Universal Journal of Environmental Research and Technology
 eISSN 2249 0256
Available Online at: **www.environmentaljournal.org**
2015 Volume 5, Issue 4: 179-187

Open Access **Research Article**

Study of Mass Concentration of Particulate Matter Exposure on Weekly Basis for Two Seasons at an Urban Industrial Site in Delhi

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Abstract:
This paper presents particulate matter load at different aerodynamic diameter for two seasons of an urban industrial site in Delhi using portable aerosol spectrometer. The result showed that seasonal average concentration varied from 57 to 457µg m^{-3} for PM_{10} in the pre-monsoon and 78 to 900 µg m^{-3} in post-monsoon season. The fine particles with aerodynamic diameter less than 2.5µm were observed from 15 to 65 µg m^{-3} in pre monsoon and 16 to 772 µg m^{-3} in post monsoon. The mean concentration variation shows an expected weekly pattern of increased values on weekdays than weekend for pre-monsoon but in post monsoon the weekend concentration was found to be higher than weekday's value. The mass fraction of $PM_{10-2.5}$ shows greater variability in post monsoon season with 105µg m^{-3} and 81µg m^{-3} for pre-monsoon season. The size ratio fraction for $PM_{2.5}/PM_{10}$ ranged from 0.17 to 0.66 in two seasons. The seasonal variation for PM_{10} and $PM_{2.5}$ showed a strong linear relationship for the weekly behavior with R^2 from 0.48 to 0.99. The correlation matrix for weekday and weekend pattern shows that particulate matter of different aerodynamic diameter was positively correlated in two different seasons. The observation indicates that despite several measures of pollution abatement the people living in nearby areas are at significant risk of respiratory health problems.

Keywords: Particulate matter, aerosol, industrial region, pre-monsoon, post-monsoon.

1.0 Introduction:
The quality of ambient air surrounding humans has always been a mix of various gases and particulate matter which get dilute and dispersed in environment before causing any adverse effect on ecology and human health. However with urbanization, industrial and economic growth the price of rapid development had been paid through introduction of pollutants in the atmosphere having complex and long residence time resulting in degraded state of air quality (Seinfeld and Pandis, 2006; Stott and Tett *et.al.*, 2000; Ramanathan and Crutzen *et.al.*, 2001). In recent years, understanding the physical, chemical and biological properties of aerosols and other air pollutants a special emphasis has been given to study the deleterious impact on ecology and human health. The various studies had shown critical relation for air-pollutants becoming a main cause for respiratory diseases and reducing human longevity (Johnson, 2004; Pope, 2000; Pope and Dockery *et.al*. 2006). The sustained exposure of increased particle concentration may lead to chronic respiratory diseases, frequent hospital admissions, premature child births and lower life expectancy (Greenstone and Nilekani *et.al.*, 2015; Mathew and Goyal *et.al.*, 2013). The earlier work had shown that the aerosol particles play a significant part role in climate change and cloud condensation nuclei process through their light absorbing properties (Poschl, 2005; Bond and Bergstrom, 2006; Krishna, 2012) which may alter the reflectivity from earth surface.

The Particulate matter (PM) or aerosol is a suspension of liquid or solid particles in atmosphere. They are studied through the standard point space they occupy in size range spectrum under different categories. From the human health perspective it has been divided into coarse, fine and ultrafine particles. The particles with aerodynamic diameter less than or equal to 10 micrometers are called PM_{10} which on inhalation through respiration can reach the upper part of nasal cavity and airways in humans. The particles with diameter of 2.5micrometers or lesser are called $PM_{2.5}$ that can pass further into lungs reaching till thoracic region. The particles with diameter lesser than 2.5micrometre are referred as $PM_{1.0}$ which represent the danger of reaching deep into alveoli sac region where they can get mixed with the blood and harms the vital organs of the body (Pope, 2000; Briggs, 2003 and Johnson, 2004). The ambient air of an area would be affected by the kind of various activities prevalent in that region. The removal process of aerosol particles from air depends on the size of particles. The particles with fine aerodynamic diameter settles within few hours while coarser particles get settled in few days through various dry and wet deposition processes (Pope and Dockery *et.al*., 2006; Raes and Van *et.al*., 2000). The developing countries in particular are at higher risk of pollution exposure since the techniques measures to check and reduce the pollution levels are not well-equipped.

In recent time's unexpected increase in aerosol particles concentration in air have felt the need for firm monitoring of pollutants in different activity based regions. Different studies have indicated that assessment needs to account for various land use based emission activities such as for residential, industrial, and institutional etc. (Guttikunda, 2012; Yadav and Sahu *et.al,*. 2014). The personal exposure to people while commuting also accounts for vehicular emission which affects health and has became a menace in Delhi (Kumar *et.al.,* 2014; Kumar and Gupta, 2013; Guttikunda and Goel *et al.,* 2014). Being a metropolitan city, Delhi serves as national commercial hub for several domestic, national and international activities. The city presents a good network of pollution monitoring station deployed by various agencies keeping a check on level of air pollutant in different areas. The seven days of week had been divided into official working days - weekdays for government and private institutions, industrial organization from Monday to Friday and non-working days as weekends on Saturday and Sunday (Gour and Singh *et.al.,* 2013; Kaushar and Chate *et.al.,* 2013). However at some places it is off on second Saturday only or there is half-day of working hours on Saturday. Previous studies on cyclic pattern of a week for aerosol particles have found that particulate matter has higher concentration on weekdays than over days of weekend (Yadav and Sahu *et.al*., 2014; Salwa and Ahmad et.al. 2013; Girgzdiene and Rameikyte, 2007). Their studies found significant relation exists between weekday and weekend behavior of aerosol particles for different land use activity. The people living close to industrial-commercial areas or coming at workplaces are exposed to the particulates released from different industrial processes affecting health and work productivity.

The present work was carried out to assess the variation of particulate matter concentration for PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ at an urban industrial location in Delhi for two seasons before and after monsoon. The observations were tested to signify whether concentration levels vary on different days (Weekdays and Weekends) of a week monitored in pre-monsoon and post-monsoon season of year 2014. It was also tested that whether changed weather conditions during two seasons made any impact on the particulate concentration level in the area.

2. Material and Methods:

2.1 Site Description:

Delhi is the capital and one of high-end metro cities of India. Recently it is being perceived as an area unsuitable for human life in terms of the degrading quality of ambient air (Guttikunda and Goel, 2013; Guttikunda and Goel *et al.,* 2014). Its geographical region lies at a latitude of 28°24'17"and 28°53'00" North and longitudes of 76°20'37" and 77°20'37" East. The weather condition for Delhi varies through different seasons of a year. The average ambient temperature observed for pre-monsoon was 25ºC - 39ºC and 20ºC -34ºC in post monsoon season. The relative humid condition was observed around 33% in pre-monsoon and 52-62% for post-monsoon season. Generally the humidity of a city area gets lower due to high temperature profile and rapid run-off of precipitation from little vegetation cover in the area (Murthy, 2004). The mean wind speed for Delhi varied from 0.5 - 4m/s for major time of the year with wind direction predominantly in north-west direction (Mohan and Bhati, 2012). Studies have shown that although insignificant but positive relation exists between the particulate matter and wind speed which slowly drifts away the particles from site (Sahu and Beig *et. al.,* 2011; Kaushar and Chate *et.al*., 2013; Yadav and Sahu *et.al.,* 2014). The months from April to May has been considered as pre-monsoon after which the south-western monsoon season prevails in the area for around two month with average rainfall of 611mm (IMD, 2010). The months from September to October was taken as post-monsoon season (Murthy 2004).

2.2 Experimental Set-Up:

The experimental setup was placed at an urban industrial site called Mayapuri in Delhi. The site is typical representative of light goods manufacturing industrial activities such as for electroplating work on switches and magnetic relays, hardening of auto parts, automobile service stations, electroplating with zinc, phosphorus and recycling of metal scrap etc. (CPCB, 2010). The selected area has residential-cum-industrial part with some commercial activities. The area is known as Mayapuri Industrial Area Phase I and Phase II. The experimental site was located in Mayapuri Industrial Phase II. The site was at a distance from some residential colonies and thus also represents the risk of particulates exposure to the people staying in them.

The monitoring of PM concentration was done with laser based GRIMM Aerosol spectrometer (Model 1.108 Germany) which was well-calibrated and had ± 2% of mono-disperse aerosol particles. The instrument works on dual principle of light scattering and gravimetric filter sampling assessing number concentration and mass concentration of the ambient particles. The instrument measures mass concentration values in environmental mode as PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ on real time monitoring basis. The ambient air is drawn into the inlet unit through internal volume controlled pump at a rate of 1.2 L/min maintained during the monitoring period. The data measured from instrument is stored in a data storage card of instrument which is transferred to computer system via port. The present data was obtained on a usual of 5 minute interval that was averaged in hourly interval for different days of observation. The instrument was kept at a height of 6m from the ground and placed at a distance away from any industrial machines and road traffic avoiding any biases for observation of data.

The present study was carried for one week in pre-monsoon season of May month from May 21, 2014 to May 27, 2014 and post monsoon season of September-October month from Sept 29, 2014 to Oct 5, 2014. The monitoring instrument was operated for eight hours from 09:00 am to 17:00 pm corresponding with timing for the industrial activities; however the chances of office hours little more 1-2 hours depending on the work cannot be neglected. We had taken the mass mode of particulate matter concentration for observation.

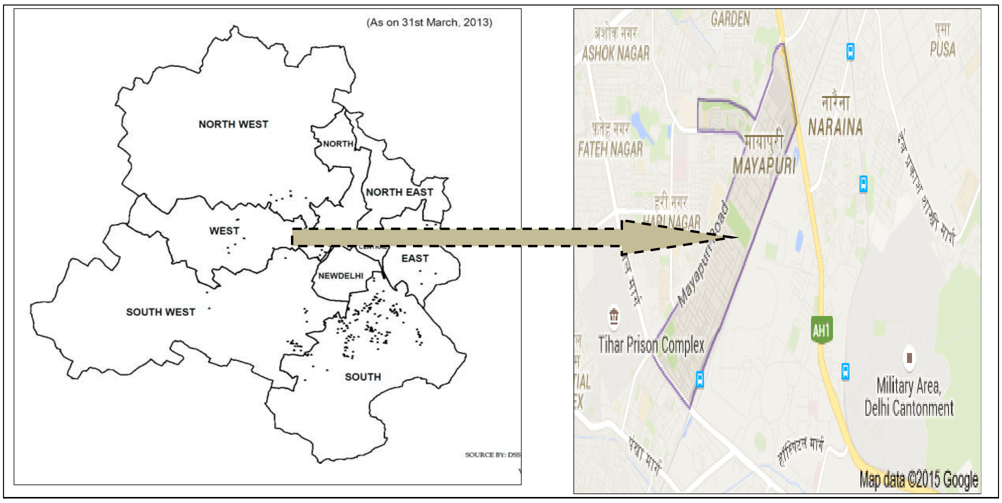


Fig.1: Location map of study-site Delhi

3. Results and Discussion:

The monitoring work was observed for one week in the month of May and September-October for eight hours as representative for pre-monsoon and post-monsoon season. Table 1 presents the statistics of the hourly average concentration of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ mass mode concentration distributions for two seasons at Mayapuri industrial site. The result showed that the average concentration observed with standard deviation for PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ level for pre monsoon time was 106±34 µg m^{-3}, 26±6 µg m^{-3} and 12±4 µg m^{-3} respectively. The post-monsoon mean values for the PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ was 177±101 µg m^{-3}, 71±103 µg m^{-3}, and 56±96 µg m^{-3} respectively. The average data values exceeded the limits prescribed by the National Pollution Regulatory Body- Central Pollution Control Board (CPCB) of 100 µg m^{-3} and 60 µg m^{-3} for PM_{10} and $PM_{2.5}$ respectively.

The range of concentration level for PM_{10} after monsoon season was observed from 92 to 491µg m^{-3} and for $PM_{2.5}$ it was from 21 to 403µg m^{-3}. The intermediate mass fraction of particulate matter $PM_{10-2.5}$ gives the difference of mass particle of aerodynamic diameter between PM_{10} to $PM_{2.5}$. The site showed an average concentration value of 81 µg m^{-3} and 105 µg m^{-3} for pre-monsoon and post-monsoon season respectively. The size fraction for particulate matter between ratio of fine/coarse particles was calculated to certain the fraction of fine particles contributing to the whole concentration of coarse particles load. The pre-monsoon and post-monsoon season shows a mean size-fraction ratio of 0.25 and 0.31 respectively. In post-monsoon the ratio reaches at maximum of 0.83 at times during the observation period contributed due to emission of fine particles from the industrial processes, high humidity and low dispersion of particles in air (Tiwari and Srivastava *et al.,* 2009). In pre-monsoon season the PM levels observed for a week was divided into weekdays and weekend. The weekday and weekend concentration for the average PM_{10} (Fig 1.) was seen as 131 µg m^{-3} and 82 µg m^{-3} while $PM_{2.5}$ (Fig. 2) had the mass concentration of 32 µg m^{-3} and 20 µg m^{-3}. The peak value for PM_{10} on weekday, weekend and whole week was 456 µg m^{-3}, 262 µg m^{-3} and 360 µg m^{-3}, while for $PM_{2.5}$ it was seen as 86µg m^{-3}, 38µg m^{-3} and 53µg m^{-3} respectively. The reduction in concentration for particulate matter on the weekends in industrial and residential areas had been observed in other studies as well (Karar and Gupta, 2006; Girgzdiene and Rameikyte, 2007; Jones and Yin *et.al,* 2008).

From Table 1 it was observed that in post-monsoon the weekday concentration for PM_{10} goes up to 414 µg m^{-3} with average mean value of 127 µg m^{-3} and the weekend had observed the average concentration of 227 µg m^{-3} with maximum value of 900 µg m^{-3}.The post-monsoon season saw higher concentration of PM compared with pre-monsoon values. Unusually the weekend monitoring observed predominant PM mass concentration and the cause is attributed to work of metal scrapping, automobile scrapping and other open garage dumping as observed at studied site. The result of weekdays and weekend for pre and post-monsoon season represented the cyclic periodicity of particulate matters emitted from industries as form of anthropogenic activity. On weekend open metal scrap activities together with parallel high intermediate mass concentration added to elevate fraction of fine particles to coarse particles load.

The average seasonal variations for PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ as given in figure (2) shows the higher concentration in post-monsoon season compared with pre-monsoon. The figure (2) shows the average concentration for PM data described as in Table 1. The peak range values had been observed around 11:00 am in morning on weekdays when the machine process and other industrial work was started. On ignition the machinery released high amount of dust in air which get dispersed in surroundings. The pre-monsoon season observed a heavy dust load coming from desert areas of Rajasthan and other combustion sources which get diluted by regular high winds blown in this season. The regular dispersion of air lowers the average concentration of particulate matter in the area (Tiwari *et.al.,* 2013). In post-monsoon season the maximum values could be attributed to humid condition in weather as well as low circulation of air which allowed little dispersion of particulates in environment. In post-monsoon season weekend had shown a large variation of dust matter concentration because of metal-scraping work, open garage discarding of automobiles together with little circulation in ambient air. The mass concentration at certain time duration gets increased showed the maximum risk of exposure to the people during the working hours.

The correlation matrix was observed for different particle diameter in weekday and weekend concentration values (table 2). In pre-monsoon, the PM_{10} on weekday was positively correlated with PM $_{2.5}$, $PM_{1.0}$ on weekday and it also showed moderate correlation with PM_{10} values on weekend. The $PM_{2.5}$ is highly correlated with $PM_{1.0}$ on a weekly pattern showing that the ultra-fine and fine particles are emitted from combustion related emission and are released from anthropogenic activities. The post-monsoon season also exhibited the similar pattern with higher association between $PM_{2.5}$ and $PM_{1.0}$. A linear regression was performed to analyze the relation between PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ for pre and post-monsoon season at industrial site (Fig. 3). The average $PM_{1.0}$ in pre-monsoon observed a strong coefficient of determination with $PM_{2.5}$ than PM_{10} with a value of 0.93 and 0.48 respectively. While in post-monsoon the regression equation for $PM_{1.0}$ is nearly to 1 with $PM_{2.5}$ and 0.91 with PM_{10}. The correlation matrix and regression equations both showed a significant degree of relation between $PM_{2.5}$ and $PM_{1.0}$ mass concentration values for post-monsoon season (Ngele and Onwu, 2015; Balakrishaniah and Kumar, 2011).

Table 1: Descriptive statistics for Pre-monsoon and Post-monsoon at industrial site Delhi 2014

Mayapuri site		Pre-monsoon			Post-monsoon			NAAQS [a]
		Weekday	Weekend	Average	Weekday	Weekend	Average	24 hr
PM_{10} ($\mu g\ m^{-3}$)	Mean ± S.D*	131 ± 50	82 ± 26	106 ± 34	127 ± 54	227 ± 203	177 ± 101	100
	Max - Min	456 - 84	262 - 57	360 - 80	414-78	900 - 101	491 - 92	
$PM_{2.5}$ ($\mu g\ m^{-3}$)	Mean ± S.D	32 ± 12	20 ± 4	26 ± 6	34 ± 44	109 ± 206	71 ± 103	60
	Max - Min	86 - 21	38 - 15	53 - 20	326 - 16	791 - 21	403 -21	
$PM_{1.0}$ ($\mu g\ m^{-3}$)	Mean ± S.D	15 ± 7	9 ± 2	12 ± 4	22 ± 41	89 ± 193	56 ± 96	
	Max - Min	44 - 8	21 - 6	27-8	298 - 8	739-9	374 - 10	
$PM_{10-2.5}$ ($\mu g\ m^{-3}$)	Mean ± S.D	98±41	63±24	81±29	93±27	118±31	105±27	
	Max - Min	372-62	241-41	306-59	285-50	249-74	267-69	
$PM_{2.5/10}$	Mean ± S.D	0.25±0.04	0.25±0.04	0.25±0.03	0.25±0.09	0.30±0.19	0.31±0.18	
	Max - Min	0.36-0.13	0.36-0.08	0.31-0.15	0.78-0.16	0.90-0.16	0.83-0.17	

*S.D - Standard deviation, [a] NAAQS – National Ambient Air Quality Standards

Table 2: Correlation matrix of Particulate matter (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$) on weekday and weekend for pre and post-monsoon

Pre-monsoon	PM_{10} Weekday	$PM_{2.5}$ Weekday	$PM_{1.0}$ Weekday	PM_{10} Weekend	$PM_{2.5}$ Weekend	$PM_{1.0}$ Weekend
PM_{10} Weekday	1					
$PM_{2.5}$ Weekday	**0.80**	1.00				
$PM_{1.0}$ Weekday	**0.73**	**0.99**	1.00			
PM_{10} Weekend	**0.54**	0.39	0.33	1.00		
$PM_{2.5}$ Weekend	-0.05	-0.21	-0.26	**0.52**	1.00	
$PM_{1.0}$ Weekend	0.03	0.00	-0.02	0.44	**0.86**	1
Post-monsoon	PM_{10} Weekday	$PM_{2.5}$ Weekday	$PM_{1.0}$ Weekday	PM_{10} Weekend	$PM_{2.5}$ Weekend	$PM_{1.0}$ Weekend
PM_{10} Weekday	1.00					
$PM_{2.5}$ Weekday	**0.87**	1.00				
$PM_{1.0}$ Weekday	**0.85**	**1.00**	1.00			
PM_{10} Weekend	-0.16	-0.12	-0.10	1.00		
$PM_{2.5}$ Weekend	-0.22	-0.13	-0.11	**0.99**	1.00	
$PM_{1.0}$ Weekend	-0.22	-0.13	-0.11	**0.99**	**1.00**	1

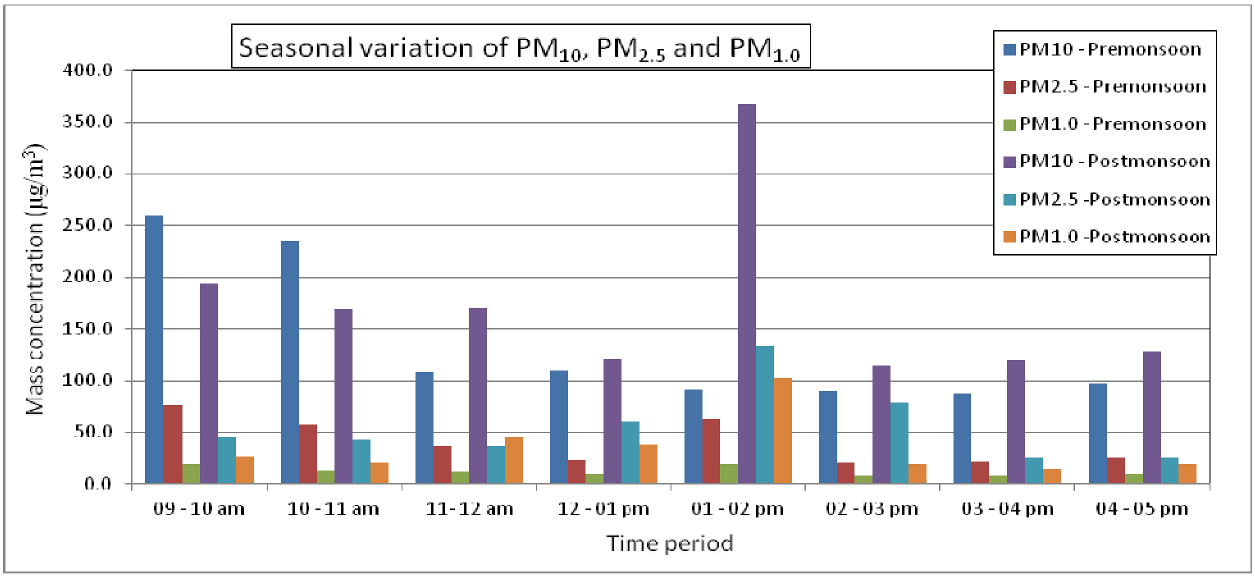


Fig. 2: Seasonal mass concentration of PM - PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ at industrial site in Delhi

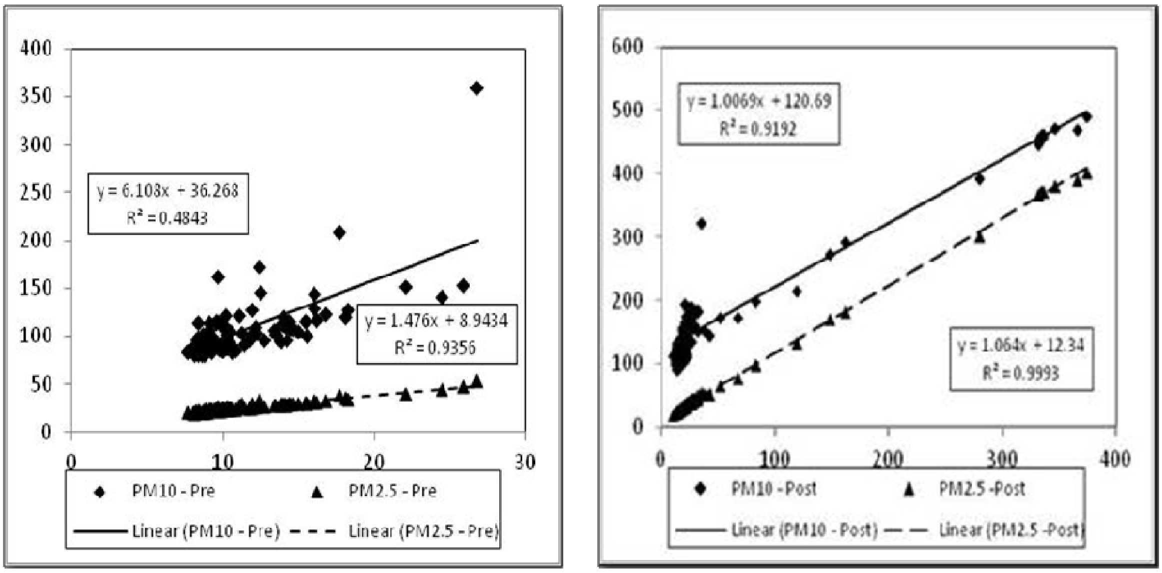
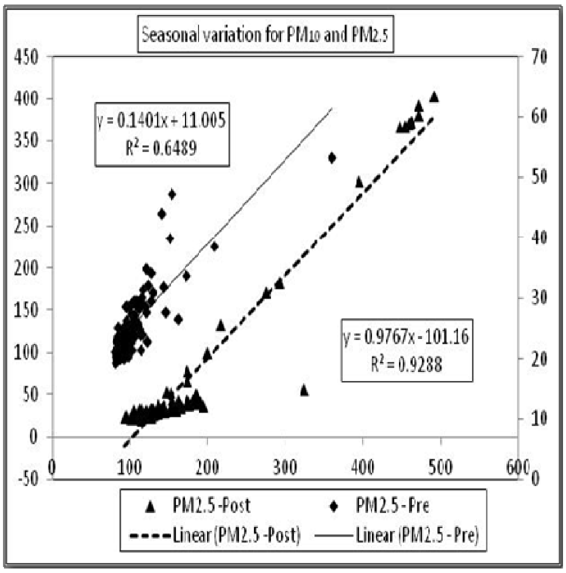
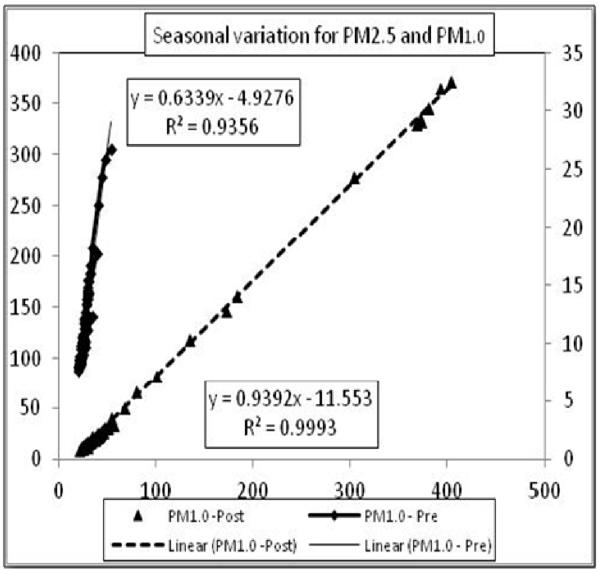


Fig. 3: Regression equations of PM_{10} and $PM_{2.5}$ with $PM_{1.0}$ for pre-monsoon and post-monsoon

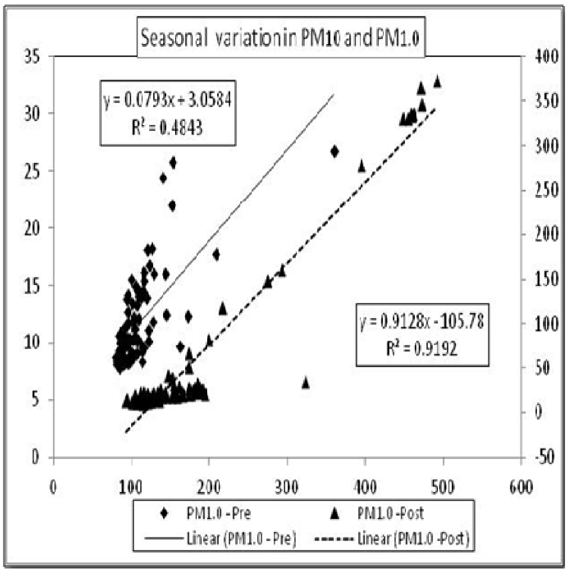
The linear regression was further applied to test the variability of PM between two seasons. As shown in Fig. 4 (A) the mean concentration of PM_{10} was related with $PM_{2.5}$ in pre-monsoon which showed the value of regression coefficient as 0.14 and coefficient of determination observed as 0.64. The post-monsoon values had strong association between the two variables as the value for the linear regression coefficient was 0.97 and the coefficient of determination as 0.92. The relationship of $PM_{2.5}$ with $PM_{1.0}$ from Fig. 4 (B) was positively related in both seasons with coefficient of determination resulting as 0.93 and 0.99 for pre and post-monsoon respectively. The regression-line for the seasonal variation in Fig. 4 (C) between PM_{10} and $PM_{1.0}$ observed a higher value for coefficient of determination as 0.91 and lower value for pre-monsoon was 0.48. It indicated that between coarse and ultra-fine particles i.e. < 2.5µm, the finer particles was able to explain only 48% of the variation in coarse fraction of total particulate matter.



(A)



(B)



(C)

Fig. 4: Regression equations for particulate matter load of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ in seasonal variation of pre-monsoon and post-monsoon (A) Scatter plot relationship between PM_{10} and $PM_{2.5}$, (B) Scatter plot relationship between $PM_{2.5}$ and $PM_{1.0}$ (C) Scatter plot relationship between PM_{10} and $PM_{1.0}$

4.0 Conclusion:

The complex nature of pollutants emitted in environment in different gaseous and liquid forms pose a significant threat to human health, economic workforce productivity and natural processes. The results indicate the high risk of danger due to increased level of PM in different emission sources with diverse range of pollutants present. The study concludes that there is significant positive relation between PM_{10} and $PM_{2.5}$ during weekday and weekends and also between two different season of pre and post-monsoon. The $PM_{2.5}/PM_{10}$ ratio indicated that the fine particles make a foremost portion of the coarse particles indicating common source of emission. The scavenging up of particles from the atmosphere during rainfall through wet deposition process gets vanished only after a few days as the industrial emission is operated round the year. The study indicated that diverse backgrounds of an urban area such as industrial processes (selected for present study) on weekdays and activities such as metal-scrapping makes a condition of continuous exposed ambient aerosols in the air. There is a need for evaluating the composition and concentration of exhaust emitted from industrial processes. The findings of this study would enhance the knowledge and efficiency for different abatement techniques employed to safeguard the health of residents and workers at these places.

5.0 Acknowledgement:

The authors are thankful to Dean, University School of Environment Management, Guru Gobind Singh Indraprastha University for supporting the research work. One of the authors Ms. Simpy Singh is thankful to University Grants Commission for providing financial support through junior research fellowship (Letter UGC- Ref. No.:3209/NET-DEC.2010).

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