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A particulate Matter Based Real-Time Analysis of Odd-Even Car Experiment in Delhi

Charu Khosla Gupta[1], Shweta Singh, Abhishek Singh,
Pragya Yagnik, Bishal K. Das and Arijit Chowdhuri[2]
[1] Environmental Monitoring and Assessment Laboratory, [2] Sensing Materials and Devices Laboratory, Acharya Narendra Dev College, Kalkaji, New Delhi
arijitchowdhuri@andc.du.ac.in

ABSTRACT

Atmosphere is known to play a pivotal role in regional and global dispersion of air pollutants and particulate matter (PM) is one of the key contaminants. As a major constituent of ambient air pollution PM is measured mainly in two particle sizes including $PM_{2.5}$ and PM_{10}. The current study involves real-time measurement of $PM_{2.5}$ and PM_{10} contaminants in the premises of a constituent college of University of Delhi during implementation of odd-even car scheme by State Government of Delhi for two weeks. Amongst other interesting results it is noted that while concentration of $PM_{2.5}$ contaminants is governed by clouds, haze or humidity whereas PM_{10} concentration is affected by wind speed. The investigation is carried out by using a true LASER particle counter.

Keywords**:** Ambient air pollution, LASER particle counter, odd-even car scheme, particulate matter (PM), World Health Organization (WHO)

INTRODUCTION

World Health Organization (WHO) defines air pollution as contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Besides SOx, NOx, Ozone and other VOCs, particulate matter (PM) has been identified as one of the major constituents of air pollution. It is understood to be an environmental health hazard affecting people worldwide, but in a skewed manner wherein people living in third world countries are disproportionately prone to experience this burden. In recent years exposure levels have increased significantly in some parts of the world, particularly countries undergoing rapid industrialization and with large population size [1-3]. Unfortunately Delhi has six times the level of airborne particulate matter than the considered safe limit specified by WHO.

WHO in its 2014 report on ambient air pollution (AAP) states existence of PM_{10} ($\mu g/m^3$) level of 134 for India whereas CNN in its 8 May, 2014 report states New Delhi as most polluted city in the world in $PM_{2.5}$ concentrations (considered to be the more hazardous) [3-5]. India Today in its May 2014 edition has reported Delhi-National Capital Region's (NCR) pollution related deaths to have gone up by shocking 100 percent since 1991 while in 2010 alone 18,229 cases of total mortality, 6,374 cases of cardiovascular mortality, 2,701 cases of respiratory mortality and 26,525 hospital admissions due to chronic obstructive pulmonary disease (COPD) have been reported. Beijing which was once considered pollution capital of the world with $PM_{2.5}$ at 56 $\mu g/m^3$ and PM_{10} at 121 $\mu g/m^3$ has now been overtaken by Delhi-NCR. WHO 2014 report on Ambient Air Pollution (AAP) database contains results of outdoor air pollution monitoring from almost 1600 cities in 91 countries and unfortunately 13 out of 20 most polluted cities of the world are from India. Delhi being followed by Patna, Gwalior, Raipur and Ahmedabad with pollution levels of 149, 144, 134 and 100 $\mu g/m^3$ for $PM_{2.5}$ respectively. Literature indicates particulate matter (PM) especially with an aerodynamic diameter of less than 2.5 microns is more hazardous and is known to cause respiratory diseases and other health problems including acute and chronic illness, lung cancer, COPD and cardiovascular diseases [6]. Worldwide, it is estimated to cause about 16% of lung cancer deaths, 11% of COPD deaths, and more than 20% of ischaemic heart disease and stroke. Human health is affected to the greatest extent by particulate matter (PM) amongst the mix of air pollutants emitted by industries, households, cars and trucks [7-11].

From the aforementioned discussion it is but obvious that all Indian cities have to improve their air quality standards so that clean breathable air is available to its citizens. In a pioneering initiative the State Government of Delhi initiated an “ODD-EVEN SCHEME” scheme for two weeks valid on non-commercial / private cars in Delhi. The project had cars with odd number registrations running on odd numbered dates and those with even number plates plying on even dates during January 1 -15, 2016 with exclusive women drivers being exempt from the scheme. The scheme was envisaged to improve Delhi-NCR’s air quality standards since available data indicates that cars account for nearly a third of Delhi’s over 90 lakh registered vehicles. Exhaust from cars and specifically diesel exhausts are known to be one of the primary sources of PM [12, 13]. Press Trust of India reported on January 22, 2016 that the first three working days after the end of odd even scheme saw rapid worsening of air quality levels of fine particulate matter registering a jump of more than 57% on the first working day itself. Likewise other media including newspapers, electronic satellite etc. besides environmental experts with private and Government agencies had differing views.

In view of the often conflicting opinions / views mostly having political overtones, a need was felt to measure real-time PM concentration levels during the odd-even scheme in an unbiased manner. Specifically, it was of interest to note and understand how the two-week long scheme affected PM levels at the workplace (in this case a constituent college of University of Delhi).

METHODOLOGY

In the current study Particulate Matter (PM) concentration levels for $PM_{2.5}$ and PM_{10} particles are measured in real-time within the premises of Acharya Narendra Dev College (University of Delhi) during the period when odd-even experiment was carried out in Delhi. The period of PM measurement under consideration in this analysis was from 1st - 18th January 2016. During the study both small and large particulate matter count were measured in seven different parts of the college at a fixed time of the day during which odd-even experiment was in place in Delhi. The areas identified within the college included a) backyard lawn, b) dumping area, c) sports ground, d) parking lot, e) new building block, f) volleyball court and g) main gate. The areas for particulate matter count measurement were so chosen wherein maximum usage by either students or college employees was expected. Post acquisition, the measurement data was averaged on each day. In order to negate the parasitic influence of anthropogenic variation from within the college and relatively lighter traffic on the roads PM measurement data was intentionally not acquired for saturdays and sundays within the period. The weather data was obtained from the international standard website http://www.timeanddate.com/weather/india/new-delhi. In the investigation a true portable LASER particle counter (DYLOS 1700, USA) with air quality monitoring capabilities in 2 particle size ranges (> 0.5 µm and > 2.5 µm) has been used for measurement of real-time particulate matter concentrations. Possessing a dynamic bar graph display for dynamic air quality monitoring DYLOS 1700 is battery powered with a LCD screen readout showing small (> 0.5 µm) and large (> 2.5 µm) particle concentrations in real-time. Within ten seconds of power-up DYLOS 1700 AQM has the ability to display in its alphanumeric readout two different counts, wherein the first is for particles in the range of 0.5 to 2.5 microns in size per 0.01 cubic foot whereas second part shows particle count for particles larger than 2.5 microns. The unit is versatile in the sense that it is able to log particle counts in multiple modes of operation including minute, hour and day while monitoring air quality. In the study $PM_{2.5}$ and PM_{10} readings on the DYLOS 1700 Air Quality Monitor (AQM) were averaged over a minute at a particular position. The $PM_{2.5}$ and PM_{10} readings though obtained per 0.01 cubic feet were properly converted to concentrations per cubic metre. The AQM is truly portable with its light-weight and has a small built-in 'CPU' fan at the end to pull in ambient air loaded with particulate matter into the unit. The 'polluted' air is made to pass between a narrow beam of the LASER and a photodetector.

The basic principle of measurement of the AQM used is scattering of light by the particulate matter. Bigger particles are expected to scatter more light and hence particle size can be gauged by the intensity of the pulse of light on the photodetector.

RESULTS AND DISCUSSION

Complex weather pattern plays a major role, especially components of wind velocity and direction. Attributes including amount and duration of sunshine, humidity levels and ambient temperature are also seen to influence the concentration levels of the particulate matter to a great extent. Table I tabulates average $PM_{2.5}$ and PM_{10} levels measured during 1400 hours at seven locations within the college. Figure 1 and Figure 2 show the plot of $PM_{2.5}$ and PM_{10} concentration level variations during the tenure of odd-even experiment in Delhi respectively.

Comparing the two figures it is interesting to note that $PM_{2.5}$ and PM_{10} contaminant particles do not show same behavioural patterns, which is attributed to their vastly different sources of origin. Table II a) to n) tabulates the weather conditions in Delhi for the 2-week period during which odd-even scheme was in place and which are specifically responsible for influencing the PM concentration levels during the time of measurement.

Figure 1 shows that the measured $PM_{2.5}$ concentration levels actually show an increase from 1st to 4th January (1247 to 1497 µg/m^3) despite imposition of the odd-even rule for passenger cars in Delhi. The result is surprising mainly because theoretically half the non-commercial passenger cars are off the roads. Looking at the weather station data [Tables II a) to d)] it is noted that during actual PM measurement the existing conditions include either scattered clouds in the sky with very low wind velocity or even if the wind picks-up then there is haze. In either of the two cases $PM_{2.5}$ particles are unable to disperse and hence its concentration levels keep on increasing for the first four days.

Table I: Average values of $PM_{2.5}$ and PM_{10} contaminants during implementation of the odd-even car scheme in Delhi

S. No.	Date	$PM_{2.5}$	PM_{10}
1.	01st January 2016	1247	45
2.	02nd January 2016	1364	70
3.	04th January 2016	1497	99
4.	05th January 2016	1066	63
5.	06th January 2016	1254	56
6.	07th January 2016	1418	79
7.	08th January 2016	1190	58
8.	11th January 2016	612	33
9.	12th January 2016	640	44
10.	14th January 2016	1334	95
11.	15th January 2016	1153	79
12.	18th January 2016	1366	107

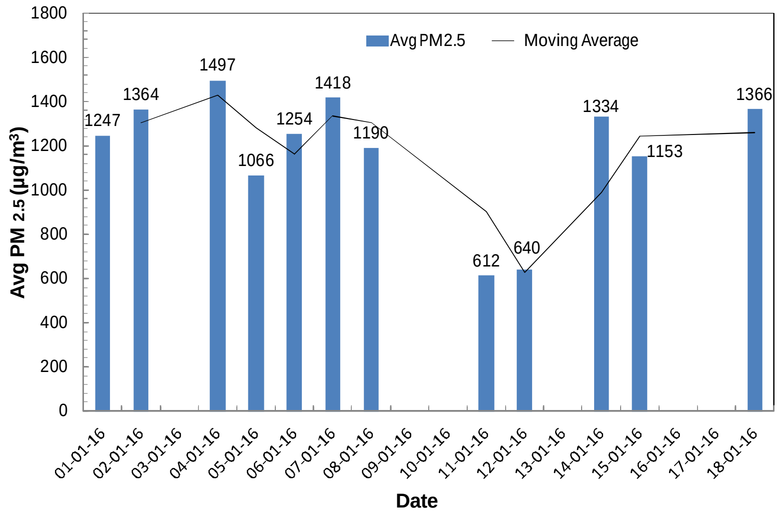

Figure 1**:** Variation of avg. $PM_{2.5}$ concentration during odd-even protocol

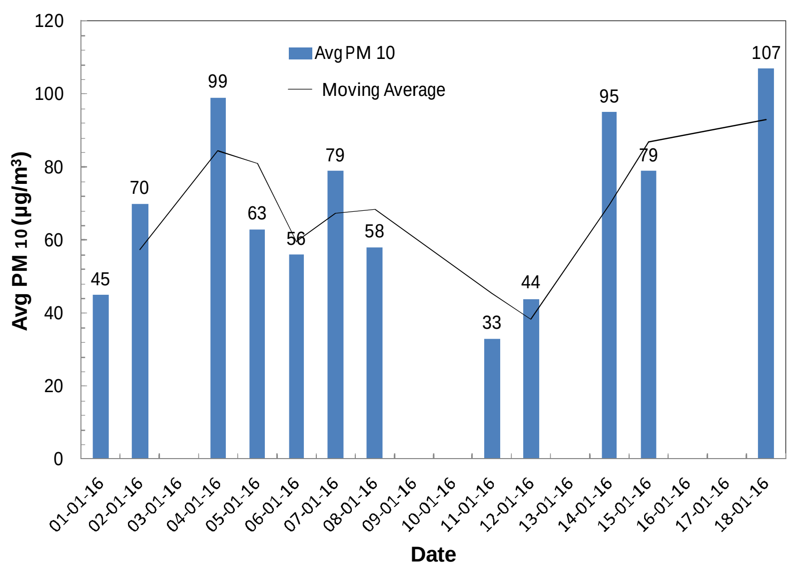

Figure 2: Variation of avg. PM_{10} concentration during odd-even scheme

This result also seems to indicate that $PM_{2.5}$ particles can stay in air for long period of time and that reduction in existing high ambient air pollution levels cannot be obtained instantly. First substantial reduction in $PM_{2.5}$ levels is noted on the 5^{th} of January 2016 and this can be attributed to the cumulative effect of reduction in passenger car traffic for the first four days. General behaviour of the PM_{10} concentration levels over the first five days also follows the same trend as that of $PM_{2.5}$ concentration levels (Figure 2).

Table II: Weather conditions existing on the days of measurement

a) 02 January 2016 (Saturday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		19 °C	Clear.	9 km/h	46%
12:00		20 °C	Clear.	11 km/h	46%
12:30		21 °C	Clear.	13 km/h	40%
13:00		21 °C	Clear.	13 km/h	40%
13:30		21 °C	Clear.	13 km/h	40%
14:00		21 °C	Haze.	15 km/h	40%

b) 03 January 2016 (Sunday)

Time	Condition	Temp	Weather	Wind	Humidity
11:00		15 °C	Clear.	9 km/h	68%
12:00		18 °C	Clear.	9 km/h	56%
12:30		19 °C	Clear.	13 km/h	49%
13:00		20 °C	Clear.	15 km/h	46%
13:30		21 °C	Clear.	13 km/h	43%
14:00		21 °C	Clear.	13 km/h	38%
14:30		21 °C	Clear.	15 km/h	38%

c) 04 January 2016 (Monday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		21 °C	Passing clouds.	No wind	43%
12:00		22 °C	Scattered clouds.	6 km/h	41%
12:30		23 °C	Scattered clouds.	6 km/h	36%
13:00		23 °C	Scattered clouds.	4 km/h	33%
13:30		23 °C	Scattered clouds.	4 km/h	33%
14:00		23 °C	Scattered clouds.	4 km/h	33%
14:30		23 °C	Scattered clouds.	7 km/h	33%

d) 05 January 2016 (Tuesday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		23 °C	Scattered clouds.	7 km/h	44%
12:00		25 °C	Scattered clouds.	7 km/h	39%
12:30		25 °C	Scattered clouds.	7 km/h	36%
13:00		25 °C	Scattered clouds.	7 km/h	36%
13:30		26 °C	Scattered clouds.	7 km/h	34%
14:00		26 °C	Scattered clouds.	6 km/h	34%
14:30		27 °C	Scattered clouds.	6 km/h	32%

e) 06 January 2016 (Wednesday)

Time	Condition	Temp	Weather	Wind	Humidity
11:00		21 °C	Scattered clouds.	11 km/h	57%
11:30		22 °C	Scattered clouds.	11 km/h	53%
12:00		23 °C	Scattered clouds.	11 km/h	50%
12:30		24 °C	Scattered clouds.	7 km/h	44%
13:30	N/A	24 °C	Mild.	9 km/h	44%
14:00		24 °C	Scattered clouds.	13 km/h	41%
14:30		24 °C	Scattered clouds.	15 km/h	41%

f) 07 January 2016 (Thursday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		22 °C	Scattered clouds.	No wind	61%
12:00		23 °C	Scattered clouds.	No wind	57%
12:30		24 °C	Scattered clouds.	No wind	54%
13:00		24 °C	Scattered clouds.	7 km/h	50%
13:30		24 °C	Scattered clouds.	7 km/h	54%
14:00		24 °C	Scattered clouds.	11 km/h	54%
14:30		24 °C	Scattered clouds.	9 km/h	54%

g) 08 January 2016 (Friday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		14 °C	Fog.	6 km/h	100%
12:00		14 °C	Fog.	7 km/h	100%
12:30		15 °C	Fog.	11 km/h	94%
13:00		17 °C	Fog.	9 km/h	83%
13:30		17 °C	Fog.	11 km/h	83%
14:00		18 °C	Fog.	11 km/h	78%
14:30		19 °C	Passing clouds.	13 km/h	73%

h) 09 January 2016 (Saturday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		18 °C	Clear.	17 km/h	60%
12:00		19 °C	Clear.	19 km/h	52%
12:30		19 °C	Clear.	20 km/h	52%
13:00		20 °C	Clear.	22 km/h	46%
13:30		21 °C	Clear.	22 km/h	43%
14:00		22 °C	Haze.	22 km/h	38%
14:30		22 °C	Haze.	20 km/h	38%

i) 10 January 2016 (Sunday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		19 °C	Passing clouds.	7 km/h	52%
12:00		21 °C	Clear.	7 km/h	43%
12:30		21 °C	Clear.	7 km/h	43%
13:00		22 °C	Clear.	9 km/h	41%
13:30		22 °C	Clear.	9 km/h	41%
14:30		23 °C	Haze.	11 km/h	36%

j) 11 January 2016 (Monday)

Time	Condition	Temp	Weather	Wind	Humidity
10:30		19 °C	Clear.	6 km/h	60%
12:00		23 °C	Clear.	7 km/h	44%
12:30		24 °C	Clear.	9 km/h	41%
13:00		24 °C	Clear.	7 km/h	39%
13:30		25 °C	Haze.	7 km/h	34%
14:00		25 °C	Haze.	7 km/h	34%
14:30		25 °C	Haze.	11 km/h	34%

k) 12 January 2016 (Tuesday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		22 °C	Haze.	17 km/h	41%
12:00		22 °C	Haze.	19 km/h	41%
13:00		23 °C	Haze.	19 km/h	38%
13:30		24 °C	Haze.	15 km/h	36%
14:00		24 °C	Haze.	15 km/h	39%
14:30		24 °C	Haze.	19 km/h	39%

l) 13 January 2016 (Wednesday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		20 °C	Scattered clouds.	7 km/h	60%
12:00		20 °C	Scattered clouds.	6 km/h	60%
12:30		21 °C	Scattered clouds.	6 km/h	57%
13:00		21 °C	Scattered clouds.	6 km/h	57%
13:30		22 °C	Scattered clouds.	6 km/h	57%
14:00		22 °C	Scattered clouds.	9 km/h	57%
14:30		22 °C	Scattered clouds.	11 km/h	57%

m) 14 January 2016 (Thursday)

Time	Condition	Temp	Weather	Wind	Humidity
11:30		15 °C	Fog.	7 km/h	77%
12:00		16 °C	Fog.	7 km/h	77%
12:30		17 °C	Fog.	9 km/h	77%
13:00		17 °C	Fog.	9 km/h	73%
13:30		17 °C	Fog.	9 km/h	73%
14:00		17 °C	Broken clouds.	9 km/h	68%
14:30		17 °C	Broken clouds.	6 km/h	68%

n) 15 January 2016 (Friday)

Time	Condition	Temp	Weather	Wind	Humidity
11:00		12 °C	Fog.	13 km/h	94%
11:30		13 °C	Fog.	9 km/h	88%
12:00		13 °C	Fog.	N/A	88%
12:30		14 °C	Fog.	11 km/h	82%
13:00		14 °C	Fog.	11 km/h	77%
13:30		14 °C	Fog.	13 km/h	77%
14:00		14 °C	Fog.	11 km/h	77%
14:30		15 °C	Clear.	15 km/h	72%

Comparing the graphs shown in figures 1 and 2 it is interesting to note that whereas the rate of increase in $PM_{2.5}$ concentration levels is 1.09% and 1.10% respectively over consecutive days, the rate of enhancement in PM_{10} concentration levels is 1.55% and 1.41%. However the fall in $PM_{2.5}$ (1.40%) and PM_{10} (1.57%) concentration levels as noted on the fifth day is comparable. The main dissimilarity between the behavior of $PM_{2.5}$ and PM_{10} concentration levels is seen on the sixth day of the odd-even scheme and it is exciting to note that whereas $PM_{2.5}$ levels show an increase in values (1.18%), PM_{10} levels on the other hand actually decrease (1.12%). The weather parameters of 6th January 2016 [Table II e)] indicate presence of scattered clouds and fairly high wind velocity (13 - 15 km/hour) at the time of PM measurement. Particulate matter concentration data obtained for six days together with existing weather pattern seem to suggest that whereas PM_{10} particles (being bigger in size) are more influenced by wind speed, whereas $PM_{2.5}$ sized particulates are prone to being taken up by the ambient (clouds, haze or humidity) and thus exist in the local environment for longer duration.

From 7th to 11th January both $PM_{2.5}$ and PM_{10} levels register a fall in their concentrations. Existing weather patterns [Tables II g) to k)] indicate presence of constant and fairly high wind speeds (on 9th January wind speed is 20 km/hour) and falling humidity levels (54% to 34%). The data also seems to reveal that PM_{10} contaminants get influenced instantly by existing weather parameters while $PM_{2.5}$ concentrations take longer to be affected with any change in the ambient. As wind speeds fall, humidity levels rise and cloud density augments and the PM levels exhibit a spurt in the period from 12th – 18th January 2016. The notable exception being 15th January wherein one can observe a bright sunny sky and a high wind speed.

CONCLUSIONS

$PM_{2.5}$ and PM_{10} contaminant particles that are the major constituents of ambient air pollution do not show same variation in characteristics during odd-even experiment in Delhi. The study indicates that $PM_{2.5}$ particles get more affected by weather parameters like clouds, haze or humidity, whereas PM_{10} contaminants are more prone to be influenced by wind speed. A bright sun appears to have an effect on both $PM_{2.5}$ and PM_{10} contaminants.

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