Ref NO-2

Clean 2008, *36* (1), 111 – 117

S. C. Barman[1]
Ramesh Singh[1]
M. P. S. Negi[2]
S. K. Bhargava[1]

[1]Environmental Monitoring Section, Industrial Toxicology Research Centre, Lucknow, India.

[2]Biometry & Statistics Division, Central Drug Research Institute, Lucknow, India.

Research Article

Fine Particles ($PM_{2.5}$) in Residential Areas of Lucknow City and Factors Influencing the Concentration

Urban populations are exposed to a high level of fine and ultrafine particles from motor vehicle emissions which affect human health. To assess the hourly variation of fine particle ($PM_{2.5}$) concentration and the influence of temperature and relative humidity (RH) on the ambient air of Lucknow city, monitoring of $PM_{2.5}$ along with temperature and RH was carried out at two residential locations, namely Vikas Nagar and Alambagh, during November 2005. The 24 h mean $PM_{2.5}$ concentration at Alambagh was 131.74 $\mu g/m^3$ and showed an increase of 13.74%, which was significantly higher ($p < 0.05$) than the Vikas Nagar level. The 24 h mean $PM_{2.5}$ on weekdays for both locations was found to be 142.74 $\mu g/m^3$ (an increase of 66.23%) which was significantly higher ($p < 0.01$) than the weekend value, indicating that vehicular pollution is one of the important sources of $PM_{2.5}$. The mean $PM_{2.5}$ at night for all the monitoring days was 157.69 $\mu g/m^3$ and was significantly higher ($p < 0.01$) than the daytime concentration (89.87 $\mu g/m^3$). Correlation and multiple regressions showed that the independent variables, i.e., time, temperature, and RH together accounted for 54%, whereas RH alone accounted for 53% of total variations of $PM_{2.5}$, suggesting that RH is the best influencing variable to predict the $PM_{2.5}$ concentration in the urban area of Lucknow city. The 24 h mean $PM_{2.5}$ for all the monitoring days was found to be higher than the NAAQS recommended by the US-EPA (65 $\mu g/m^3$) and can be considered to be an alarming indicator of adverse health effects for city dwellers.

Keywords: Air Pollution; Fine Particles; $PM_{2.5}$; Relative Humidity; Temperature

Received: May 10, 2007; *revised:* September 20, 2007; *accepted:* September 24, 2007

DOI: 10.1002/clen.200700047

1 Introduction

Atmospheric particles play important roles in a wide range of fields, including epidemiological, visibility degradation, and global climate change, owing to their optical properties. Epidemiological studies have indicated statistical associations between human health effects and ambient concentrations of particulate matter (PM), particularly of finer particles, which can penetrate into the lungs and are therefore more likely to increase the incidence of respiratory and mutagenic diseases [1, 2, 3]. On the basis of epidemiological studies, [4, 5] reported that, an increase of 10 $\mu g/m^3$ $PM_{2.5}$ (as annual average) was associated with a relative risk for total mortality of 1.14 and 1.07, respectively. It was also reported that both short and long term exposures to PM_{10} and $PM_{2.5}$ are associated with an increase in mortality, especially in case of elderly adults with cardiopulmonary illness [6].

A variety of sources release fine particles into the atmosphere, including automobiles, heavy-duty trucks, wood burning, and food cooking. In general, the major source of fine particles in any urban area is automobile pollution. It is also released by tailpipe emission or burning of gasoline or diesel and depends on the extent of friction between the road and tires and the resuspension of street dust etc. $PM_{2.5}$ can also form in the atmosphere through chemical reactions that convert gaseous pollutants into a particle phase. The overall concentration, composition and the particle size of suspended particulate matter at a given site are determined by factors such as the meteorological properties of the atmosphere, topographical influence, emission sources, and by particle parameters such as density, shape and hygroscopy [7 – 11].

Historically, studies of atmospheric particulate matter have focused on annual and monthly average and seasonal trends in concentrations and chemical compositions. Recently, however, there has been a recognition that observations of daily differences in pollutant concentrations can help to elucidate the impacts of various sources of emissions and photochemical transformations on atmospheric pollutant concentrations [12, 13]. In this paper, we have emphasized the hourly trend, which is not only directly related to human activity patterns but also removes the biasness of the conventional practice of averaging results over a month or a year, which obscures peak concentrations, the concentrations at which people are exposed to the maximum levels. From a health perspective, and for mitigative purposes, it is necessary to know the peak concentration hours of the day.

Keeping in view the above and the lack of literature data for $PM_{2.5}$ for this historic city, continuous 24 h monitoring was carried out at

Correspondence: S. C. Barman, Environmental Monitoring Section, Industrial Toxicology Research Centre, M. G. Marg, Lucknow-226001, India.
E-mail: scbarman@yahoo.com

two representative residential areas, namely Vikas Nagar and Alambagh (approx. 12 km apart) of Lucknow city to see the hourly as well as 24 h average concentration of $PM_{2.5}$ at receptor level heights (approximately 2 m above the ground level). The selection of these two locations was based on our earlier study on PM_{10} at 10 different locations in the urban area of Lucknow city during the summer season of 2005 [14]. The average concentration of PM_{10} was found to be in the range of 107.6 to 214 µg/m³ with the Vikas Nagar level at 166.5 µg/m³ and the Alambagh level at 140.3 µg/m³. The total average concentration of 11 metals associated with PM_{10} were found to be in the range of 169.57 to 423.98 ng/m³ with Vikas Nagar being 179.00 ng/m³ and Alambagh was 253.79 ng/m³ [14] whereas the 24 h average concentration of $PM_{2.5}$ at Vikas Nagar and Alambagh were found to be 35.5 and 57.0 µg/m³, respectively [15]. This study focused on the hourly variation of fine particles and influence of temperature and relative humidity (RH) on the concentration of fine particles in ambient air.

2 Materials and Methods

Lucknow is the capital of Uttar Pradesh, situated in Northern India with a population of 2.245 million (2001 census), and lies between 26° 52′ N latitude and 80° 5′ E longitude at 128 m above sea level. Vehicular traffic is one of the main sources of atmospheric particulate matter in Lucknow city [14] like other cities in India [16, 17], and the total vehicular population was 0.749 million on March 31st 2005, with growth rate of 10.38% over the previous year.

The two residential locations selected, Vikas Nagar and Alambagh, are situated at trans (northern site) and cis (southern site) Gomti areas of the city, respectively. The Gomti river divides the city into cis and trans areas. The cis area is a mixed area consisting of commercial activities and residential areas whereas the trans area is mostly a residential area. The monitoring locations were selected on the basis of surrounding activities and an earlier study, and the monitoring instruments were placed at suitable representative places as per the Bureau of Indian Standard [18].

The major sources of air pollution at both locations are vehicular emission, mainly dominated by two wheelers, passenger cars and public transport (three wheeler and buses). The main road (public transport routes) of Vikas Nagar and Alambagh is 400 and 500 m away from the monitoring locations respectively. Comparatively, public transport as well as other traffic volume is higher in the Alambagh area than in Vikas Nagar. In our earlier separate study [19], we observed vehicular traffic numbers for 30 minutes during day and night times, and the result was 612 and 95 at Vikas Nagar, and 982 and 495 at Alambagh, respectively. During daytime, about 80% vehicles were petrol driven whereas during night time about 52% vehicles were diesel driven. During night hours, trucks and long distance buses are the main sources of pollution. There are no point emission sources of air pollutants in the nearby area and all of the major sources are mobile.

A battery-operated analyzer, Haz-Dust Environmental Particulate Air Monitor model EPAM-5000, from Environmental Devices Corporation, USA, was used. It is a real-time monitor of particulate matter with a high sensitivity (1 µg/m³ to 2000 µg/m³) designed for ambient and indoor environments. The functional features are calibrated to NIOSH methods for lung damaging particles, filter sampling for gravimetric analysis, internal air sampling pump, auto purging sensor, inter changeable size selective samples inlets, measuring particle size range 0.1 to 100 µm, precision ±3 µg/m³.

The analyzer is based on infrared light scattering detected by a photodetector. The scattering intensity is proportional to the aerosol concentration. The infrared analyzer recorded the one-minute data with a flow rate of 4 L/min. Thus the hourly average values consisted of an average of 50–60 values per hour and the monitoring was carried out according to the user's guide [20].

The monitoring was conducted on the 10th (Thursday – day 10), 13th (Sunday – day 13), 16th (Wednesday – day 16) at Vikas Nagar and 6th (Sunday – day 6), 7th (Monday – day 7) and 19th (Saturday – day 19) at Alambagh, in November 2005 (post monsoon). During monitoring of $PM_{2.5}$, two data points (every 30 minutes) per hour of temperature and RH was also recorded in ambient air with a portable digital hygro thermometer manufactured by Chung Instrument Electronics, South Korea, for measurement of indoor and outdoor temperature and humidity. The instrumental measuring range was −10 to +50°C with 0.1°C resolution for temperature, and 10 to 99% with 1% resolution for humidity. The instrument is battery operated with an LCD display. The two hourly data points of temperature and RH were also averaged. The hourly averaged data of $PM_{2.5}$ (µg/m³), temperature (°C), and RH (%) of all the monitoring days were submitted for statistical analysis.

2.1 Statistical Analysis

Between days, 24 h mean of temperature, RH and $PM_{2.5}$ were compared separately by one-way analysis of variance (ANOVA) and the significance of ANOVA was calculated with the Newman Keuls post hoc test. Comparison of the mean between locations, weekend and weekdays, and day and night were compared by Student's *t* test. Considering $PM_{2.5}$ as the dependent variable, and time, temperature and RH the independent variables, simple linear and multiple regression analysis based on the method of least squares were calculated to determine the best predictor variable. In addition, simple correlation coefficients were also calculated between the investigated variables. Before analyzing the data statistically, all the hourly data of investigated variables, including time, was transformed by $\log_{10}$ transformation, which made the data more homogeneous. All the statistical analysis was done on the transformed data. Interpretation and graphical representation was done on actual data, except regression, which is in $\log_{10}$.

3 Results and Discussion

3.1 Hourly Trend and Variations between Days

Temperature (°C), relative humidity (%), and $PM_{2.5}$ concentrations (µg/m³) of all the observed days are summarized in Tab. 1. Hourly variations of these three variables for all the days seem to be similar (Figs. 1, 2, and 3). As the day progresses, temperature increases from morning hours to mid day and after reaching a maximum at around 2 PM, decreases gradually until the next morning. RH and $PM_{2.5}$ follow the same trend but in an opposite direction vis a vis temperature. In other words, when the temperature increases, both RH and $PM_{2.5}$ decrease and vice versa. This relationship indicates that RH and $PM_{2.5}$ are inversely proportional to temperature, whereas $PM_{2.5}$ is directly proportional to RH. The hourly concentration of $PM_{2.5}$ is an S-shaped (sigmoidal) curve.

The daily hourly variation for $PM_{2.5}$ showed similar trends on all the monitoring days at both the locations, i.e., decline in the con-

Table 1. Summary statistics ($n = 24$) of temperature (°C), relative humidity (%) and $PM_{2.5}$ (μg/m³) for all observed days.

Statistic	Vikas Nagar									Alambagh								
	Day 10 – Thursday			Day 13 – Sunday			Day 16 – Wednesday			Day 6 – Sunday			Day 7 – Monday			Day 19-Saturday		
	T	RH	$PM_{2.5}$	T	RH	$PM_{2.5}$	T	RH	$PM_{2.5}$	T	RH	$PM_{2.5}$	T	RH	$PM_{2.5}$	T	RH	$PM_{2.5}$
Mean ± SD	24.28 ±4.20	56.85 ±9.43	183.37 ±56.86	24.14 ±5.36	55.22 ±10.91	75.85 ±19.52	22.88 ±4.94	55.52 ± 11.80	88.26 ±32.64	25.94 ±2.84	51.25 ±9.59	95.89 ±30.26	25.72 ±2.83	52.40 ±10.52	125.24 ±49.50	21.15 ±5.31	60.90 ±16.23	174.09 ±77.38
Cov(%)	17.31	16.59	31.01	22.19	19.75	25.74	21.60	21.25	36.98	10.96	18.71	31.56	11.02	20.08	39.53	25.13	26.65	44.45
Min	16.10	41.00	89.20	15.10	39.60	35.80	15.10	37.80	31.10	21.60	35.40	51.70	21.10	36.20	51.30	13.80	38.40	51.80
Max	29.30	71.80	250.60	31.80	70.80	115.00	30.50	72.10	152.60	30.10	65.20	151.80	29.90	67.00	205.90	30.20	82.40	291.30
Range	13.20	30.80	161.40	16.70	31.20	79.20	15.40	34.30	121.50	8.50	29.80	100.10	8.80	30.80	154.60	16.40	44.00	239.50

T = Temperature, RH = Relative humidity

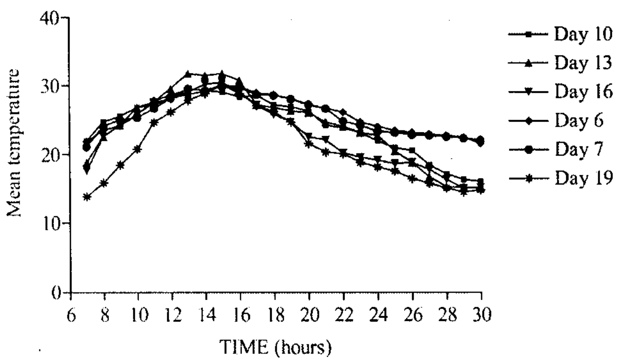

Figure 1. Hourly variation in temperature (°C) during different days.

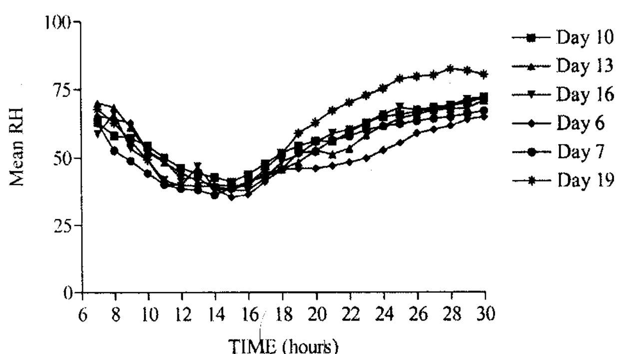

Figure 2. Hourly variations in RH (%) during different days.

centrations towards noon and increase in the concentration in the afternoon hours. A similar trend was also observed by others [21, 11]. This variation is probably due to a dilution process, as well as the thickening of urban boundary layers or a decrease in the atmospheric stability and increase in the vertical mixing height. Furthermore, higher concentrations during the night hours is due to the concentration process caused by the thinning of the mixing layer [22, 23, 11].

On comparing 24 h means between days, the temperature of day 19 significantly ($p < 0.05$) differed and was lower than that of days 6, 7, 10, and 16, whereas no significant ($p > 0.05$) difference were observed in the case of RH, which remained more or less the same during the study period, and the mean $PM_{2.5}$ of day 6, 13, 16 and of 10 and 19 also did not differ significantly ($p > 0.05$). The rest of the combinations for temperature and $PM_{2.5}$ were found statistically to

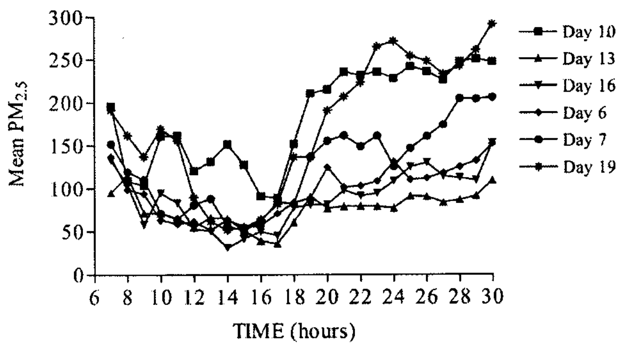

Figure 3. Hourly variation in $PM_{2.5}$ concentrations (μg m⁻³) during different days.

be the same ($p > 0.05$) and different ($p < 0.05$), respectively (see Tab. 2).

3.2 Variations between Locations, Weekend & Weekdays, and Day & Night

$PM_{2.5}$ data for locations, weekend and weekdays, and day and night are summarized in Tab. 3 and shown graphically by Figs. 4–6. $PM_{2.5}$ at Alambagh ranged by 240.00 μg/m³ (51.30–291.30 μg/m³) with an average of 131.74 μg/m³, and at Vikas Nagar ranged by 219.50 μg/m³ (31.10–250.60 μg/m³) with an average of 115.83 μg/m³. The 24 h mean concentration of $PM_{2.5}$ at Alambagh was found to be significantly higher, 13.74% (1.14 times) than at Vikas Nagar ($p < 0.05$).

During weekdays, the $PM_{2.5}$ concentration at both the locations ranged by 260.20 μg/m³ (31.10–291.30 μg/m³) with an average of 142.74 μg/m³ and at the weekend ranged by 116.00 μg/m³ (35.80–151.80 μg/m³) with an average of 85.87 μg/m³. Mean $PM_{2.5}$ on weekdays showed an increase of 66.23% (1.66 times) and was found to be significantly higher ($p < 0.01$) than the weekend level. This result indicates vehicular emission is responsible for the higher concentration on weekdays. Normally in city areas, higher traffic volume is observed on weekdays.

Similarly, during the night, $PM_{2.5}$ ranged by 214.60 μg/m³ (76.70–291.30 μg/m³) with an average of 157.69 μg/m³ and at daytime it ranged by 165.40 μg/m³ (31.10–196.50 μg/m³) with an average of 89.87 μg/m³. Mean $PM_{2.5}$ during the night, showed an increase of 75.46% (1.75 times) and was significantly higher ($p < 0.01$) than the daytime level. During the night, comparatively, the weather condition remains calm with a low temperature and higher RH, which might be the cause of higher accumulation of fine particles in the

Table 2. Mean comparisons of temperature (°C), relative humidity (%) and $PM_{2.5}$ (μg/m³) between days by the Newman Keuls test (DF = 138).

Variables	Day 10 vs.				Day 13 vs.				Day 16 vs.			Day 6 vs.		Day 7 vs.	
	Day 13	Day 16	Day 6	Day 7	Day 19	Day 16	Day 6	Day 7	Day 19	Day 6	Day 7	Day 19	Day 7	Day 19	D19
Temp.	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns	ns	**	**
Rh	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
$PM_{2.5}$	**	**	**	**	ns	ns	ns	**	**	ns	*	**	*	**	*

ns = not significant ($p > 0.05$), * = significant ($p < 0.05$), ** = significant ($p < 0.01$)

Table 3. Summary statistics and mean difference of $PM_{2.5}$ between locations, weekend and weekdays, and day and night by Student's t-test.

Statistic	Locations		Weekend and Weekdays		Day and Night	
	Vikas Nagar	Alambagh	Weekend	Weekdays	Day	Night
N	72	72	48	96	72	72
Mean ± SD	115.83 ± 62.09	131.74 ± 63.91	85.87 ± 27.15	142.74 ± 67.65	89.87 ±40.45	157.69 ± 64.03
Cov (%)	53.61	48.52	31.62	47.39	45.01	40.60
Min	31.10	51.30	35.80	31.10	31.10	76.70
Max	250.60	291.30	151.80	291.30	196.50	291.30
Range	219.50	240.00	116.00	260.20	165.40	214.60
t (DF=142)	1.71*		5.19**		8.10**	

* = significant ($p < 0.05$), ** = significant ($p < 0.010$)

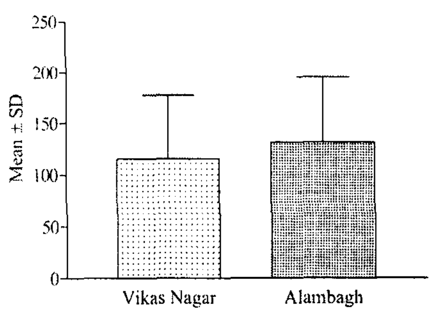

Figure 4. Avarage variations in $PM_{2.5}$ concentrations (μg m^{-3}) at two residential locations.

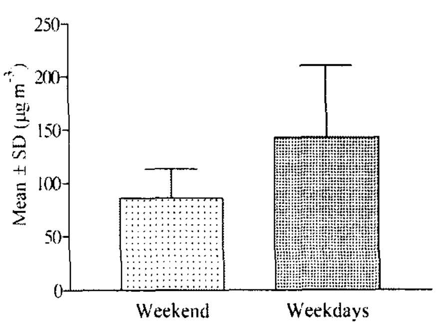

Figure 5. Avarage variations in $PM_{2.5}$ concentrations (μg m^{-3}) during weekend and weekdays.

atmosphere. The atmospheric parameters that mainly influence aerosol concentrations, size distributions, emission characteristics of the sources, temperature, RH, wind direction, wind speed, atmospheric stability and mixing heights which vary on time scales substantially smaller than 24 h [24]. So it can be expected that the said meteorological factors are responsible for higher accumulation during night hours.

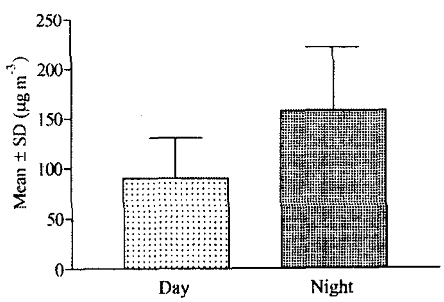

Figure 6. Avarage variations in $PM_{2.5}$ concentrations (μg m^{-3}) during day and night.

During night hours, the low temperature caused low dispersive condition due to thermal inversion and accumulation of local emissions and the breakdown of the thermal inversion due to higher temperature during day time induced the dilution of the pollutants even though emission rate was constant or more [22, 25, 26].

Coefficient of variations (COV) indicates that Alambagh (48.52%) is more consistent than Vikas Nagar (53.61%), and weekdays (47.39%) are more variable than the weekend (31.62%), and night (40.60%) is more consistent than day (45.01%), indicating that Alambagh has more traffic than Vikas Nagar.

3.3 Simple Linear Correlation

Overall data (see Tab. 4) of temperature, RH, and $PM_{2.5}$ consisted of 144 hourly data points. Temperature ranged by 18.00°C (13.80–31.80°C) with an average of 24.02°C, RH ranged by 47.00% (35.40–82.40%) with an average of 55.36%, and $PM_{2.5}$ ranged by 260.20 μg/m³ (31.10–291.30 μg/m³) with an average of 123.78 μg/m³. The mean ratios of RH and $PM_{2.5}$ to temperature are 2.30 and 5.15, respectively, whereas the ratio of RH and temperature and of $PM_{2.5}$ and RH are

Table 4. Overall summary statistics ($n = 144$) of temperature (°C), relative humidity (%) and $PM_{2.5}$ (µg/m³).

Statistics	Temperature	Relative Humidity	$PM_{2.5}$
Mean ± SD	24.02 ± 4.61	55.36 ± 11.86	123.78 ± 63.29
COV (%)	19.19	21.42	51.13
Minimum	13.80	35.40	31.10
Maximum	31.80	82.40	291.30
Range	18.00	47.00	260.20

Table 5. Correlation ($n = 144$, DF = 142) between time (hour), temperature (°C), relative humidity (%), and $PM_{2.5}$ (µg/m³).

Variables	Time	Temperature	Relative Humidity	$PM_{2.5}$
Time	1.00			
Temperature	−0.51**	1.00		
Relative Humidity	0.54**	−0.87**	1.00	
$PM_{2.5}$	0.44**	−0.60**	0.73**	1.00

** = significant ($p < 0.01$)

2.30 and 2.24, respectively. The correlation coefficient between time, temperature, RH, and $PM_{2.5}$ are presented in Tab. 5. All the variables significantly correlate ($p < 0.01$) with each other and show a linear dependence on each other. Temperature shows a negative association with time whereas RH and $PM_{2.5}$ show a positive association, suggesting that as the day progresses and the temperature decreases, RH and $PM_{2.5}$ increase. The negative association of RH and $PM_{2.5}$ with temperature and the positive association of $PM_{2.5}$ with RH also suggest the same more statistically: RH is negatively associated with temperature and $PM_{2.5}$ is positively associated with the RH.

The RH as well as the water content play an important role, as absorption of water by the particulate matter changes its dimensions, density and its optical properties [24]. At high RH values, an important portion of atmospheric aerosol mass is constituted by condensed vapor and for values greater than 80% water could represent half of the aerosol mass [27]. Water is an important constituent of PM and its presence depends on the chemical composition of the PM, especially the inorganic salts like ammonium sulfate and ammonium nitrate, which can absorb water [28, 29].

3.4 Simple Linear and Multiple Regression

Linear dependence of $PM_{2.5}$ on time, temperature and RH was investigated by simple linear and multiple regression analysis, considering $PM_{2.5}$ the dependent variable, and time, temperature and RH the independent variables. The regression summary of these independent variables with the dependent variable is presented in Tab. 6. Four different combinations of independent variables were analyzed to know the best predictor variable, which could predict the $PM_{2.5}$, the dependent variable, the best. Comparative results revealed that time, temperature, and RH together accounted for 54% of total variations of $PM_{2.5}$, whereas RH alone accounted for 53% (see Fig. 7). So for $PM_{2.5}$ in Lucknow, RH is a better indicator than the other investigated variables. The best regression equation follows as:

$$PM_{2.5} = -0.94 + 1.72\ RH \quad (1)$$

The above best-fit regression equation also indicates that $PM_{2.5}$ concentration increases with an increase of RH, in other words, $PM_{2.5}$ is directly proportional to RH. The 24 h average concentrations of $PM_{2.5}$ during the pre monsoon season at the Vikas Nagar and Alambagh residential areas were recorded at 35.5 and 57.0 µg/m³, respectively [15]. These values are much lower than the current recorded values, which might also be due to the variation of meteorological parameters, like temperature and RH, and also suggest seasonal variations.

The study concludes that the concentrations of $PM_{2.5}$ in a city has a close relationship with its meteorological parameters, especially the RH. Within a city, the particulate matter concentration varies

Table 6. Regression summary ($n = 144$).

Predictors 95%	Coefficients	SE	t stat	p value	Lower 95%	Upper 95%
(i) Independent variables – time (hour), temperature (°C), relative humidity (%)						
multiple R = 0.74, R^2 = 0.54, adjusted R^2 = 0.53, SE = 0.15, F = 54.87						
Intercept	−1.83	0.84	2.18	0.03	−3.49	−0.17
Time	0.08	0.08	1.06	0.29	−0.07	0.23
Temperature	0.32	0.29	1.11	0.27	−0.25	0.89
Relative humidity	1.92	0.28	6.89	0.00	1.37	2.47
(ii) Independent variables – temperature (°C), relative humidity (%)						
multiple R = 0.73, R^2 = 0.54, adjusted R^2 = 0.53, SE = 0.15, F = 81.68						
Intercept	−1.81	0.84	2.15	0.03	−3.47	−0.15
Temperature	0.31	0.29	1.08	0.28	−0.26	0.88
Relative humidity	1.97	0.27	7.21	0.00	1.43	2.52
(iii) Independent variable – temperature (°C)						
Multiple R = 0.60, R^2 = 0.37, adjusted R^2 = 0.36, SE = 0.18, F = 81.90						
Intercept	4.08	0.23	18.02	0.00	3.64	4.53
Relative humidity	−1.49	0.16	9.05	0.00	−1.82	−1.17
(iv) Independent variable – relative humidity (%)						
Multiple R = 0.73, R^2 = 0.53, adjusted R^2 = 0.53, SE = 0.15, F = 162.01						
Intercept	−0.94	0.23	4.01	0.00	−1.40	−0.48
Relative humidity	1.72	0.13	12.73	0.00	1.45	1.98

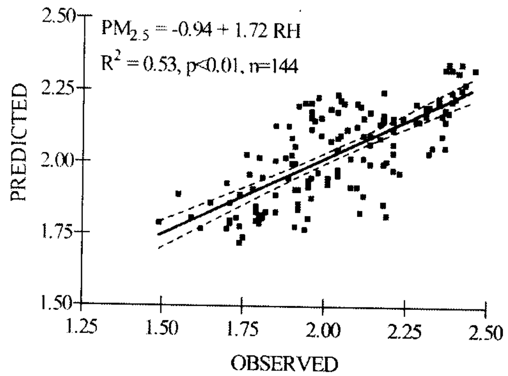

Figure 7. Predicted concentrations of $PM_{2.5}$ ($\mu g\ m^{-3}$) by RH with 95% confidence limits for β.

significantly between locations, during weekdays and weekend, and day and night, depending upon the meteorology and traffic volume. Several reports in the literature have revealed that vehicular pollution is one of the major sources of fine particulates in any urban city, which is also applicable to Lucknow city.

The recorded values clearly indicate that weekend values are comparatively lower than the weekdays and it might be because of low traffic volume. Diurnal variation of $PM_{2.5}$ concentration as well as the higher concentration during the night hours might be the result of prevailing meteorological parameters. Normally, calm, low ambient temperature and higher relative humidity, might be the cause of higher concentration. Further more, regression analysis showed that RH is a better and dependable indicator than the other investigated variables and $PM_{2.5}$ concentration increases with the increase in the RH.

There is no national air quality standard (NAAQS) for fine particulate matter ($PM_{2.5}$) in India. In this study, the recorded values were found to be much higher than the 24 h average value (65.0 $\mu g/m^3$) of NAAQS of the US-EPA standard [30]. The elevated concentration of fine particles is expected to cause serious health problems for human beings, especially for elderly people. A higher concentration during the early morning hours may have a serious impact on the fresh air breather. The data presented in this paper indicates that the alarming level of the fine particles may have a serious impact on public health in the long run but for a final conclusion more monitoring data is needed, especially for the other seasons.

Acknowledgement

We are thankful to Dr. C. M. Gupta, Director of ITRC, for his encouragement and support. We acknowledge all other staff of the Environmental Monitoring Sections for their support during different phases of work.

References

[1] J. Shwartz, D. W. Dockery, L. M. Neas, Is daily mortality associated specifically with fine particles?, *J. Air Waste Manag. Assoc.* **1996**, *46*, 927.

[2] K. Sasaki, K. Sakamoto, Vertical differences in the composition of PM_{10} and $PM_{2.5}$ in the urban atmosphere of Osaka, Japan, *Atmos. Environ.* 2005, *39*, 7240.

[3] L. Curtis, W. Rea, P. Smith-Willis, E. Fenyves, Y. Pan, Adverse health effects of outdoor air pollutants, *Environ. Int.* **2006**, *32*, 815.

[4] D. W. Dockery, C. A. Pope, X. P. Xu, D. J. Spengler, H. J. Ware, E. M. Fay, G. B. Ferris, E. F. Speizer, An association between air pollution and mortality in six US cities, *New Eng. J. Med.* **1993**, *329*, 1753.

[5] C. A. Pope, M. J. Thun, M. M. Namboodiri, D. W. Dockery, J. S. Evans, F. E. Speizer, C. W. Heath, Particulate air pollution as a predictor of mortality in a prospective study of US adults, *Am. J. Resp. Crit. Care. Med.* **1995**, *151*, 669.

[6] A. J. Ghio, J. Stonehuerner, L. A. Dailey, J. D. Carter, Metals associated with both the water soluble and insoluble fractions of an ambient air pollution particle catalyse an oxidative stress, Inhalation Toxicol. **1999**, *11 (1)*, 37.

[7] A. Koliadima, A. Athanasopoulou, G. Karaiskakis, Particulate Matter in air of the cities of Athens and Patras (Greece): particle-size distribution and elemental concentrations, *Aerosol Sci. Technol.* **1988**, *8*, 292.

[8] L. Morawaska, E. R. Jayaratne, K. Mengersen, M. Jamriska, S. Thomas, Differences in airborne particle and gaseous concentrations in urban air between weekdays and weekends, *Atmos. Environ.* **2002**, *36*, 4375.

[9] G. C. Fang, Y. S. Wu, S. H. Huang, J. Y. Rau, Review of atmospheric metallic elements in Asia during 2000–2004, *Atmos. Environ.* **2005**, *39*, 3003.

[10] A. Dahl, A. Gharibi, E. Swietlicki, A. Gudmundsson, M. Bohgard, A. Ljungman, G. Blomqvist, M. Gustafsson, Traffic-generated emissions of ultrafine particles from pavement-tire interface, *Atmos. Environ.* **2006**, *40*, 1314.

[11] M. T. Freiman, N. Hirshel, D. M. Broday, Urban-scale variability of ambient particulate matter attributes, *Atmos. Environ.* **2006**, *40*, 5670.

[12] J. C. Chow, Introduction to special topic: weekend and weekday differences in ozone levels, *J. Air Waste Manag. Assoc.* **2003**, *53 (7)*, 771.

[13] D. R. Lawson, The Weekend Ozone Effect-The Weekly Ambient Emissions Control Experiment, *EM* **2003**, 17.

[14] K. Sharma, R. Singh, S. C. Barman, D. Mishra, R. Kumar, M. P. S. Negi, S. K. Mandal, G. C. Kisku, A. H. Khan, M. M. Kidwai, S. K Bhargava, Comparison of trace metals concentration in PM_{10} of different location of Lucknow city, *Bull. Environ. Contam. Toxicol.* **2006**, *77 (3)*, 419.

[15] I.T.R.C., Environmental Status of Lucknow, A Pre-Monsoon Random survey report for World Environment Day, 5th June, Lucknow **2005**.

[16] S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, G. D. Agarwal, Fine Particulates in the Ambient Air of Shilong, *Indian J. Air Pollut. Contrl.* **2005**, *5 (2)*, 1.

[17] A. Kumar, D. K. Dhawan, M. L. Garg, Airborne Particulate Matter and Human Health: Perspective and case study, *Indian J. Air Pollut. Contrl.* **2005**, *5 (2)*, 54.

[18] Bureau of Indian Standards (BIS), Indian Standard Methods for measurement of air pollution, **2000**, IS 5182 (Part 14).

[19] I.T.R.C., Environmental Status of Lucknow, A Post-Monsoon Random survey report for ITRC Foundation Day, 4th November, Lucknow **2005**.

[20] User's Guide, Haz-Dust TM Environmental Particulate Air Monitor, Model EPAM-5000, DOC #HD50103, Environmental Devices Corporation, 88 Essex Street, Haverhill, MA **1999**.

[21] L. Laakso, T. Husseina, P. Aarniob, M. Komppulac, V. Hiltunena, Y. Viisanenc, M. Kulmala, Diurnal and annual characteristics of particle mass and number concentrations in urban, rural and arctic environments in Finland, *Atmos. Environ.* **2003**, *37*, 2629.

[22] X. Querol, A. Alastuey, S. Rodriguez, F. Plana, R. Carmen, N. Cots, G. Massague, O. Puig, PM10 and PM2.5 source apportionment in the Barcelona Metropolitan area, Catalonia, Spain, *Atmos. Environ.* **2001**, *35*, 6407.

[23] I. Allegrini, A. Febo, A. Pasini, S. Schiarini, Monitoring of the nocturnal mixed layer by means of particulate radon progeny measurements, *J. Geophys. Res.* **1994**, *99*, 18765.

[24] A. Donateo, D. Contini, F. Belosi, Real time measurement of $PM_{2.5}$ concentrations and vertical turbulent fluxes using an optical detector, *Atmos. Environ.* **2006**, *40*, 1346.

[25] C. Soriano, J. M. Baldasano, M. Countinho, in *Seasonal Variation of the Atmospheric Circulatory Patternsinthe Bareelona Area*, (Eds: A.R.Maarouf, N. Barthakur, N.O. Mhaute), Proc. of the Seasonal Urban Environmental Symp., 13th Conf. on Biometeorology and Aerobiology, American Meteorology Society, Albuquerque, NM **1998**, p. 55.

[26] I. Toll, J. M. Baldasano, Modelling of Photochemical air pollution in the Barcelona area with highly disaggregated anthropogenic and biogenic emissions, *Atmos. Environ.* **2000**, *34 (19)*, 3069.

[27] P. H. McMurry, A review of atmospheric aerosol measurements, *Atmos. Environ.* **2000**, *34*, 1959.

[28] C. Pilinis, J. M. Seinfeld, D. Grosjean, Water content of atmospheric aerosol, *Atmos. Environ.* **1989**, *23*, 1601.

[29] C. Hueglin, R. Gehrig, U. Baltensperger, M. Gysel, C. Monn, H. Vonmont, Chemical characterisation of $PM_{2.5}$, PM_{10} and coarse particles at urban, near-city and rural sites in Switzerland, *Atmos. Environ.* **2005**, *39*, 637.

[30] EPA (Environmental Protection Agency, USA), *Revision to the National Ambient Air Quality Standards for particulate matter, Final rule*, Fed Reg 62:38652-38760, **1997**.