Influence of Heterogeneous Traffic on the Roadside Fine ($PM_{2.5}$ and PM_1) and Coarse (PM_{10}) Particulate Matter Concentrations in Chennai City, India

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Abstract**—**In this paper the influence of heterogeneous traffic on the temporal variation of ambient PM_{10}, $PM_{2.5}$ and PM_1 concentrations at a busy arterial route (Sardar Patel Road) in the Chennai city has been analyzed. The hourly PM concentration, traffic counts and average speed of the vehicles have been monitored at the study site for one week (19^{th}-25^{th} January 2009). Results indicated that the concentrations of coarse (PM_{10}) and fine PM ($PM_{2.5}$ and PM_1) concentrations at SP road are having similar trend during peak and non-peak hours, irrespective of the days. The PM concentrations showed daily two peaks corresponding to morning (8 to 10 am) and evening (7 to 9 pm) peak hour traffic flow. The PM_{10} concentration is dominated by fine particles (53% of $PM_{2.5}$ and 45% of PM_1). The high $PM_{2.5}/PM_{10}$ ratio indicates that the majority of PM_{10} particles originate from re-suspension of road dust. The analysis of traffic flow at the study site showed that 2W, 3W and 4W are having similar diurnal trend as PM concentrations. This confirms that the 2W, 3W and 4W are the main emission source contributing to ambient PM concentration at SP road. The speed measurement at SP road showed that the average speed of 2W, 3W, 4W, LCV and HCV are 38, 40, 38, 40 and 38 km/hr and 43, 41, 42, 40 and 41 km/hr respectively for the weekdays and weekdays.

Keywords**—**particulate matter, heterogeneous traffic, fine particles, coarse particles, vehicle speed, weekend and weekday.

I. Introduction

URBAN air quality has become an increasingly stressing public health concern in many cities of the world, especially in developing countries like India. Automotive emission is the main air pollution problem in urban areas. Vehicles emits various pollutants, such as particulate matter (PM), carbon dioxide (CO_2), carbon monoxide (CO), hydro carbons (HCs), oxides of nitrogen (NOx) and sulphur dioxide (SO_2). Among the vehicular air pollutants, particulate matter (PM) is considered to be cause more adverse effects to human health [1] - [4], impact on climate e.g. absorbing or reflecting the radiation, modifying the scattering, favoring or preventing the formation of clouds, the albedo of them and its life time, heating may cause the burn-off of clouds, effects on the global radiative budget [5], ecosystems [6] , [7] building materials [8] and reduction of visibility [9].

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PM is defined as any airborne finely divided solid or liquid material with an aerodynamic diameter smaller than 100 µm (40CFR51.100-91). PM_{10}, $PM_{2.5}$ and PM_1 are the classifications of particulate matter based on aerodynamic diameters smaller than 10, 2.5 and 1 µm, respectively [10]. Particles with different sizes deposit in different sections of the human respiratory system and have various effects on human health [11]. It is reported that fine particles ($PM_{2.5}$ and PM_1) do more harm to human health [12] – [14] than the coarse PM. The reason being, fine particles are toxic in nature and it carriers reactants and harmful substances [15].

In general, the traffic-generated emissions are accounting more than 50% of the total PM emissions in the urban areas [16]. The main sources for ambient particulates at urban roadways are vehicle exhausts, emissions from tyre and brake wear and re-suspension of road dust. The main factors influencing PM emissions are the vehicle type, technology and fuel used, maintenance and the operating mode of the vehicle i.e. speed, acceleration and engine temperature [17].

Air quality in Chennai city is getting worse due to fast urbanization and industrialization. The city is located on a flat coastal plain area known as the Eastern Coastal Plains. Its average elevation is about 6.7 m. In 2001 Chennai had approximately 4.56 million inhabitants living in an area of 174 km^2 [18]. The city has a diversified economic base anchored by the automobile, software services, hardware manufacturing, healthcare and financial services industries. Chennai is the automobile capital of India with the establishments of manufacturing base (30%) of many India's automobile industry [19] and 35% of its auto components manufacturing industry [18]. A large number of automotive companies including Hyundai, Ford, BMW, Mitsubishi, TVS Motors, Ashok Leyland and Madras Rubber Factory (MRF), setup their manufacturing units in and around Chennai. The Integral Coach Factory manufactures railway coaches and other rolling stock for Indian Railways.

The buses run by the Chennai metropolitan transport corporation are the predominant mode of public transport in the city. The city has the total road length of 780.95 km [18]. Bus services are inadequate to move the commuters from one location to another [20]. This made the increase in personal mode of transport. Motor vehicle ownership in Chennai city has been increasing at unprecedented rates, between 10 to 20% per annum. The current ownership level is about 536 individual passenger vehicles per 1,000 populations in Chennai and the density of motor vehicles per sq. km has increased from 22 in 1996 to 76 in 2009. In 2009, the number of registered vehicles in Chennai is dominated by 2-wheelers (includes scooters, motorcycles and mopeds, about 1.81 million i.e. 75.6% of the total vehicle composition) followed by Cars 4, 35, 487 i.e. 18.2% of the total vehicle composition [21]. A recent study by Ramachandra and Shwetmala [22] reported that number of vehicles in the city is 20, 14, 776, emitting the 23.01 of PM, 34903.5 of CO_2, 429.13 of CO, 18.99 of CH_4, 118.95 of HC, 353.67 of NOx and 108.04 Mg/km of SO_2. The result further confirms that Chennai have higher proportion of emissions in PM. In recognition of the severity of the PM pollution problem Central Pollution Control Board (CPCB) has designated Chennai city as a non attainment area. Therefore, there is an urgent need for the management of PM emitted from vehicular sources.

In this paper, the influence of heterogeneous traffic on the temporal variation of ambient PM_{10}, $PM_{2.5}$ and PM_1 concentrations measured during January 2009 at a busy arterial road (Sardar Patel Road) in the Chennai city has been analyzed.

II. Materials and Methodology

A. Study Region

Fig. 1 shows the details of study region. The sampling site is located in the premises of Indian Institute of Technology Madras (IITM) on the roadside of a major arterial route (Sardar Patel Road) within the Chennai City in India. Traffic flows on SP road is 1, 70,000 vehicles per day. Braking is frequent near the measurement site due to the presence of traffic lights coupled with the intersections, located one at 50 meters to the west and another at 500 meters to the east. Many primer institutes such as Cancer Institute's, hospitals, Central Leather Research Institute, Anna University, central polytechnic, software companies and tourist spots (Children's park, Kamarajar Mandapam and Gandhi Mandapam) are also located in the study region. In addition, many heavy industries are also located about 30 km away in the NNE direction from the study area. The study region is also surrounded with dense residential cum commercial areas. Therefore, this region has intense human activity and having heavy traffic flow.

B. PM Data

The PM_{10}, $PM_{2.5}$ and PM_1 mass concentrations at the study site are measured using portable environmental dusts monitor (GRIMM-107) for the winter week (19 to 25[th] January 2009). The Grimm dust monitor is small portable instrument designed to provide continuous number and mass size distributions of particulate matter suspended in the ambient air. The dust monitor samples air at 1.2 lit/min into a light scattering optical particle counter, with a lower cut-off at 0.25 µm. The instrument kept at a distance of about 6.5 meters from the SP road and the sampling inlet is placed at 1.2 m above the ground level. The PTFE-Teflon Filter, 47 mm diameter, 0.2 micron size is being used for PM sampling. During the monitoring the 1-minute average concentrations of PM_{10}, $PM_{2.5}$ and PM_1 are recorded on a data storage card. The hourly and 24-hour average concentrations are subsequently calculated from 1 minute readings.

Fig. 1 Details of the study region

C. Traffic Data

A traffic census has been conducted at the study region. The traffic counts have been made manually for 7 days (Monday to Sunday) at 15 minutes intervals. The vehicles have been grouped into five major categories namely 2-wheelers, 3-wheelers, 4-wheelers (cars and mini carriers), light commercial vehicles (LCV) and the heavy commercial vehicles (HCV) (lorries/trucks and buses/coaches). The maximum numbers of vehicles per day at the study period are found to be 1, 69,254 and 1, 36,830 on working days and weekends, respectively. Weekday traffic density is 20% more than weekend traffic density. The maximum traffic at SP road (study region) during peak hour is found to be 11, 226 vehicles per hour. Table I presents the heterogeneous traffic flow composition and vehicles classification at the study site.

During the working days maximum share of traffic has been dominated by 2-weelers (58%) followed by the cars (28%), autos (3-wheeler) (6%), buses (3%), carriers (3%), lorries and mini carriers (1% each). On weekends i.e. Saturday and Sunday traffic flow is significantly different from the weekday traffic. This is because most of the government, private offices located at the study region, Saturday and Sunday being holidays and some schools and colleges which are off only on Sundays. During weekends it is found that 2-wheelers have been reduced from 58% to 50% and cars have been increased from 28% to 33%. Similarly, 3-wheelers (auto) have also been increased from 6% to 8%. Apart from 2 and 3 wheelers, all the other types of vehicles have also been increased 1% from the weekday composition, except carriers. At the SP road, 75% of the vehicles are powered by gasoline engines and 25% is by diesel driven vehicles. The 4-wheelers diesel driven vehicles composed of 41% of buses, 8% of lorries, 36% of carriers and 15% of mini carriers during the working days and 39% of buses, 11% of lorries, 21% of carriers and 29% of mini carriers during the weekends.

TABLE I
PERCENTAGE DISTRIBUTION OF EACH VEHICLE CLASSES AT THE STUDY AREA

Period	Gasoline driven vehicles (%)				Diesel driven vehicles (%)					
	2W	CAR	3W	MC	CAR	3W	BUS	C	MC	L
Whole week	55	20	7	0.57	10	1	3	2	0.43	1
Week days	56	19	6	0.57	10	1	3	3	0.43	1
Week end	49	22	8	1.14	11	1	4	2	0.86	1
Day hours	57	19	6	0.57	10	1	3	2	0.43	1
Night hours	52	20	7	0.57	11	1	4	3	0.43	1
Heavy traffic hours	56	20	6	0.57	10	1	3	2	0.43	1
Lean traffic hours	52	20	7	0.57	11	1	4	3	0.43	1

Whole week - Monday to Sunday; Week Days - Monday to Friday; Week Ends - Saturday and Sunday; Day Hours - 6 am to 6 pm; Night Hours - 6 pm to 6 am; Heavy Traffic Hours - 6 am to 10 pm; Lean Traffic Hours - 10 pm to 6 am; MC – Mini Carriers; C – Carriers; L – Lorries.

The vehicle speed on SP road has been measured by using Z-15^{TM} handheld stationary traffic radar (make: MPH Industries Inc., MPH Z-15^{TM}) for the weekdays (Monday to Friday) and weekends (Saturday and Sunday). Table II shows the observed vehicle speed for various types of vehicles at the study site. Further, parking lot survey has also been carried out at the study region (300 samples in each 2-W, 3-W and 4-W categories; 200 samples in LCV; 100 samples in HCV) to know the category and year of manufacture for each vehicles type.

TABLE II
PERCENTAGE DISTRIBUTION OF EACH VEHICLE CLASSES AT THE STUDY AREA

Period	Gasoline driven vehicles (%)					Average speed (km/hr)
	2W	3W	4W	LCV	HCV	
Whole week	38.63	41.34	39.10	40.62	39.11	39.76
Weekdays	37.78	39.68	37.69	39.55	37.77	38.49
Week end	39.48	42.99	40.50	41.70	40.44	41.02
Day hours	34.22	29.62	32.59	31.42	30.50	31.67
Night hours	42.31	51.71	43.46	49.02	46.21	46.54
Heavy traffic hours	36.27	34.86	37.21	34.52	34.49	35.47
Lean traffic hours	44.46	56.34	46.29	53.71	50.59	50.28

L – Light Commercial Vehicles; HCV – Heavy Commercial Vehicles.

III. RESULTS AND DISCUSSION

Fig. 2 presents the hourly variations or fine and coarse particulate matter at the study site for one week. It is observed that the concentrations of coarse (PM_{10}) and fine PM ($PM_{2.5}$ and PM_1) concentrations having similar trend during peak and non-peak hours irrespective of the days. The analysis of PM-hourly trends on both weekdays and weekends of the monitoring period showed daily two peaks corresponding to morning and evening peak hour traffic flow. During the weekdays, the maximum PM concentrations occur during morning hours between 8.00-10.00 hours and in the evening, it is between 19:00-21:00 hours. Similarly, on weekends, it is observed between 9:00-11:00 hours in the morning and 19:00-21:00 hour in the evening. This is because of sufficient source emissions, poor dispersion conditions and suspension of fine particulates in the ambient environment for longer hours of the day due movement to vehicles. The minimum concentrations on both the weekdays and weekends are observed between 01:00-02:00 hour (night time), when the traffic flow trickle. The minimum PM concentrations are also observed during daytime between 14:00-15:00 hours. This is mainly because of reduced traffic flow and increased atmospheric turbulence (sea breezes and increase in mixing height). Further, the lower PM concentrations have been observed between nighttime 01:00–05:00 and during daytime 12:00-16:00 hours. The hourly average $PM_{2.5}$ and PM_1 concentrations showed marginal variation between traffic flow hours (6 am to 10 pm) and trickle traffic flow hours (10 pm to 6 am). This is mainly because of higher settling time of fine size particulates. During day time considerable amount of PM mass is generated because of movement of vehicles (exhaust emissions and re-suspension). The PM emissions released during evening rush hours are accumulated in the ambient environment because of inversion conditions. This PMs are gradually reduces during night time and reach to minimum levels at midnight. However, some of the fine size particulates are developing into large size particulates under favorable inversion conditions. This resulted in slightly increase in PM levels after midnight.

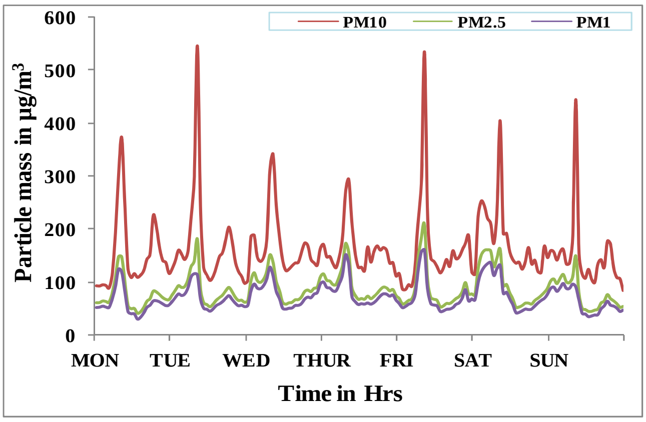

Fig. 2 Hourly variations of coarse and fine particle matters at the study area

The analysis of the PM data showed the significant (short-term) variability in coarse particles (PM_{10}) than the fine particles ($PM_{2.5}$ and PM_1). The mass concentration in PM_{10} is dominated by fine particles (53% of $PM_{2.5}$ and 45% of PM_1).

The difference between the PM_1 and $PM_{2.5}$ are close, which indicates presence of considerable amount of the PM_1 concentration in the ambient environment. Though the standards for PM_1 are not existing but based on the aerodynamic size it is more toxic than $PM_{2.5}$ concentrations and results significant health risks to public using this corridors.

The high $PM_{2.5}/PM_{10}$ ratio indicates that the majority of PM_{10} particles originate from re-suspension of dust. The resuspended dust results due traffic had a clear effect on the $PM_{2.5}/PM_{10}$ ratio but not on the $PM_1/PM_{2.5}$ and $PM_1/PM_{2.5}$ ratios. The PM_{10} concentration is strongly correlated with $PM_{2.5}$ (R^2 =0.67) concentration than PM_1 concentration (R^2 =0.53). Table III and Table IV presents the summary of hourly average PM mass concentrations and PM ratios, mass distributions and correlation between coarse and fine PMs respectively.

TABLE III
SUMMARY OF HOURLY AVERAGE PM MASS CONCENTRATIONS AND ITS RATIOS

Period	Particulate mass concentrations (µg/m³)			Particulate mass ratios		
	PM_{10}	$PM_{2.5}$	PM_1	$PM_{2.5}/PM_{10}$	PM_1/PM_{10}	$PM_1/PM_{2.5}$
Whole week	162.87	87.05	73.59	0.55	0.47	0.85
Weekdays	162.87	87.05	73.59	0.55	0.47	0.85
Week end	163.22	88.09	74.01	0.54	0.46	0.84
Day hours	180.93	86.83	72.25	0.49	0.41	0.84
Night hours	144.82	87.29	74.94	0.61	0.53	0.86
Heavy traffic hours	172.88	86.11	72.30	0.51	0.43	0.84
Lean traffic hours	138.56	89.37	76.75	0.65	0.56	0.86

TABLE IV
SUMMARY OF HOURLY AVERAGE PM MASS DISTRIBUTIONS AND ITS CORRELATION COEFFICIENTS

Period	Particulate mass distributions (%)			Particulate mass regression correlation coefficient (R^2)		
	% of $PM_{2.5}$ in PM_{10}	% of PM_1 in PM_{10}	% of PM_1 in $PM_{2.5}$	$PM_{2.5}$ vs. PM_{10}	PM_1 vs. $PM_{2.5}$	PM_1 vs. PM_{10}
Whole week	53.45	45.18	84.54	0.67	0.97	0.53
Weekdays	53.45	45.18	84.54	0.72	0.97	0.57
Week end	53.97	45.34	84.02	0.59	0.96	0.44
Day hours	47.99	39.93	83.21	0.78	0.96	0.63
Night hours	60.27	51.75	85.85	0.56	0.98	0.48
Heavy traffic hours	49.81	41.82	83.96	0.72	0.96	0.57
Lean traffic hours	64.50	55.39	85.88	0.83	0.98	0.77

Fig. 3 shows the hourly variation of PM concentrations and corresponding traffic flow. From the figure, it is found that 2W, 3W and 4W are having similar diurnal trend as PM concentrations. This indicates that the 2W, 3W and 4W are the main emission source contributing to ambient PM concentration at SP road. The number of HCV on the SP road during weekday and weekend is almost same with marginal variations. This is because of the buses run by state government transport corporations with regular trips in a day. Table V shows the PM concentrations, corresponding TVC and vehicle speed during morning and evening peak hours.

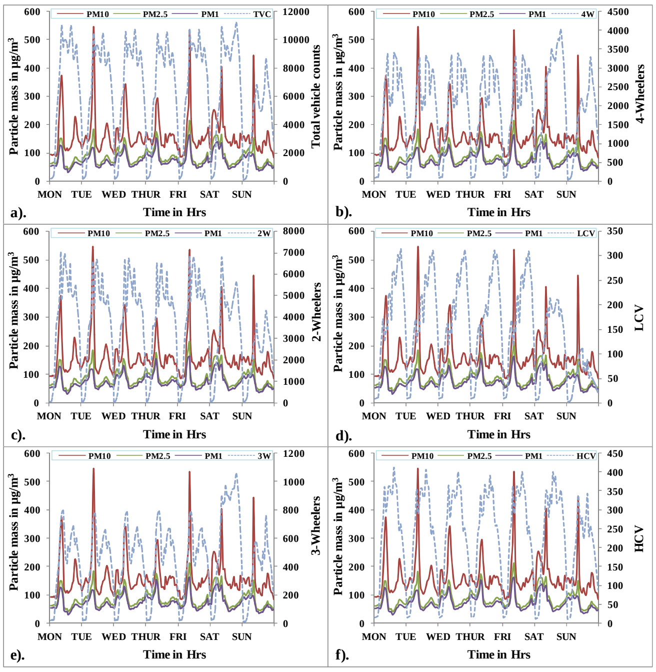

Fig. 3 Hourly variations PM concentrations and corresponding traffic flow at the study site during the monitoring period

TABLE V
SUMMARY OF PM_{10}, $PM_{2.5}$ AND PM_1 CONCENTRATIONS AND TRAFFIC CHARACTERISTICS DURING PEAK HOURS

Description		Peak /Rush hours: Weekdays Morning 08:00-10:00	Weekdays Evening 19:00-21:00	Weekends Morning 09:00-11:00	Weekends Evening 19:00-21:00
Particle mass (µg/m³)	PM_{10}	211-545	139-226	114-443	119-177
	$PM_{2.5}$	88-211	62-92	51-164	59-77
	PM_1	69-163	59-80	42-134	50-66
Total vehicle count	2W	4229-7019	4284-5475	2752-6698	3024-5606
	3W	632-796	519-602	465-894	457-1059
	4W	2466-3378	2643-3014	1671-2987	2350-4017
	LCV	118-216	268-313	65-192	42-191
	HCV	280-365	226-262	262-351	197-353
Traffic speed (km/hr)	2W	23-38	30-36	31-39	28-42
	3W	18-36	29-36	32-35	28-22
	4W	28-35	32-36	31-36	29-42
	LCV	28-33	23-34	35-37	25-35
	HCV	28-34	26-30	32-39	23-35

Speed measurements at SP road indicated that the average speed of 2W, 3W, 4W, LCV and HCV is 38, 40, 38, 40 and 38 km/hr and 43, 41, 42, 40 and 41 km/hr respectively for the weekdays and weekdays. During, traffic jams, the vehicle speed at SP road is reduced 2 km/hr. On Tuesday and Friday traffic jams have been occurred between 8:30 am and 10:00 am and very high PM concentrations have been observed (Fig. 4).

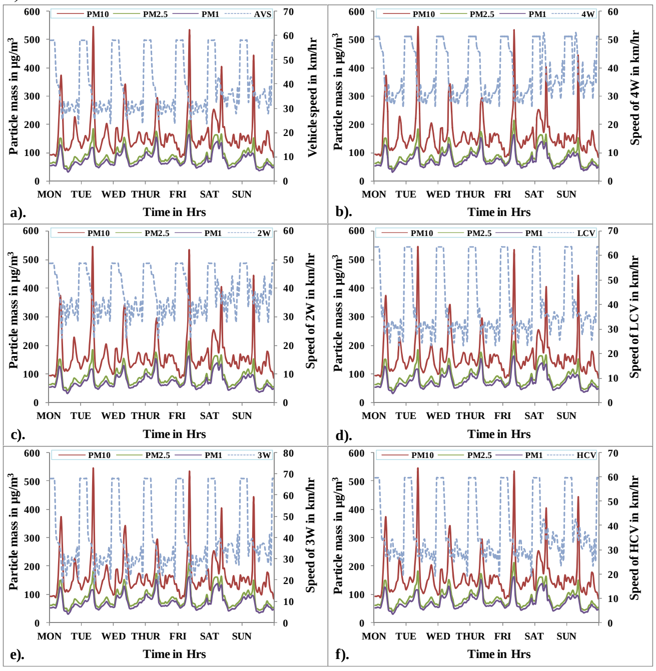

Fig. 3 Hourly variations PM concentrations and corresponding vehicle speeds at the study site during the monitoring period

IV. Conclusion

In this study the interrelationship between PM, traffic and vehicles average speed has been studied using one week monitored data (19-25th January 2009) at SP road in Chennai city in India. It is found that the coarse (PM_{10}) and fine PM ($PM_{2.5}$ and PM_1) concentrations at SP road are having similar trend during peak and non-peak hours irrespective of the days. PM concentrations showed daily two peaks corresponding to morning and evening peak hour traffic flow. During the weekdays, the maximum PM concentrations occur during morning hours between 8.00-10.00 hours and in the evening, it is between 19:00-21:00 hours. Similarly, on weekends, it is observed between 9:00-11:00 hours in the morning and 19:00-21:00 hour in the evening. Further, it is found that 2W, 3W and 4W are having similar diurnal trend as PM concentrations. This indicates that the 2W, 3W and 4W are the main emission sources contributing to ambient PM concentration at SP road.

The mass concentration in PM_{10} is dominated by fine particles (53% of $PM_{2.5}$ and 45% of PM_1). The high $PM_{2.5}/PM_{10}$ ratio indicates that the majority of PM_{10} particles originate from re-suspended dust. At SP road the average speed of 2W, 3W, 4W, LCV and HCV is found to be 38, 40, 38, 40 and 38 km/hr and 43, 41, 42, 40 and 41 km/hr respectively for the weekdays and weekdays.

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