Snapshot of PM Loads Evaluated at Major Road and Railway Intersections in an Urban Locality

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***Abstract*- Results from this air pollution monitoring study reveal high particulate matter mass concentrations (PM10, PM2.5, and PM1) emitted from different sources at major road and railroad intersections in Kanpur city during summer and winter seasons of the year 2011. Construction activity was found to contribute significantly to coarse PM load in ambient air. Total Suspended Particulate Matter (TSPM) and PM10 levels were generally higher at vehicular intersections and construction sites. Among the three railroad sites examined within the city, Kalyanpur, which allows passage of Heavy Duty Vehicles as well, had the highest PM10 (1110 μg m^{-3}), PM2.5 (124 μg m^{-3}), and PM1 (46 μg m^{-3}) levels. Our observations suggest that railroad intersections are possibly important sources contributing significantly to total PM load in ambient air. Results are expected to aid in highlighting 'hot spots' and help focus pollution prevention and mitigation efforts.**

***Keywords*- PM10; PM2.5; PM1; Air Pollution; Vehicular Emission; Construction Activity; Railroad Intersection**

I. INTRODUCTION

Kanpur city (26.4583 °N, 80.3173 °E) with a high population density (1366 people km^{-2}) is a major industrial area in the Indo-Gangetic Plain. The World Health Organization (WHO) urban air pollution database, released in September 2011, states that Kanpur is the second most polluted city in India. Vehicular emissions have been reported to account for up to 50% of total particulate matter (PM) emissions in urban areas [1]. For Kanpur, these vehicular emissions were found to contribute 21% of SPM (Suspended Particulate Matter) load in a 2007 [2]. Epidemiological research [3] has shown that both fine (0.1–2.5 μm) and ultrafine (<0.1 μm) particles, and specifically fine combustion particles from mobile sources, are associated with increased mortality [4]. PM2.5 or Respirable Suspended Particulate Matter (RSPM) (particle diameter ≤ 2.5 μm) is of greater health concern than coarser particles because it can penetrate deeper into the respiratory tract, finer particles being deposited in the alveolar region in lungs, which can lead to increased rates of respiratory diseases [5]. Finer particles, which form a major part of RSPM, are of greater concern since they act as carriers of toxic substances [6] and contain relatively high concentrations of toxic metals. It is important to note here that air pollution is the fifth leading cause of death in India [7]. The report states that in 2010, outdoor air pollution contributed to over 620,000 premature deaths in India, up from 100,000 in 2000 – a six fold increase within a decade.

Studies on PM load in several Indian cities (Kolkata, Delhi, Chennai, Mumbai & Kochi) clearly show that the presence of PM10, and especially PM2.5, in ambient air results in significant health problems and an overall decrease in lung function [8-13]. Like other mega cities, status of air quality in Kanpur is deteriorating alarmingly. Even though Kanpur city as compared to Delhi is smaller (and densely built) and has fewer vehicles (Kanpur has 10% of total vehicles registered in Delhi, Road Transport Year Book 2007-2009), the city is showing early signs of a mobility crises [14]. Enhanced urban sprawling led to tremendous increase in the number of vehicles (almost doubled: 35000 to 65000) between 2000 and 2010 in Kanpur. Not only vehicular emission, but railway traffic has been documented to contribute to high PM load near railway lines passing through the heart of the city [15]. It is important to note that although PM measurements have been conducted at locations with high PM load and exposure throughout Kanpur city including sites near bridges, road sides, industrial and residential areas [14], measurements close to construction sites and railway activity are lacking. This combined with urbanization and industrialization including poor infrastructure, and has negated control strategies initiated by the Indian government.

The monitoring study reported here was undertaken to provide information on the major PM "hot spots" in Kanpur, to help identify the influencing factors to PM load. The air quality was determined in real time and samples were collected at major road and railway intersections around the city in summer (June) and at a few selected places in winter (December) 2011. There were major construction activities underway in the city during the summer sampling period and we examined the influence of construction activities at a major intersection. In summary, the main objectives were to:

1. Determine PM levels in ambient air at locations where possibility of human exposure is high.

2. Investigate factors that influence PM levels observed.

3. Investigate possible influence of railroads and construction activities on PM levels.

The study provides a 'snapshot' of the PM levels at several locations in Kanpur city and results are expected to aid in evaluation of risk from air pollution.

II. MATERIAL AND METHODS

A. Sampling Sites

PM levels were measured at seven sites across Kanpur city (Figure 1). The sites were selected based on type and location of intersections (road and/or railroad) and sources of air pollution (vehicular exhaust and/or construction activity). Details of sample collection locations along with site abbreviations use henceforth are noted in Table 1.

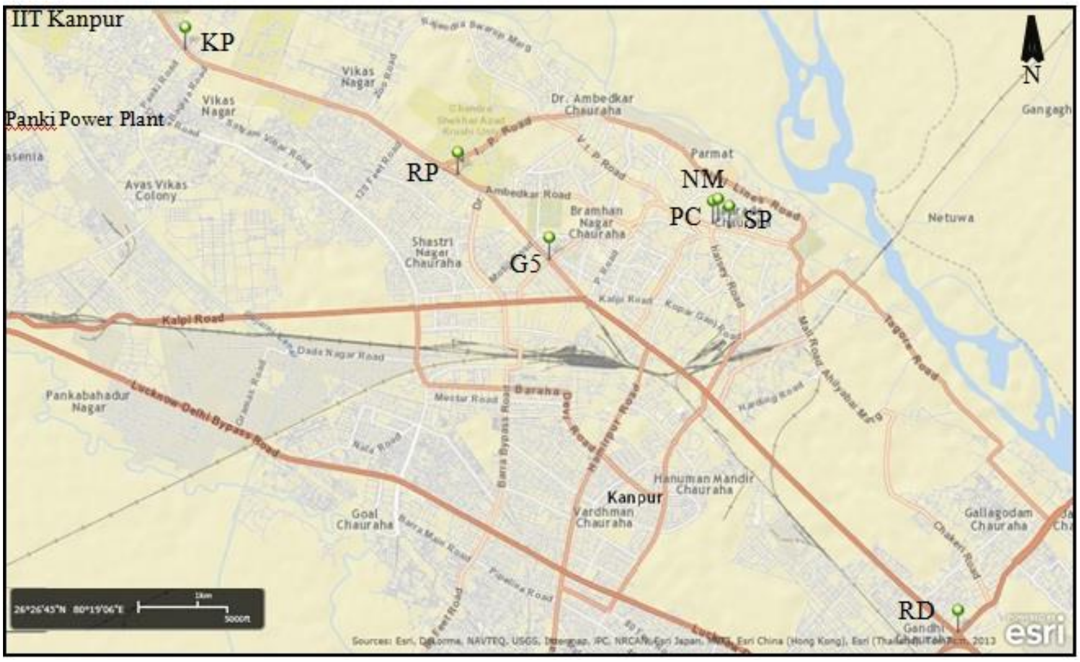

Fig. 1 Map of the sampling sites

TABLE 1 SAMPLING LOCATIONS DESCRIPTION SAMPLING TIME

Location	Abbreviation	Site Description
Sampling Time: June 2011		
Naveen Market	NM	Near a Shop 50m from Construction Site
Somdutt Plaza	SP	Near the roadside
Ramadevi	RD	Near the Intersection ('Chouraha')
Parade Chowk *	PC	Parade Chowk Road Intersection
Kalyanpur *	KP	KP Railroad Intersection
Rawatpur	RP	RP Railroad Intersection
Gumti No. 05	G5	G5 Railroad Intersection
* Sites Sampled Again in December 2011		

Sites RD and KP are located on the city outskirts. RD is a busy intersection of roads connecting three major cities, Kanpur, Lucknow, and Allahabad. KP is a major railroad intersection. Both KP and RD are influenced by emissions from heavy vehicle activity. G5 and RP are also railroad intersections. At RP vehicular traffic is greater than at the typical railroad intersection, G5. Sites SP and NM, close to major roadways are mostly influenced by light vehicular activity. Both these sites are located near the roadside and were chosen primarily to observe influence of on-road vehicles on ambient PM load. PC is a major road intersection that was affected by construction activity during the summer sampling period.

B. Sample Collection

Real time samples were collected at all seven locations for at least 6 h (at each site) during peak daytime traffic hours (0900 hrs-1200 hrs and 1600 hrs-1900 hrs) in summer (June) 2011. Selection of sampling time was based on preliminary traffic volume observations conducted earlier. Although originally planned, time constraints did not permit collection of samples at all sites in winter, only two (PC and KP) out of seven locations were sampled again in December 2011, which were the locations that showed the highest PM levels in summer. Data from these two sites has been used to assess seasonal variations in PM levels (Table 1). Ambient temperature recorded during sample collection ranged from 34.2 to 41.9°C in summer, with highest values recorded at two adjacent locations NM and PC. In winter, temperature at the two sites ranged between 12.8 and 14.5°C.

Dust Aerosol Spectrometer, generally referred to as an Optical Particle Counter (OPC; Grimm Laser Aerosol Spectrometer model 1.108, Grimm Aerosol Technik GmbH & Co, Ainring, Germany) was used in this study. OPC, a portable instrument operating at a flow rate of 1.2 LPM (L min^{-1}) with sample resolution of 1 min average provides real-time measurement of aerosol number concentration in the size range 0.3–20 μm in 15 different channels. Briefly, OPC first converts particle diameter to a particle volume using the mean spherical particle diameter, then the volume data is converted into a mass distribution (μg m^{-3}) using a density factor for urban environments established by the OPC manufacturer. For this study, data from OPC was used to determine TSPM (Total Suspended PM, particle diameters dp≤ 20 μm), PM10 (dp ≤ 10 μm), PM2.5 (dp ≤ 2.5 μm), and PM1 (dp ≤ 1 μm). Values for PM2.0 and PM3.0 were extrapolated to estimate PM2.5. Rest PM levels are calculated directly by the data obtained from OPC. OPC was factory-calibrated just before the study. Field and laboratory blanks were collected to check for contamination.

III. RESULTS AND DISCUSSION

PM levels (TSPM, PM10, PM2.5, and PM1) at all seven locations in summer (June 2011) observed using OPC are shown in Figure 2. PM10 and PM2.5 levels at all locations exceeded the National Ambient Air quality Standards by CPCB India (NAAQS; [16]) and also standards set by USEPA [17]. The only exception is PM2.5 at RP. As expected, highest concentrations of TSPM (2104 μg m^{-3}) and PM10 (1390 μg m^{-3}) and PM2.5 (141 μg m^{-3}) were noted at RD, which is a major road intersection also influenced by heavy duty vehicles (HDVs).

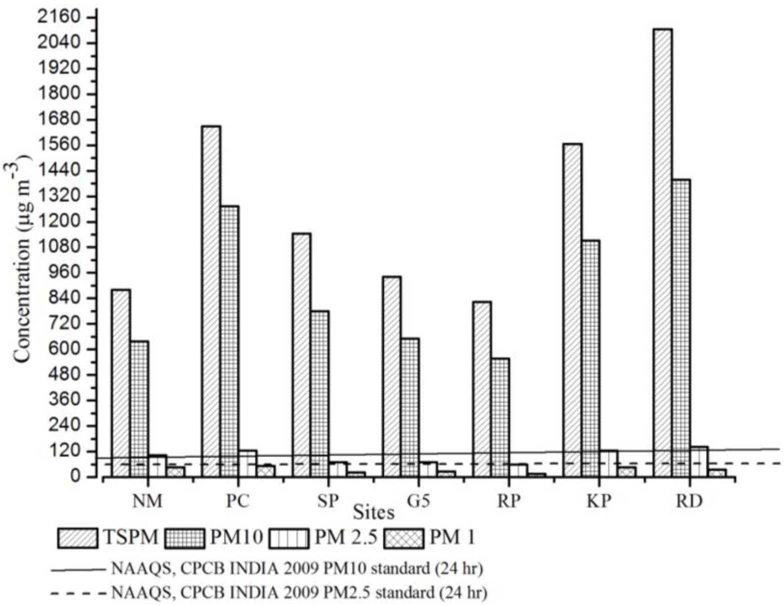

Fig. 2 PM levels (TSPM, PM10, PM2.5, and PM1) at sampling sites (n=7) in summer 2011

Levels observed in this study are approximately an order of magnitude higher than those reported by another study in Kanpur which focused on human exposure [18]. This study focused on locations in the city frequented by students and was conducted in 2009 (March to May) roughly two years before our study. Even though the study does not include any major road intersection in Kanpur, it provides a good comparison of the status of air quality in the city. Levels of PM10 and PM2.5 in our study (637 μg m^{-3} and 103 μg m^{-3}) at Naveen Market (NM), the only location in common, are much higher than the values reported by Ashok et al., 2013 (PM10 ~ 150 μg m^{-3}, PM2.5~ 50 μg m^{-3}). This variation in observed levels highlights the deterioration in air quality over time.

A. Influence of Construction Activity on TSPM and PM10

Average TSPM values at all 7 locations in summer ranged from 822 μg m^{-3} to 2104 μg m^{-3}, and the average PM10 ranged from 556 μg m^{-3} to 1390 μg m^{-3}. It is noteworthy that PM10 contributed more than 66% (range 66–77%) of the TSPM levels at all seven sampling locations.

Highest contribution by PM10 was found at PC (77%) followed by NM (72%). The lowest PM10 contribution was found at RD (66%). Major construction work related to a sewage pipeline was underway at PC during time of summer sampling. Construction activity is suggested to release more coarse particles to the atmosphere [18] and is the most likely reason for the highest PM10 contributions found at PC (77%) and second highest PM contribution (72%) at the site which is approximately 50 m away from PC (NM). It is interesting to note that at none of the other 5 sites, any construction activity was noted during sampling time. Contribution of PM10 to TSPM at all these sites is less than at PC and NM, and other factors affecting levels of PM10 at these sites are discussed in later sections. Briefly, our observations suggest that construction activities could be probable causes of raised PM10 levels in ambient air.

B. PM2.5/PM10 Mass Ratio: Influence of Construction Vs. Vehicular Traffic

PM2.5/PM10 mass ratio has been used extensively to identify the relative contributions of mobile and stationary PM sources [19]. A higher PM2.5/PM10 mass ratio suggests that vehicular exhaust emissions and secondary particulates dominate [20], and a lower ratio suggests that coarse particles from the resuspension of dust and traffic-induced abrasion are dominant [19].

Two main sources, vehicular emission and construction activity, appeared to be the major contributors to PM levels in Kanpur city. As mentioned most affected sites by traffic (KP, G5, NM, and RP) which had higher PM2.5/PM10 mass ratios are shown in Table 2. The contribution of fine particles to the RSPM (from the PM1/PM2.5 mass ratio) was also found to be high at these sites, indicating that vehicular exhausts are important particle sources at these locations. Analysis of data from another study conducted in Kanpur in 2009 [18], reveals that PM2.5/PM10 and PM1/PM2.5 ratios at NM (0.233 & 0.579 respectively) are similar to the ratios obtained in current study (0.163 & 0.438 respectively). These observations are similar to the results of a recent study in Chennai [8], in which the authors suggest that a high PM2.5/PM10 mass ratio (0.62–0.73) indicates significant contributions from vehicular emissions in urban locations. Even though the values obtained in this study are lower (max ~ 0.43), results suggest need for re-examination of criteria based on nature and traffic type in an urban location. In Kanpur, poor infrastructure, mainly damaged roads results in frequent resuspension of road dust and probably leads to lower PM2.5/PM10 ratios than those in a well developed metro city with higher traffic density like Chennai. This observation is supported by the fact that PM2.5/PM10 mass ratio was lower at sites PC, SP, and RD than at the other sites (Table 2), indicating that coarser particles were dominant at these sites, which would have been caused by high traffic on dusty roads leading to the resuspension of dust.

TABLE 2 PM MASS RATIOS (PM2.5/PM10 AND PM1/PM2.5) AT DIFFERENT SITES IN THE SUMMER AND WINTER

Location	**PM2.5/PM10**	**PM1/PM2.5**
NM	0.163	0.438
SP	0.089	0.320
RD	0.101	0.251
PC	0.082	0.428
	0.187*	0.711*
KP	0.112	0.368
	0.205*	0.737*
RP	0.105	0.254
G5	0.109	0.371

* Sites Sampled Again in Winter

Combined influence of vehicular and construction activity on ambient PM levels: It is interesting to note that at NM, both PM2.5/PM10 and PM1/PM2.5 mass ratios (0.233 & 0.579 respectively) are high which suggests the influence of traffic and vehicular exhaust is more at this site. As noted before, second highest PM10 contribution to TSPM (72%) was recorded at NM which is located very close to PC where intense construction activity was underway at time of summer sampling. Both these observations together suggest that construction as well as vehicular activity both contributed significantly to the air quality at this location.

C. Influence of Railroads on PM Load

As noted in the previous section, higher PM10 levels observed at PC can be attributed to construction activity underway at the time of sampling. Although rather high PM10 levels were observed near three major railroad intersections within the city, KP, G5, and RP (Figure 2), no construction activities were noted near the sampling locations. Similar PM ratios at the three railroad sites (Table 2) strongly point to similar PM source (most likely the railroad) at these locations. It must be noted that railroad traffic at these locations is high, with four to five trains using each intersection every hour. The most likely explanation for the high PM10 levels that were found at these sites is the proximity of the railroad junctions and the long waiting time for road vehicles at the intersections.

A study in underground and ground-level railroad stations in Taipei, Taiwan [21] suggested that coarser particles are generated by mechanical friction between train wheels and the railroad track. Similar studies performed at a busy railroad track in Zurich, Switzerland [15, 22, 23] showed that railroad induced PM, fine and coarse (PM1, PM2.5, and PM10), was mainly produced by different forms of abrasion, i.e., from the tracks, wheels, and brakes. The railroad-derived particles also came from abrasion of the gravel bed and the resuspension of mineral dust.

Observations in this study match results by these earlier studies that suggest railroads as source of coarse and fine PM to nearby locations. Influence of a couple other site specific sources of coarse PM load is discussed below.

Impact of Traffic Standstill: At the three railroad sites in this study, traffic regularly comes to a standstill at the railroad intersections and the average waiting time, when the vehicles are idling, is 10–15 min. Even though the traffic movements are slow until the railroad crossing gates reopen, dust is resuspended by the constant movement of large numbers of vehicles.

Impact of HDV: Among the 3 railroad sites examined, the highest PM10 and TSPM levels were found at KP (Figure 3). This was expected since KP is the only railroad intersection at which heavy road vehicles (trucks) are permitted in the daytime. Since the other two railroad intersections, G5 and RP, are located inside the city, no heavy road vehicles are allowed to use them during the day, and only a restricted number are permitted at night. In addition, there is considerable movement of pedestrians in a huge vegetable market near KP, which leads to the resuspension of dust.

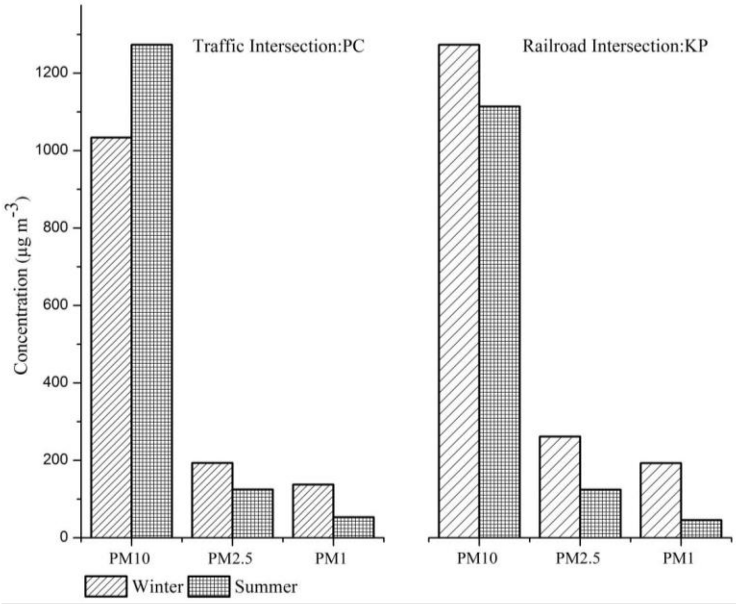

Fig. 3 Seasonal variations in levels of PM10, PM2.5, and PM1 at traffic (PC) and railroad (KP) intersection

It must be noted that even though the prominent source of high PM10 content at these locations is most likely proximity to railroad, the two factors just described (i.e., high road vehicular and pedestrian traffic) together might contribute significantly to the high PM10 values found at KP.

D. Respirable Suspended Particulate Matter (RSPM or PM2.5)

Compared to the other three sites, RSPM levels (Figure 2) were high at four sites, PC (125 µg m^{-3}), KP (124 µg m^{-3}), NM (104 µg m^{-3}), and RD (141 µg m^{-3}). These high RSPM levels were most likely caused by vehicular exhausts because no other combustion sources were observed. This is in keeping with results from an emissions inventory and source apportionment study in Kanpur, in which vehicular emission was found to be the biggest PM2.5 emission source (28–37%), the next biggest sources being secondary particles (15–30%), open burning (7–23%), road dust (3–6%), and coal burning (0–13%). Emissions from vehicles are a major health concern because they occur within the human breathing zone and increase the typical human daily exposure to toxins [24]. PM1 contribution to the RSPM was significantly higher in winter, as is explained below (Sec III E).

E. Seasonal Variation in PM Levels

Two locations which showed highest PM levels in summer (PC and KP) were sampled again in winter to assess influence of change in weather conditions on PM levels. In general, higher PM levels in winter are expected and can be attributed to more stable atmospheric conditions (leading to poor dispersion of pollutants) and lower rainfall (resulting in less washing out of particles). Except for PM10 at PC levels of PM in winter were higher than in summer at both locations (Figure 3).

PM2.5 levels increased in winter, consistent with observations from a previous study in Kanpur city [25]. Higher PM2.5 levels in winter can be attributed to stable atmosphere, increased PM emitting activities such as open burning [26], and occurrence of meteorological conditions favouring formation of finer particles [27]. In keeping with observations in summer (Sec III A), increase in PM2.5 and PM1 levels was higher at the railroad intersection KP than at traffic intersection PC.

Increased PM10 levels in winter at KP can be attributed to foggy conditions which lead to settling of coarse particles. Surprisingly, PM 10 levels showed a slight decrease (19%) at PC in winter. As discussed earlier, construction activity resulting in dusty roads was found to contribute significantly to high PM levels in summer. Construction activities were completed and dusty roads were replaced with paved roads before the winter sampling period. This is the most probable reason for the unexpected reduction in PM10 levels observed in winger at PC. Therefore, as per our observation, construction activity could be considered as a major cause of raised PM10 levels in the city.

Contribution of fine PM to RSPM: Excessive biomass burning [28] and local heating during the winter result in higher contributions of finer particles [29]. As expected, a higher contribution from PM1 to PM2.5 (Figure 4) was found in winter:

PM1 contribution being approximately 28% and 37% higher in winter than summer at sites PC and KP, respectively. This highlights increased health risk due to significant increase in fine particles that can penetrate deeper into lungs, in RSPM during winter.

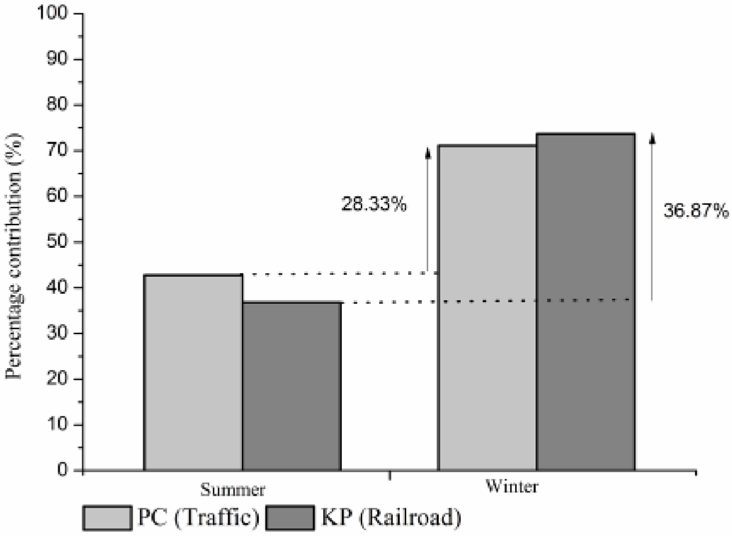

Fig. 4 Percentage contribution of PM1 to PM2.5 in summer and winter 2011 at traffic (PC) and a railroad (KP) intersection

IV. CONCLUSIONS AND IMPLICATIONS

This study provides a snapshot of recent air quality conditions in Kanpur city under different traffic conditions. Pollution in Kanpur city is reaching alarming levels and as expected PM load is associated with the increasing number of vehicles on roads. It is apparent that economic growth leading to improved lifestyles is causing increased detriment to air quality that is outpacing pollution prevention efforts being implemented by Indian government. The fact that current study which was conducted for a very short span provides information on variation of PM load with location and sources, is useful in the identification of ‘hot spots’. Although previously conducted studies in Kanpur provide information on PM levels and identify major factors, it may be noted that influence of railroad and construction activity on ambient PM levels is highlighted by this monitoring study. Most important contribution of this study is that it provides a view of the emission sources not currently considered seriously. Research focused on the cities with railway lines passing through densely populated areas should seriously consider this source when evaluating air quality in future. In summary, results from this study highlight the need for review of strategies currently in use to achieve goals of sustainable and safe environment.

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