were performed to infer frequency distributions and to identify dominant meteorological factor affecting the pollution levels. Both the RPM and TSP levels were well below the permissible limits set by the US Environmental Protection Agency. As expected, lognormal distribution always fit the data during the study period. However, fit with the normal was also acceptable except for very few seasons. The RPM concentrations ranged between 20.9 and 198.2 $\mu g/m^3$, while the TSP concentrations varied from 51.5 to 333.3 $\mu g/m^3$ during the study period. There was a better correlation between PM_{10-100} and TSP concentrations than that of PM_{10} (RPM) and TSP concentrations, but the correlation of RPM fraction was also acceptable. It was found that wind speed was the most important meteorological factor affecting the concentrations of the pollutants of present interest. Significant seasonal variations in the pollutant concentrations of present interest were found at 5% significance level except for TSP concentrations in the year 2006.

Keywords ANOVA · Coal-fired power station · Correlation · Frequency distribution · RPM · Seasonal variation · TSP

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Introduction

Population growth and enhancement in standards of living in developing countries like India causes strong growth in the energy demand. So, it is essential to increase the power production so as to match the demand and supply of energy. It is reported that coal- and oil-fueled power stations contribute substantially to the power production in India, and the emissions from these industries degrade the environmental media like air, water and land slowly but steadily. Particularly, the air environment is the worst affected among the environmental media, as emissions are from several processes like processing of fuel materials, transportation and combustion, and it is reported that particulate matter is one of the major pollutants emitted during combustion. In 1987, US Environmental Protection Agency (EPA) promulgated a new size-specific air quality standard, concerning the pathologies associated with particulate matter pollution. In the last few years, various studies have been carried out on atmospheric particulate matter, in the perspectives of epidemiology, and reports revealed that particulate matter was capable of causing various pathologies to the respiratory tract (Berico et al. 1997). It is essential to monitor the levels of particulate matter, which is the first step in air quality management and epidemiological analysis, and a study has recently been conducted in this connection to analyse the trends of atmospheric particulate matter in an industrial zone of Tuticorin, Tamil Nadu. A measurement campaign on particulate matter in the city was carried out from February 2005 to December 2006. In fact, this preliminary investigation included objectives like assessment of total suspended particulate matter (TSP) and PM_{10} levels during various seasons of the study period, analysis of the air

quality trends and presentation of background information on air quality standards for the city.

Materials and methods

Study area

Tuticorin is one of the industrial cities in the state of Tamil Nadu, India. As shown in Fig. 1, it is geographically located nearby the Gulf of Mannar, at a latitude of 8°48′N and a longitude of 78°11′E. The study area is Kovilpillai Nagar, which is nearby to the industrial complex (SIPCOT). It is located at a distance of about 5 km from the Tuticorin Thermal Power Station and about 6 km from the Port of Tuticorin in the southwest direction. The stacks of the

Tuticorin Thermal Power plant are equipped with electrostatic precipitator of efficiency 99.5% to control the particulate pollutants, and the SO_2 emissions are controlled through the use of low-sulphur coal (0.05%).

Sample collection and data analysis

Round the clock sampling was carried out using a commercially available respirable dust sampler (RDS; Envirotech APM 460 BL model) on a weekly basis from February 2005 to December 2006. The number of collected samples varied from two to five for a month during the study period. Simultaneous measurements of surface meteorological parameters like temperature, relative humidity, wind speed and wind direction were also carried out during the sampling hours. The particulate pollutant
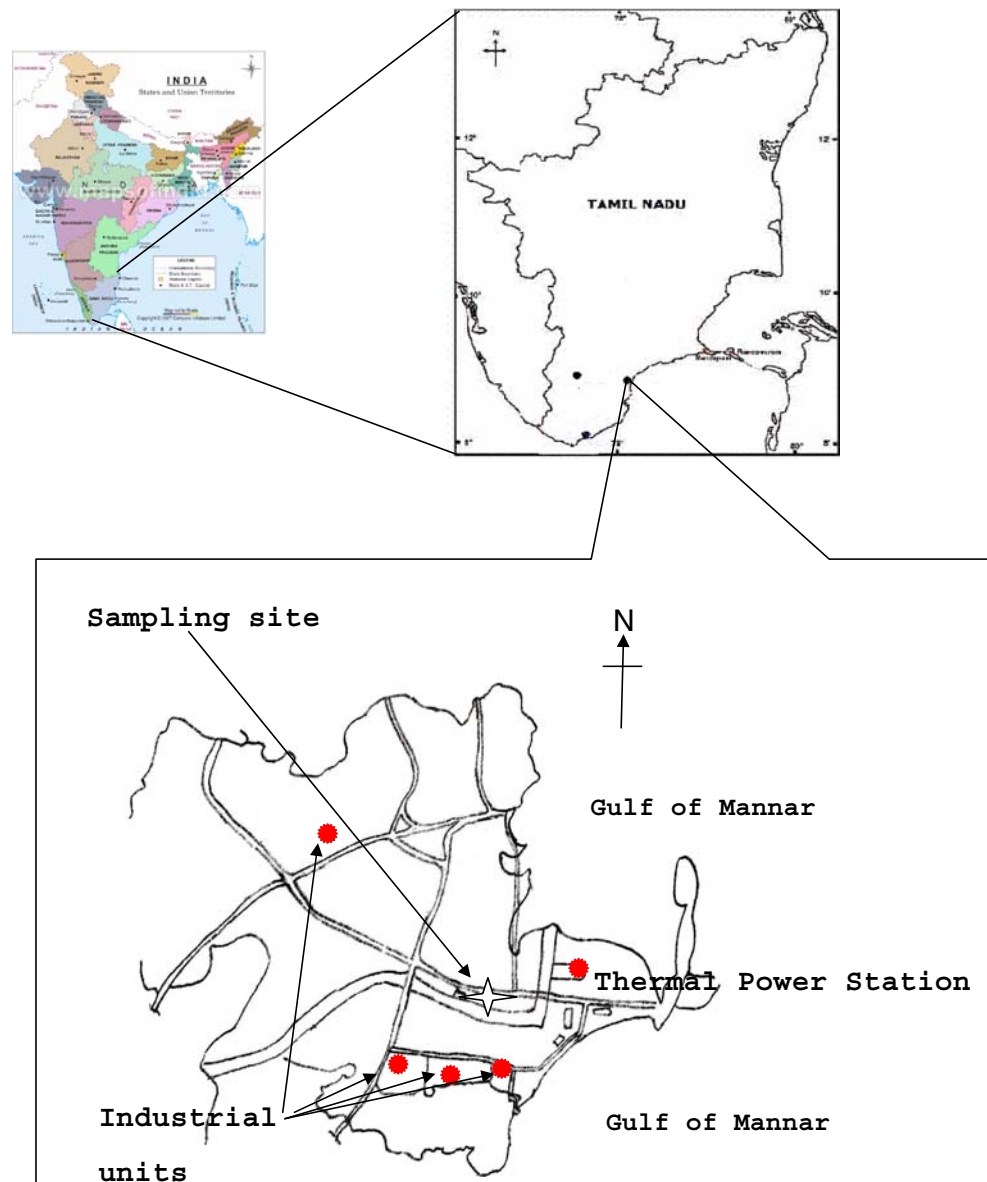
Fig. 1 Location of the study area

Table 1 Summary statistics for the respirable particulate matter and total suspended particulate matter concentrations at Tuticorin, India

Season	RPM				TSP			
	Mean	SD	Skewness	Kurtosis	Mean	SD	Skewness	Kurtosis
Post-monsoon 2005	39.6	17.1	0.3	−1.4	83.4	8.9	−1.1	2.3
Summer	65.3	47.9	2.2	5.5	157.1	87.9	0.8	−0.2
Pre-monsoon	52.1	15.4	0.9	0.8	130.4	48.1	1.6	2.4
Monsoon	41.3	9.9	1.5	3.0	120.4	24.9	−0.03	−1.3
Post-monsoon 2006	52.6	26.9	1.5	2.6	104.5	44.6	1.6	2.9
Summer	54.3	14.3	0.7	−0.6	146.6	28.4	0.8	2.7
Pre-monsoon	49.3	14.2	0.6	−1.2	125.4	31.5	0.7	−0.4
Monsoon	54.2	22.8	0.6	−0.8	127.9	36.4	−0.3	0.4

Mean, SD are given in $\mu g/m^3$

concentrations were estimated by adopting gravimetric method subsequently.

In the gravimetric method of determination of particulate pollutants, measured volume of air could be drawn into the covered housing of RDS. Usually, the air was drawn at a flow rate of 1.1 to 1.4 m^3 per minute. The air inside the sampler passed through a combination of cyclone separator and filter in two stages. At the first stage, the cyclone separator was used to collect the bigger particles (particles in the size range of 10 to 100 μm). The rest of the particulates in the size range of 0.1 to 10 μm were collected over a previously dried and weighed glass micro fibre filters (Whatman GF/A). Thus, the collection inside the container attached with the cyclone separator could give the mass of PM_{10-100}, and the collection over the filter paper could represent the mass of PM_{10} (respirable particulate matter (RPM)). Though the glass micro fibre filters had less affinity towards moisture absorption, samples collected on filter papers were not ordinarily weighed. The loaded and unloaded filters were weighed after conditioning them in desiccators for 48 h at 25°C and constant humidity of about 50% for the gravimetric determination of the RPM concentrations. Finally, the TSP concentration was calculated by summing the PM_{10} and PM_{10-100} concentrations.

The generated database on the pollutant concentrations was analysed for frequency and normality of distribution.

The Shapiro–Wilk W test was used to investigate the data normality. According to this test, the test statistic represented the maximum cumulative distance between the histogram of measured data and Gaussian distribution curve of data. The acceptable level of significance was set to be 0.05, assuming no significant discrepancy at the 5% significance level between the estimated and predicted distributions of pollutants. The same procedure was used to investigate the lognormal distribution. The data analysis also included an examination of the relationship between pollution levels and meteorological variables using multiple regression analysis.

In addition, one-way analysis of variance (ANOVA) was performed so as to analyse the seasonal variability of the pollutant concentrations. The results of ANOVA presented the degree of variability in the sample data of present interest. In fact, the variances (σ^2) of more than two populations were compared in ANOVA to determine the equality of means. This could be accomplished by the use of a distribution called the F distribution. The F test is the ratio of the variance explained to the error or unexplained variance. The F test was performed against the null hypothesis, which has been given below:

$$H0 : \mu_1 = \mu_2 = \ldots = \mu_i$$

$$H1 : \text{not all } \mu \text{ are equal}$$

Table 2 Meteorological conditions measured at Tuticorin

Season	Mean temperature (°C)	Average wind speed (m/s)	Predominant wind direction	Average relative humidity (%)
Post-monsoon 2005	28.5	3.8	NE	73.0
Summer	27.7	4.2	SW	72.7
Pre-monsoon	29.9	2.8	SW	62.7
Monsoon	28.0	2.3	NE	76.3
Post-monsoon 2006	28.1	4.1	NE	76.1
Summer	31.1	4.2	SW	74.3
Pre-monsoon	29.7	4.0	SW	75.3
Monsoon	28.3	3.8	NE	75.0

It was initially assumed in the null hypothesis (H0) that there were no significant differences in the means of different population. If the calculated value of F was found to be smaller than the table value of F at 5% level of significance, then the null hypothesis would be accepted. Otherwise, the alternate hypothesis (H1) would be accepted.

Results and discussion

A total of 88 samples of PM_{10} and PM_{10-100} were collected by using high volume RDS. The statistical results for the pollutant concentrations for different seasons of the study period have been presented in Table 1. The seasons of the year were classified as Post-monsoon (January to March), Summer (April to June), Pre-monsoon (July to September) and Monsoon (October to December) seasons, and the average meteorological conditions for different seasons of the study period have been presented in Table 2. The variation of the average monthly RPM and TSP levels in the years 2005 and 2006 has been presented in Figs. 2 and 3, respectively. The observed minimum RPM concentration was 20.9 μg/m³ recorded in February, and maximum was 198.2 μg/m³ encountered in June in the year 2005, but in the year 2006, the minimum concentration of 21.8 μg/m³ and maximum of 115.1 μg/m³ were recorded in February. The annual average was calculated to be 51.2 μg/m³ in the year 2005 and 52.6 μg/m³ in the year 2006. As expected, lognormal distribution could always fit the data for all the seasons in both the years 2005 and 2006. However, fit with the normal distribution was also acceptable except in the summer season of the year 2005 (Table 3). In summer season of the year 2005, the FD was more peaked (kurtosis higher) and asymmetric (skewness, >0), tailed on to the right (Table 1).

In the year 2005, the minimum TSP concentration observed was 56.5 μg/m³ recorded in April, and maximum was 333.3 μg/m³ recorded in June, but in the year 2006, a
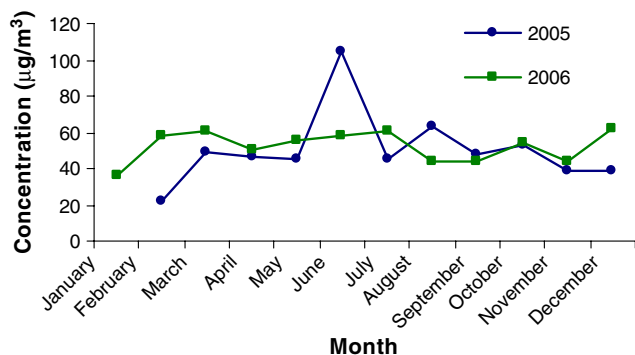
Fig. 3 Variation of monthly average total suspended particulate matter concentrations in the years 2005 and 2006

minimum concentration of 51.5 μg/m³ was recorded in November, and maximum of 214.9 μg/m³ was recorded in May. The annual averages of this pollutant were calculated, which were 128.6 and 127.1 μg/m³ in 2005 and 2006, respectively. It was noticed that lognormal distribution fit for the data in all the seasons for TSP also. However, the normal distribution also fit the data for all the seasons except pre-monsoon period of the year 2005 (Table 4).

The particulates are directly emitted into the atmosphere through natural and manmade (anthropogenic) processes including transportation, fuel combustion in stationary sources, industrial processes, land cleaning, wild fires and solid waste disposal (Vakeva et al. 1999; Mazzera et al. 2001; Querol et al. 2001; Viana et al. 2006; Adachi and Tainosho 2004). In urban conditions, small aerosol particles are mostly emitted from combustion processes, i.e. car engines and industry. However, the high concentration of gaseous pollutants and atmospheric chemistry (including photochemistry) are able to produce sufficient amount of condensable gases for gas to particle conversion. Urban aerosols have a higher proportion of vehicular (and possibly industrial) emissions, which are in very fine size range. The larger particles correspond to the effects of human activities including road dust raised by vehicular motion, building activities and industrial emissions (Clarke et al. 1999). From the particle formation studies, it could be assumed that the majority of the submicron particles were primary emissions from traffic, or at least particles were formed very close to the sources (car engines) of precursor gases (Vakeva et al. 1999).

The sampling station was situated of about 5 km from the coal-fired Tuticorin thermal power station of 1,050 MW power-generating capacity, comprising a stack of 220 m height and two stacks of 120 m height each. The sampling site was also situated near the Tuticorin port and in the national highway. A large number of vehicles were operated daily in connection with the port activities in this region. The industrial source strength including the thermal power station in around the study area was obtained from
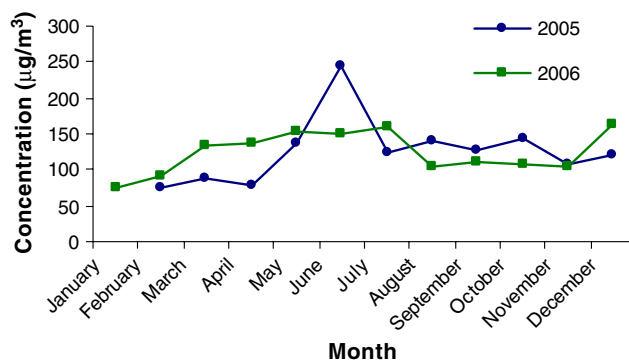
Fig. 2 Variation of monthly average respirable particulate matter concentrations in the years 2005 and 2006

Table 3 Normality test results for respirable particulate matter concentrations

Season	Number of Samples	Normal		Lognormal		5% critical value
		Test statistic	Result	Test statistic	Result	
Post-monsoon 2005	6	0.932	Passed	0.916	Passed	0.788
Summer	12	0.711	Failed	0.862	Passed	0.859
Pre-monsoon	12	0.914	Passed	0.958	Passed	0.859
Monsoon	11	0.878	Passed	0.946	Passed	0.850
Post-monsoon 2006	10	0.87	Passed	0.969	Passed	0.842
Summer	12	0.871	Passed	0.895	Passed	0.859
Pre-monsoon	12	0.865	Passed	0.893	Passed	0.859
Monsoon	13	0.901	Passed	0.920	Passed	0.866

state pollution control board, Tuticorin, and the vehicular source strength was estimated by conducting traffic survey during the period of investigation. The sulphur content of the coal was found to be 0.05%. The coal composition was estimated, and it had 29.99% of fixed carbon, 6.16% of moisture content and 19.66% of volatile matter. The calorific value of the coal was estimated to be 33.6%. Most of the suspended particulate matter was emitted through the tallest stack at a rate of 484.2 g/s, and the remaining quantity was emitted through the smaller stacks at an emission rate of 208.3 and 253.61 g/s. On the basis of the so-obtained source strengths, it was found that the emissions from the thermal power station might be a main possible potential source for the recorded concentrations during the study period. The emissions from the other industrial units and automobiles might have also been contributed to the recorded concentrations.

Seasonal variation

While the seasonal averages of the pollutant concentrations have been presented in Table 1, the variation of RPM and TSP concentrations have been presented in Figs. 4 and 5. The RPM concentrations ranged between 20.9 and 63.4, between 31.9 and 198.2, between 29.4 and 85.4 and between 29.4 and 65.4 $\mu g/m^3$ during the post-monsoon, summer, pre-monsoon and monsoon periods of the year 2005, respectively, but in the year 2006, the concentrations varied from 21.8 to 115.1, from 39.6 to 79.5, from 34.2 to 71.4 and from 29.5 to 98.7 $\mu g/m^3$, respectively. The recorded TSP concentrations ranged between 67.6 and 94.4, between 56.5 and 333.3, between 77.4 and 247.2 and between 82.1 and 154.6 $\mu g/m^3$ during the post-monsoon, summer, pre-monsoon and monsoon periods, respectively, in the year 2005, but the variation of the concentrations was from 56.5 to 209.4, from 100.1 to 214.9, from 90.8 to 185.5 and from 51.5 to 190.9 $\mu g/m^3$, respectively, in the year 2006.

One-way ANOVA was used so as to test significant variation in the pollutant concentrations, if any, among these different seasons, and the results have been given in Table 5. From the results, it was observed that significant seasonal variations at 5% significant level were found in the RPM concentrations during the study period. The same trend of significant seasonal variations was also found for

Table 4 Normality test results for total suspended particulate matter concentrations

| Season	Number of Samples	Normal		Lognormal		5% critical value
		Test statistic	Result	Test statistic	Result	
Post-monsoon 2005	6	0.909	Passed	0.882	Passed	0.788
Summer	12	0.925	Passed	0.968	Passed	0.859
Pre-monsoon	12	0.830	Failed	0.920	Passed	0.859
Monsoon	11	0.947	Passed	0.946	Passed	0.850
Post-monsoon 2006	10	0.853	Passed	0.951	Passed	0.842
Summer	12	0.902	Passed	0.929	Passed	0.859
Pre-monsoon	12	0.913	Passed	0.931	Passed	0.859
Monsoon	13	0.976	Passed	0.896	Passed	0.866
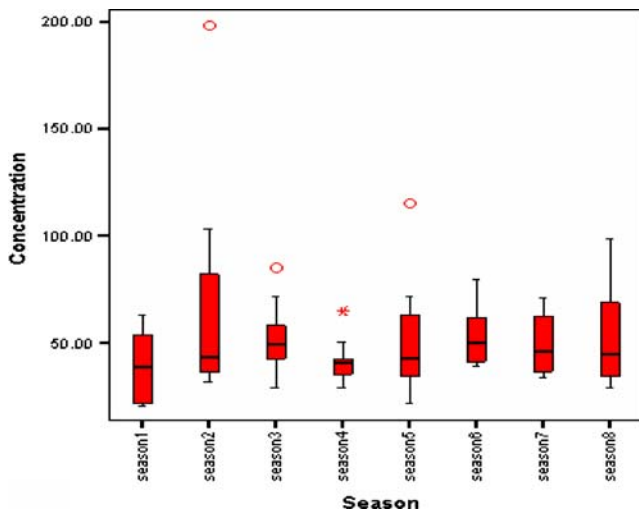
Fig. 4 Seasonal variation of respirable particulate matter concentrations during the study period

TSP concentrations in the year 2005, but there were no significant seasonal variations found in the TSP concentrations in the year 2006.

The ANOVA test was performed between the years 2005 and 2006 also for both the pollutant concentrations of present interest. While the F value was found to be 0.07 ($P<0.05$) for the RPM concentrations, the same was 0.02 ($P<0.05$) for the TSP concentrations. From these results, it was interesting to note that there were no significant variations between the concentrations in the years 2005 and 2006 at 5% confidence level.
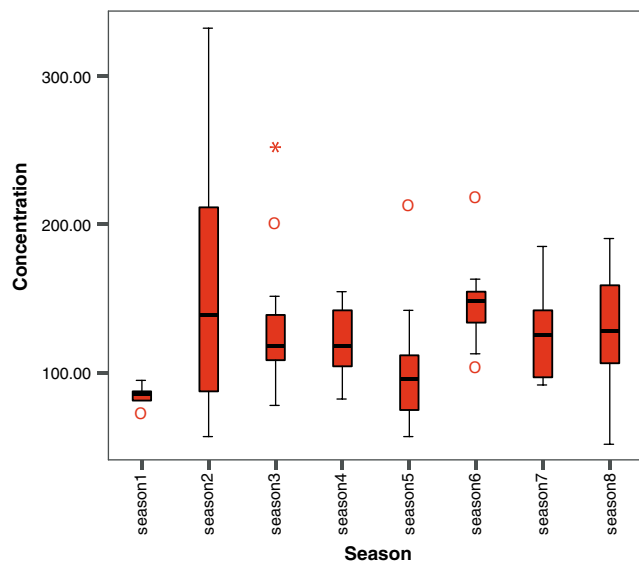

Fig. 5 Seasonal variation of total suspended particulate matter concentrations during the study period. *Upper and lower whiskers* correspond to tenth and 90th percentiles. *Thick line inside the box* represents the median value. *Asterisk* represents the extremes, and *o* represents the outliers. Seasons 1 and 5, post-monsoon; 2 and 6, summer; 3 and 7, pre-monsoon; 4 and 8, monsoon

Table 5 Analysis of variance results for the seasonal variability of the pollutant concentrations

Pollutant	Year 2005		Year 2006	
	F value	p value	F value	p value
RPM	1.74	>0.05	0.17	>0.05
TSP	2.15	>0.05	3.10	<0.05

Average monthly concentrations of RPM and TSP were almost the same in all the months except the month of June 2005, which showed marked peaks in the concentrations. It was found that the source strength was almost constant throughout the study period of the present investigation. So, the recorded highest concentration in the month of June may mainly be correlated with the prevailed meteorological conditions especially with wind speed, relative humidity and rainfall.

It was observed from the meteorological data that the levels of wind speed were appreciably high in the month of June 2005. This would have caused higher wind turbulences in that month, which in turn might have caused more wind-blown dust in the atmosphere due to dusty nature of the land surface around the station. It was noted that the humidity levels were low, which might have caused lower rate of particulate coagulation which in turn would have resulted in poor gravitational settling.

The rainfall might also be correlated with the recorded levels of the pollutants during the specific period. In fact, lowest rainfall (0.7 mm) was recorded in this month for the year 2005, and this might have resulted in less scavenging of particulates due to precipitation.

As far as RPM was concerned, higher concentrations were observed in the summer seasons. In summer, the weather conditions were usually associated with the high temperatures and long hours of intense sunlight. This would have resulted in the occurrence of photochemical reactions (Garnett 1979), thereby supporting the conversion of NOx into nitrates and SO_2 into sulphates. The pollutants produced in this way could combine with the already persisting particulates in the atmosphere and could have caused the increment in the concentration in summer seasons. The TSP concentrations were relatively lower in the post-monsoon seasons. This was due to the fact that in the post-monsoon season, higher relative humidity prevailed in the atmosphere which could make the particulate to coagulate and to become heavier thereby helping in quick settling. Besides, sufficient moisture content on roads could reduce the airborne dust due to the wind turbulences. Relatively higher TSP concentrations were observed in the summer seasons of the study period. This could be attributed to the higher wind turbulences observed in these seasons. The RPM and TSP concentrations were low in the

northeast monsoon season than in the southwest monsoon season. It is to be noted that in Indian subcontinent, monsoon is categorised as summer monsoon (from June to September) and winter monsoon (from October to December). The summer monsoon is also referred to as southwest monsoon as winds are predominant in SW direction during this period, is intense and rainfall occurs throughout India; whereas winter monsoon is also referred to as NE monsoon, rainfall occurs in Tamil Nadu (where this study has been made) and some parts of NE India, where it is winter in the rest of India. In Tamil Nadu, NE monsoon is predominant, and majorities of precipitation is experienced over the SW monsoon. Actually, in the year 2005, the cumulative rainfall recorded during the SW monsoon season was 48.4 mm in the study area, whereas the total rainfall in the NE monsoon period was 453.6 mm (almost ten times the SW monsoon rainfall). This was mainly because of the topographical location of this state. In particular, the study area was located at the eastern coastal line, and the SW monsoon became almost dry while reaching this part of the country due to the presence of western ghats in the Tamil Nadu-Kerala border. So, higher precipitation scavenging was possible in the NE monsoon season than in the SW monsoon season in the study area.

Role of meteorology

Generally, the changes in the meteorological conditions cause more variations in air pollutant concentrations than changes in pollutant emissions over a monthly or seasonal period (Chang and Lee 2007). So, to examine the possible relationships between the pollutant concentrations and various meteorological parameters, stepwise multiple regression analysis was performed between the pollutant concentrations of current concern (as dependent variables) and the meteorological parameters (as independent variables). The major meteorological parameters of influence included the temperature, wind speed and relative humidity. The results of the multiple regression analysis have been given in Table 6. The R^2 values, which value represents the fraction of the variance in the air pollution levels due to variability of the correlated meteorological parameters, were

Table 6 Multiple regression analysis results for the pollutant concentrations

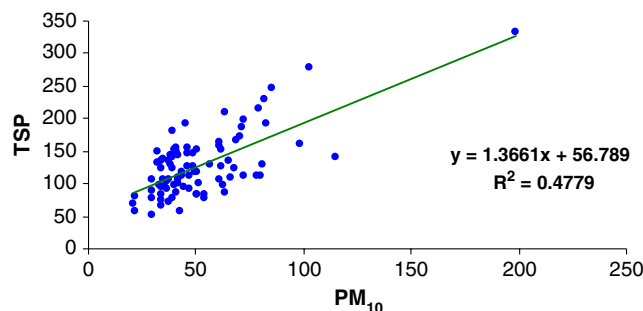| Parameter	Regression coefficient	
	RPM	TSP
Temperature	0.4	−0.8
Wind speed	−0.7	−4.4
Relative humidity	−0.6	0.3

Fig. 6 Correlation between PM_{10} and total suspended particulate matter concentrations

obtained to be 0.61 and 0.76 for the RPM and TSP concentrations, respectively. The regression coefficients suggested an inverse relation between wind speed and particulate concentrations. This indicated that higher wind speed favoured better dispersion and consequently lowered the particulate concentrations. Wind direction which was not included in the regression analysis also played an important role in determining the pollutant concentrations. Predominant wind direction was in SW direction during summer and pre-monsoon seasons, whereas NE was the predominant wind direction in the monsoon and post-monsoon seasons. It was observed that the particulate concentrations were high in strong SW and low NE winds, whereas the concentrations were low in strong NE and low SW winds. This suggested the predominance of the local sources existing in the study area. The study of Shrestha et al. (2000) also showed that the ambient concentrations of particulate matter and its chemical components could strongly be influenced by the wind dynamics in a study area. The positive relationship between RPM and temperature could be attributed to the photochemical production of particulates.

Correlation of TSP with PM_{10} and $PM_{10–100}$

Correlation between the TSP concentration with PM_{10} and $PM_{10–100}$ concentrations have been displayed, respectively, in Figs. 6 and 7. $PM_{10–100}$ correlated clearly with TSP
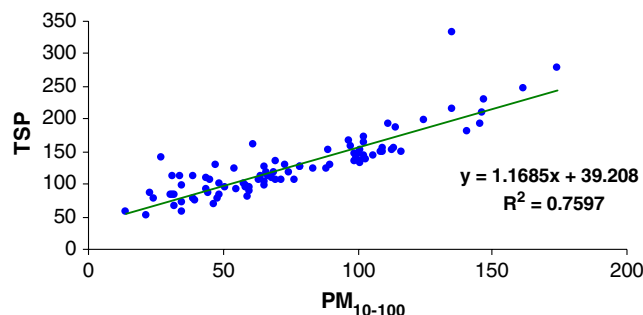

Fig. 7 Correlation between $PM_{10–100}$ and total suspended particulate matter concentrations

concentration ($TSP = 1.17\ PM_{10-100} + 39.2$, $r^2 = 0.76$). The correlation of PM_{10} fraction with TSP was not as good as PM_{10-100} ($TSP = 1.36\ PM_{10} + 56.8$, $r^2 = 0.48$), but it was acceptable. The correlation of TSP with PM_{10} and PM_{10-100} were calculated for the other three places in Tuticorin city (data obtained from central pollution control board, India), and the r^2 values were obtained to be 0.41 and 0.68, 0.38 and 0.73 and 0.52 and 0.8, respectively. It was reported earlier that the r^2 of 0.69 for the relation of PM_{10} and TSP in the ambient air of Mumbai, India (Gupta et al. 2004), and this value could be comparable with the values obtained in the present study.

The mass concentration of particulates in the ambient air of the study area was compared with the different sites in Tuticorin. The average mass concentration of RPM was calculated to be 51.9 μg/m^3 at the study area, whereas it was obtained as 74.3, 69.0 and 39.0 μg/m^3 at site 1 (an industrial area), site 2 (residential and others) and site 3 (residential and others), respectively. Similarly, the average mass concentration of TSP was calculated to be 127.8 μg/m^3 at the study area, whereas it was found to be 174.0, 166.0 and 88.4 μg/m^3 at site 1, site 2 and site 3, respectively. The overall levels of PM_{10} were, in general, lower in site 3, than in site 1 and site 2. The higher correlation of PM_{10-100} with TSP showed that this fraction made up a large portion of TSP concentration in the ambient air of the study area.

Conclusions

The present study has provided a preliminary assessment of RPM and TSP concentrations and its frequency distributions in Tuticorin for the first time. The seasonal RPM and TSP concentrations showed a well-defined variation and were relatively lower in the post-monsoon seasons and higher in the summer seasons. The multiple regression analysis confirmed that wind speed was the most important meteorological parameter affecting the particulate pollutant concentrations during the study period. The ANOVA results showed that there were significant variations at 5% critical level in the pollutant concentrations of present interest with respect to different seasons during the study period except for the TSP concentrations in the year 2006. PM_{10-100} correlated clearly with the TSP concentrations during the study period. The correlation of PM_{10} with TSP was not as good as PM_{10-100}; however, it was acceptable. The

correlation results showed that PM_{10-100} fraction made up a large portion of TSP concentration in the ambient air of the study area during the study period. Though all the recorded values were well below the permissible limits set by US EPA as well as Central Pollution Control Board, India, regular monitoring of the pollutants of current concern would be mandatory for the pollution abatement purposes.

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