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OUTDOOR AMBIENT AND ON-ROAD $PM_{2.5}$ MASS CONCENTRATION LEVELS IN THE CITY OF MYSORE, INDIA

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ABSTRACT

This study reports on the outdoor $PM_{2.5}$ mass concentration measurements and mobile on-road measurements made for the first time in a moderately big city of Mysore, India. Sampling sites were divided into two types – urban periphery and urban centre. The results reveal remarkable high outdoor mass concentrations. The busier urban center regions showed concentration averages nearly two times higher than the urban peripheral regions. Also, urban center regions are statistically different from the peripheral regions at 5% level of significance. Urban centre on-road mass concentration average was four times higher than the peripheral on-road average. High concentration levels at the urban center were found to be linked to the higher vehicular activities. The results obtained in the city of Mysore are compared with the results reported of other major Indian cities.

KEY WORDS: $PM_{2.5}$, air quality, mass concentration, outdoor air pollution, traffic-emission, real-time measurements, on-road concentration levels

Understanding health effects caused by exposure to outdoor aerosols is essential to control outdoor air pollution and consequent health issues. Studies show specific respiratory illnesses could be attributed to the particulate matter pollution in air (Bruce et al., 2000; Smith, 2000). In India, every year, nearly 2 million people suffer from respiratory disorders and premature deaths caused due to this very prevalent issue of air pollution (Saksena and Dayal, 1997). This is the case, especially in big cities, for the daily commuters, school children and roadside vendors. According to Kandlikar and Ramachandran (2000), we find that the vehicular emissions on narrow roads are the major sources of outdoor air pollution. The study also found factory effluents and waste burning as the other sources for outdoor air pollution.

There are several ways to improve the quality of outdoor air in cities, such as by using efficient and cleaner fuels, decreasing the traffic density, and improving the road conditions and enabling faster movement of vehicles. Also, reducing waste burning and situating factories to the remote parts of the city ensures better air quality for the city residents.

Even though there are many studies conducted in India to monitor the outdoor air quality and measure particulate matter, they are focused on the much larger size particles in the category of suspended particulate matter SPM, and respirable particulate matter RPM (approximately to PM_{100} and PM_5). For e.g., according to Kulkarni and Patil (1999) study, outdoor workers are exposed to an average 322 $\mu g/m^3$ of respirable particulate matter (RPM, corresponding to PM_5) in the Metropolitan city of Mumbai on a daily basis. These levels are many times higher than the regulatory standards of 100 $\mu g/m^3$ (MEF, 1994). However, recent studies (Schwartz et al., 1996; USEPA 1997; Zhou and Cheng, 2000; Samet et al., 2000; Churg and Brauer, 2000) strongly associate $PM_{2.5}$ (particulate matter whose aerodynamic diameter is less

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than 2.5 µm) with the respiratory health disorders and suggest $PM_{2.5}$ to be a better indicator for the air quality than RPM or SPM. Hence, controlling $PM_{2.5}$ mass concentration is becoming more important for achieving the air quality.

There have been very few studies conducted in India for monitoring the fine particles like $PM_{2.5}$ at ambient and traffic-affected city centre zones. Keeping this in view, the present research study was carried out in these environments to monitor outdoor $PM_{2.5}$ levels in the Indian city of Mysore. This paper presents the $PM_{2.5}$ mass concentration data at 10 different ambient sites spread over the city in the urban centre as well as the peripheral regions. The paper also presents on-road $PM_{2.5}$ mass concentration levels collected on two different weekdays. The objective of this research was 1) to determine whether urban center regions differed significantly in $PM_{2.5}$ concentration levels compared to the urban peripheral regions, and 2) to assess the contribution of traffic-related emissions to the outdoor $PM_{2.5}$. These data strongly suggest that the urban centre is more $PM_{2.5}$ polluted compared to the urban periphery.

MATERIALS AND METHODS

Study design

For the present study, a small south Indian city of Mysore with an area of about 152 sq km and having a population of 8.87 lakh (or population density of 5800 per sq km) was chosen (2011 census). Mysore is about 150 km to the southwest of Bangalore, the capital of the state of Karnataka. The city is having very few industries with moderate business activities and is surrounded by moderate forests, hill ranges and small villages. Ambient measurements were carried out at places selected from peripheral zones (beyond the radius of 5 km from the city centre) and urban centre commercial zones (within the radius of 2 km from the city centre). A total of 10 samplings were done at randomly chosen sites on different days, five from the peripheral parts and five from the urban center. The peripheral sites and the urban center sites were chosen uniformly from different parts of the city. One 24-hour measurement was made at each fixed site (during August to December 2002).

In addition, mobile on-road measurements on a pre-selected trajectory were carried out on a randomly selected week-day. On-road measurements were conducted thrice in a day, morning (10 –11:30 am), afternoon (2-3:30 pm), and evening (6 – 7:30 pm). The measurements were taken on a moving auto rickshaw traversing from the edge of the city through the city central region till the edge on the other side. Every time, the same trajectory of 7km length was chosen. The whole one round of journey, to and fro, took about 90 minutes time. Times were also noted down for few selected locations while traversing along the trajectory. This helped to map the concentration levels with the category of either urban periphery or urban centre. A total of two days of on-road sampling data were obtained.

Instruments used and sampling

DustTrak 8520 (TSI Inc., St. Paul, MN, USA) was used in the present study for detecting particles in the size range 0.1 to 2.5 µm. It measures the particle mass concentration in real-time by 90^{o} light scattering (Baron and Willeke, 2001). Before sampling, the DustTrak flow-rate was set at 1.7 lpm. The DustTrak measured values are usually 3-5 times the true mass concentration. Hence, for calibrating the DustTrak data and to obtain the true data, simultaneous gravimetric filter sampling was conducted. Gravimetric 24-hr $PM_{2.5}$ mass concentration was obtained using $PM_{2.5}$ monitoring inlets (PEM^{TM} Model 200, MSP Inc., Minneapolis, MN) along with the Teflon filters. The PEM

(Personal Environmental Monitor) consists of a single-stage impactor and a final filter. Aerosol particles above the 50% cut-point of 2.5 µm in aerodynamic diameter in the air being sampled are removed using the single-stage impactor. Teflon filters then collect the remaining particles by impaction. During the sampling, 10% filters were also used as filed blanks which were loaded into the sampler inlet and kept next to the active pump. Measured aerosol concentrations were subtracted by weight changes in the unexposed field blank filters.

Before each sampling, any previous sampling mass collected on the impactor plate is cleaned off and then given an even and thin coating of a layer of grease to prevent the bouncing of particles. Ambient air from the sampling environment is drawn through the inlets at 10 lpm using sampling pumps (BGI Pumps, BGI, Waltham, MA) run by a rechargeable lithium ion battery.

For sampling and data collection, measuring instruments were kept in a secure place like a shop or a house, but away from the road-traffic. During each sampling at 10 ambient fixed locations, DustTrak along with the PEM pumps were taken to the sampling sites and were run by battery for 24 hrs. Plastic tubings connected to the inlets were kept hanging into the ambient air outside the building at a distance of about 20 cm from the building wall. For mobile on-road measurements, instruments were kept running on a moving auto rickshaw while sampling the on-road air.

DustTrak instrument recorded and stored the data every 5 seconds which is the average over 5 seconds. After sampling, the data were downloaded to the computer and were averaged over a 5-minute rolling period.

After-sampling data calibration

The Teflon filters were weighed before and after each sampling with a microbalance having accuracy of 1 µg in accordance with the US EPA protocol (US EPA, 1997). A stabilization time of 30 seconds was given to record the initial and the tare weight for each filter. For calculations of concentrations, field blank weights were subtracted from sample weights. A correction factor was obtained by finding the ratio of 24-hr average mass concentration value from the gravimetric filter to the value obtained from the DustTrak real-time data. Correction factors were found to vary in the range 0.327 to 0.360. All the data points in the DustTrak were multiplied by the corresponding correction factor to obtain the true mass concentration.

Statistical Analysis

All the calibrated DustTrak data were analysed to obtain the summary statistics such as the arithmetic mean, standard deviation, and variance. The results were used to compare the concentration levels between the urban center and peripheral regions of the city. The two types of fixed sampling sites were also analysed using a t-test.

RESULTS AND DISCUSSION

Urban periphery and urban centre regions
Average mass concentration

Table 1 gives the summary of $PM_{2.5}$ mass concentration levels for urban periphery and urban centre in the city of Mysore. Background mass concentration levels were calculated for all sampling sites from the mass concentration values at each site during no-activity period of midnight to 4 am. Background level average comes to be about 24µg/m^3 which is nearly the same as 24-hr average mass concentration for the peripheral regions with range 5 to 45 µg/m^3. However, the urban center regions show mean mass concentration values at 46 ± 5 µg/m^3 (range:

32 to 66 µg/m^3). Thus we find the 24-hr $PM_{2.5}$ average ambient mass concentrations in urban center regions of Mysore city are about 1.92 times higher than the 24-hr $PM_{2.5}$ average mass concentration for remote regions. Moreover, two-tailed t-test for the two categories, urban center and peripheral regions showed that they are statistically different at 5% level of significance with p-value of 0.036.

Comparisons with other $PM_{2.5}$ studies in India show similar results. In a much denser and metropolitan city of Mumbai, ambient levels at peripheral parts range from 21 to 82 µg/m^3 averaging at 43 µg/m^3 (Kumar et al., 2005a; Ajmal et al., 2005) - this is higher than the peripheral-region concentration levels of 24 µg/m^3 in Mysore. Urban center Delhi region show an average of 94 µg/m^3 (Kumar et al., 2005b) and in an urban center location of Mumbai, it is found to be 102 µg/m^3 (Goyal et al., 2005). However, in the present study, urban center Mysore showed an average of 46 µg/m^3. Thus we conclude that urban centre regions of Delhi and Mumbai were about two times more polluted than Mysore. This is probably linked to the fact that Mysore has less dense population and lesser commercial as well as industrial activities.

Real-time data and Variation pattern

Fig.1 shows an example of the outdoor mass concentration at a) an urban peripheral site and b) an urban centre site. During low human activity times between midnight to 4 am, background mass concentration levels in urban centre region was very low
at 12 µg/m^3 whereas peripheral site showed much higher concentration levels at 30 µg/m^3. Morning sharp peaks reaching highest concentration of 142 µg/m^3 are seen between 6:30 am – 8.30 am in Fig. 1a) for urban periphery, which can be attributed to the smoke generated by nearby household combustion activities like cooking as well as heating water for bath. Fig. 1b) shows numerous short-term sharp peaks in the urban centre between 5.00 am - 12 noon. Highest mass concentration recorded during this period is 215 µg/m^3. These are associated with the onset of commercial activities as well as vehicular activities.

The concentration levels gradually came down between 12 noon to 5 pm with the average values around 20 µg/m^3 and 23 µg/m^3 in urban periphery and urban centre site respectively. Decrease in commercial activities as well as a decrease in the vehicular activities in the afternoon hours explains this. Also, in the evening, sharp peaks are found between 5 pm to 10 pm, most likely associated with the increase in the vehicular activities during this interval. For a peripheral site within the residential region, additionally, the household combustion activities in the evening play a major role for outdoor pollution levels. Peak values recorded during this period were 50 µg/m^3, 71 µg/m^3 in urban periphery and urban centre site respectively. These peak values are much smaller compared to the morning peaks. The comparatively very high peak values in the morning in both the measuring sites are probably due to the influence of wind and dust factors, as well as longer duration of combustion activities.

In India, it is a practice among few people to start heating water for bath purposes the previous night itself using different types of biomass. Thus due to the combustion activities going on in the nearby households, we find that in peripheral sites, even after 10 p.m., the concentrations still remained high and did not come down.

The 5-sec data from each category of sampling site were lined up over all days and subjected to ANOVA test to analyse the within–day variations. Variance is expressed in terms of percentage of Arithmetic Mean

(A.M.). For urban center regions, there is considerable within-day variance of 64% of arithmetic mean (A.M.). For peripheral locations, slightly small variance (50% of A.M. for within-day variation) was found.

On-road mass concentration across the city

Fig 2 shows an example of on-road 1-min average mass concentration measurement from the city periphery through the city centre till the periphery on the other side. The on-road concentration data show numerous peaks due to the regular emission from frequent vehicular activities. The data shows a clear variation pattern in the concentration as one moves from the periphery of the city through the center to the periphery on the other side.

From Table 2, we see $PM_{2.5}$ average mass concentration for on-road measurements to be 197 ± 20 $\mu g/m^3$. Peak values ranging from 1200 –1950 $\mu g/m^3$ were found nearer busy traffic circles in the city center. These concentrations were significantly higher, about 20-25 times higher than at the peripheral regions (Fig. 2). Evening (6 –7:30 pm) traffic vehicle emission seems to be the highest in a day.

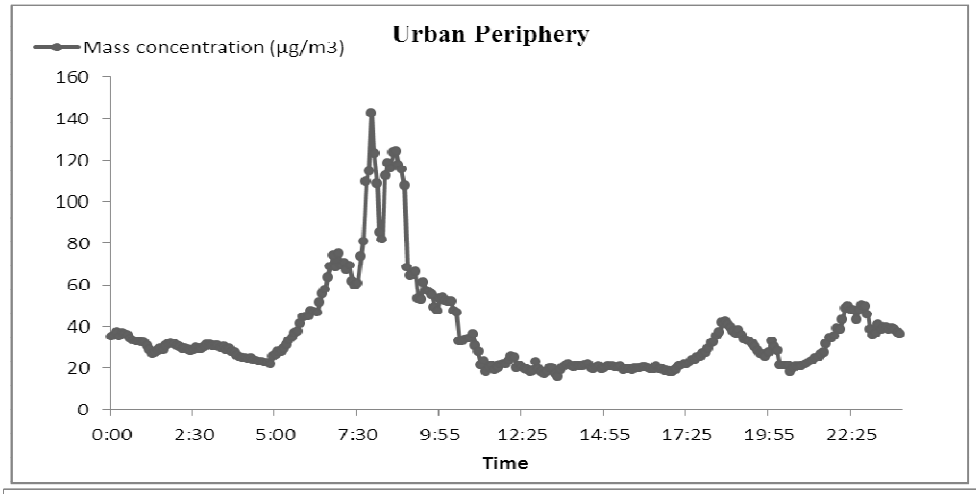
Comparing these values with the ambient mass concentration levels from Table 1 show the remarkably high nature of vehicle-emission related concentration levels. The average on-road concentration levels in Mysore were about 8 times higher than the levels at the peripheral ambient sites and 4 times that of the urban centre ambient sites. The real-time 1-minute average data show the on-road peak concentrations could be as high as 9 times the on-road average level.

Peripheral on-road concentrations averaged at 79 $\mu g/m^3$ which is 3.3 times the urban peripheral ambient site average. Urban centre on-road concentration averages were found to be about 343 $\mu g/m^3$. This is 7.4 times the urban centre ambient site average. This clearly shows the association of $PM_{2.5}$ outdoor concentrations with the traffic activity in that region.

The on-road concentration levels of Mysore can be compared with one other closer study (Kumar et al., 2005c) where roadside concentration levels in Delhi were measured, it is found to be about 134 $\mu g/m^3$. On-road levels are more influenced by heavy-traffic than the road-side regions. Road-side concentration levels, therefore, would be lesser compared with the on-road levels. Consistent with this, we find the average on-road levels in Mysore to be 197 $\mu g/m^3$. Ginzburg et al, (2015) study shows the contribution of roadway sources is 12 to 17 % of the $PM_{2.5}$ at the near-road site.

For the same city of Mysore, Andresen et al. (2005) study shows that the 24-hr indoor A.M. levels ranged from 71-155 $\mu g/m^3$, which is significantly (5% level) higher than the 24-hr ambient outdoor levels of range 5-66 $\mu g/m^3$ obtained from the present study. This indicates the dominance of indoor sources over outdoor sources for $PM_{2.5}$ exposure levels. However, we cannot say anything about the contribution of outdoor sources to the indoor levels or the converse, which in turn requires detailed indoor - outdoor correlation studies. Such a study has been conducted by Latha et al., (2005), in another Indian city of Hyderabad, which showed an Indoor – outdoor ratio (I/O) of 1.6. This indicates higher probability of indoor exposures in the urban centre regions compared to the indoor exposures in the urban periphery. This also agrees with the result of Andresen et al. (2005) study.

a)



b)

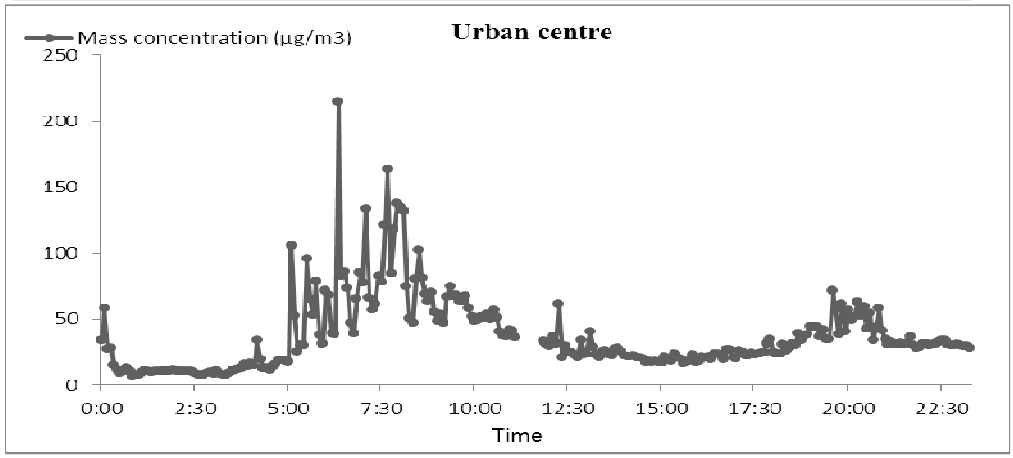


Fig. 1: 24-hr data of real-time mass concentration showing temporal variation in a) an urban peripheral site, and b) an urban centre site

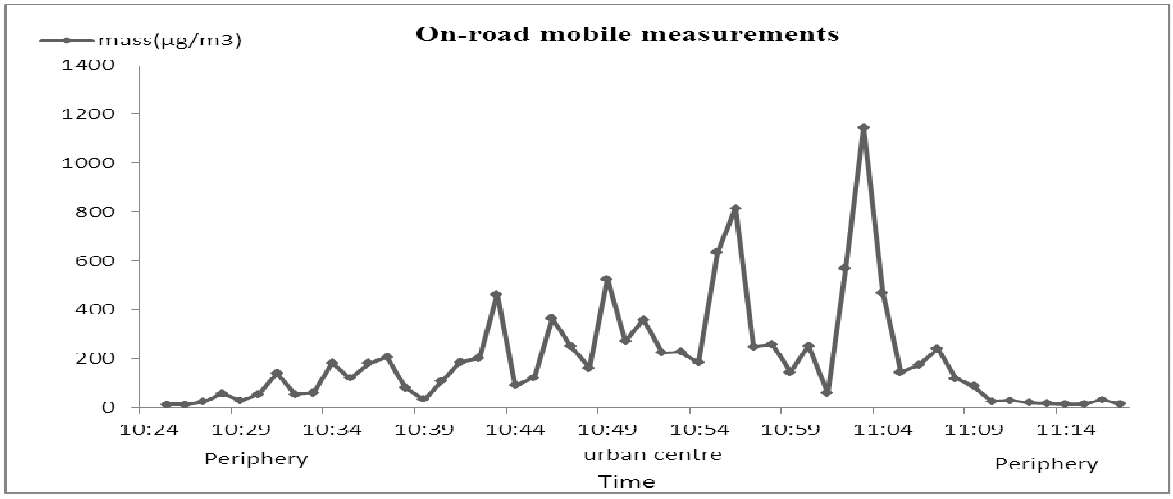


Fig. 2:A plot of on-road mass concentration traversing through the city on a pre-selected trajectory

Table 1: 24-hr $PM_{2.5}$ arithmetic mean mass concentration in Mysore (arithmetic mean ± Standard Error), range and t-test for comparing urban periphery and urban centre region

Background ambient $PM_{2.5}$ pollution: 24 ± 8

Number of measurements	24-hr $PM_{2.5}$ mass concentration A.M. ± SE (µg/m^3), Range		P-value for comparing peripheral and urban center (two-tailed)	Arithmetic Mean ratio
	Urban periphery	Urban center		
N = 5	24 ± 8 (5 - 45)	46 ± 5 (32 - 66)	0.036*	1.92

* $P < 0.05$

Table 2:On-road traffic measurements on a selected trajectory passing through the city center, three times in a day

Number of measurements		**Arithmetic Mean mass concentration (µg/m^3)**	**Max (µg/m^3)**	**S.E.**
	Sample 1			
	Morning (10–11:30 am)	162	1330	
N = 4, each type	Afternoon (2-3.30 pm)	175	1907	26
	Evening (6-7.30 pm)	247	1157	
	Sample 2			
	Morning (10–11:30 am)	230	1188	
	Afternoon (2-3.30 pm)	130	647	35
	Evening (6-7.30 pm)	237	1958	
	Overall Arithmetic mean (mean ± SE)	**197 ± 20 µg/m^3**		

CONCLUSION

The present study conducted in the city of Mysore in South India focused on the $PM_{2.5}$ mass concentration measurements and variation pattern in three types of outdoor environments – city peripheral, city center and on-road. The present study explores sensitiveness of urban center regions being influenced by traffic-related emissions. In the light of health effects associated with aerosol exposure, the present study indicates significantly high concentration levels in busy urban center regions and rising to alarming levels with traffic related emissions on the roads. The exposure affects many people like roadside vendors, traffic police, school children, daily commuters, drivers and passengers of public transport.

US EPA (1997) recommends a standard of 65 µg/m^3. NAAQS, India (2009) prescribes a 24 –hr average standard of 60 µg/m^3. Urban peripheral regions of Mysore city were well within this standard. Overall average for the urban center is also within this standard, though, it exceeded the standard in some of the sampling sites. However, the traffic related on-road concentration levels exceeded the standard by a large factor.

So far, studies in India have been made mostly on SPM and PM_{10} with very scarce studies on $PM_{2.5}$. Since the studies on

SPM and PM_{10} do not give clear picture about the pollution problems, there is the need for updating the particulate standards as related to pollution control policies and epidemiology studies.

Swach Sarvekshan (2016), a National City Rating conducted in 2015 by Ministry of Urban Development, Government of India and Central Pollution Control Board, India listed Mysore as number one cleanest city in India. This is also seen from the fact that $PM_{2.5}$ concentration levels in Mysore are half as much in comparison to other major cities like Mumbai and Delhi. The high concentration levels in these major cities is probably because of their unplanned growth resulting in large number of industrial as well as commercial activities, dense population, poor infrastructure conditions etc. If focus is given by the local and central government to improve the conditions in these metropolitan cities by considering the example set by Mysore, pollution levels could be well controlled. And surely this would result in bringing the pollution levels within the regulated standards thereby ensuring healthy living conditions for the city population.

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