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Experimental Implementation of Odd-Even Scheme for Air Pollution Control in Delhi, India

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Abstract: Delhi, the Capital of India, is having worst air pollution due to rapid rate of urbanization, construction activities, increasing population, and increasing number of vehicles. Number of measures implemented by Delhi Government to control air pollution prior to 2000 gave favorable results during 2000 to 2006. But now, the air pollution has again increased to serious levels. Therefore, Delhi Government recently implemented the Odd-Even Scheme to restrict plying of even and odd number private vehicles on odd and even dates respectively, for 15 days from January 1 to 15, 2016. Present investigation revealed that the air pollution increased in the first week of January, due to low wind speed and low mixing height. However, in the second week air pollution level reduced considerably as compared to air pollution levels during pre - and post - scheme period and similar period in previous year 2015. The success of this scheme proved its utility as one of the tools to reduce air pollution in urban environment, along with other benefits namely easy and fast flow of traffic, no traffic jams, reduced travel time, fuel saving etc. After scheme period, the air pollution levels increased again, indicating success of odd-even scheme. This experiment succeeded in limited way due to shorter period of implementation and other active sources of air pollution. If the scheme is implemented for longer duration in integrated way, it may succeed in reducing air pollution in Delhi and other cities.
Key Words: Delhi, Air Pollution, Odd-Even Scheme; Emission Control

1. INTRODUCTION

The rapid urbanization, urban heat islands, construction activities, congested urban colonies, increasing number of vehicles and intense traffic on roads led to moderate to severe air pollution in Delhi, the capital city of India [1]. The increasing air pollution has deteriorated the outdoor and indoor environment making human being difficult to lead healthier life. It is reported [2] that among 1600 cities across 91 countries, Delhi topped the list of cities with the highest level of air pollution and most of the cities in the world are polluted and only 12 per cent of people were living in cities with clean air and rest in polluted environment of urban areas. WHO says that air pollution is now the world's largest single environmental health risk. The cities in the world with the worst air pollution are Delhi (India), Patna (India), Gwalior (India), Raipur (India), Karachi (Pakistan), Peshawar (Pakistan), Rawalpindi (Pakistan), Khoramabad (Iran), Ahmadabad (India), Lucknow (India). The people are revolting against severe air pollution and asking the government to take corrective measures. Various techniques are being tested and carried out in different countries. Similarly, Delhi also introduced number of control measures to reduce the pollution prior to and after the year 2000 with improvement in air quality up to 2005. However, afterwards the level of air pollution witnessed gradual increase to severe levels. Finally the Delhi government implemented Odd-Even scheme (O-E scheme) on experimental basis from January 1 to 15, 2016 to restrict plying of even and odd number private vehicles on odd and even dates respectively, for 15 days, to evaluate its effect on control of vehicular pollution. Sincere campaign for voluntary public participation during this period was made. Public gave their full participation and made the scheme successful.

2. MATERIALS AND METHODS

Fine atmospheric particulate matter less than 2.5 µm (PM2.5), generally associated with toxic metals, chemicals, toxic compounds, is the deadliest form of air pollution due to their ability to penetrate deep into the lungs and blood stream causing DNA mutations, heart attacks, and premature deaths [3, 4]. WHO considers PM2.5 as the best indicator of air pollution for assessing health impacts, and there is no safe level of PM2.5 pollution. The permissible limit for PM2.5 is 60 µg/m3 as per Indian Standard [5]. PM2.5 data was used to evaluate the severity of air pollution in the present investigation. The air pollution data related to PM2.5 was obtained from the website of U.S. Embassy and Consulates in India Real Time Data Analysis who maintains an air quality monitoring programme with on-site instruments for measurement of only one parameter PM2.5 (µg/m3) covering the area of Chanakyapuri of Delhi. The U.S. EPA NowCast algorithm converts raw PM2.5 readings

over a 3-12 hour period into an Air Quality Index (AQI) value that can help inform the public about air quality status and health-related decisions (Table I) (http://newdelhi.usembassy.gov/airqualitydataemb.html).

3. RESULTS AND DISCUSSION

3.1 Environment and Air Pollution in Delhi

Delhi is a landlocked city, and hence cannot rely on breeze from the sea to carry away pollutants. A characteristic of seasonal extremes that is very hot in summer and very cold in winter in Delhi is that the inversion layer (mixing layer height) is high in summer, but significantly lower in winter [6]. Due to low inversion layer in winter, the emissions are more concentrated over the city because they cannot get distributed high into the atmosphere. Average mixing layer heights are almost twice as high in summer months as compared to winter. Winds are also much lower strength in winter, and hence any pollution that is created tends to stay for longer. The Delhi, thus, experiences more occasions of smog and fog during winter season and increase in public health problems.

3.2 Vehicular Emission as Important Factor of Air Pollution

The first prominent reason for air pollution in Delhi is increasing vehicle population, especially diesel vehicles having high emissions. There has been nearly 350% rise in the number of vehicles in the National Capital Region, which includes Delhi and neighboring areas in the bordering states of Uttar Pradesh and Haryana, from 800,000 in 1990 to 2.8 million in 2006 (Delhi State Transport Authority). This figure is adjusted for the vehicles that were decommissioned because they were older than 15 years. Within this, the relative share of diesel vehicles has increased from a low 3% in 1990 to about 11% in 2006 or from about 25,000 to some 240,000 vehicles. Estimates of the relative share of diesel vehicles among cars range from 18% to 30% (Society of Indian Automobile Manufacturers, SIAM) [7]. From 2008 to 2015, the total number of registered vehicles is 38,74,934 [8].

3.3 Novel Odd-Even Scheme to Limit Vehicular Emission

The aim of Odd-Even scheme (O-E scheme) was suggested to spread one days air pollution to two days, thus emission get diluted. The O-E scheme was applied to four wheeler passenger/private cars. The public transport buses, two wheelers, trucks, CNG operated passenger/private cars, and three wheelers were exempted from the scheme. In addition, cars driven by women were also exempted apart from a select number of VIP and emergency vehicles. It is encouraging that public gave good cooperation in this O-E scheme. O-E scheme is based on the assumption that overall contribution of vehicular pollution in ambient air of Delhi during winter season is estimated to be around 20-25% in respect of PM10 and PM2.5. However, according to IIT Kanpur study, in terms of emission load, it contributes about 9% and 20% respectively for PM10 and PM2.5, of which the 4-wheeler passenger cars contribute about 10%. The O-E scheme could have theoretically contributed to PM reductions and marginal reduction in road dust and secondary particulates.

3.4 Air Pollution History of Delhi

The polluted air of Delhi is a noxious mixture of smoke, fumes, and particulate matter (PM10 and PM2.5) with heavy concentrations of chemicals, acids, metals and carcinogens and PM2.5 produced by vehicle emissions peaked around 1998. That time, Supreme Court ordered the city's fleet of buses, autorikshaws, and taxis to switch from diesel to compressed natural gas (CNG). Delhi Government had passed a slew of other measures to cut emissions from vehicles, like introduction of unleaded petrol as well as diesel and petrol with low levels of sulphur. This led to drop in the levels of sulphur dioxide (SO2), lead and PM10. Lot of these gains has been reversed because of the sharp increase in the number of vehicles till 2015, especially those running on diesel. So, nitrogen oxides and ozone, the byproducts of emissions from cars, trucks, construction etc. have been rising, while other pollutants such as sulphur dioxide have reduced. Data compiled by the CPCB between 2000 and 2006, shows that in residential areas, the presence of sulphur dioxide (SO2) in the air has declined by nearly 50% and it is actually well within the norms that are considered safe. This fall is due to the adoption of technologies such as the multi point fuel injection system in vehicles, the three-way catalytic converter, and an overall shift in two wheelers from two stroke to four stroke engines [7]. But suspended particulate matter (SPM) and nitrogen dioxide (NO2) levels were well above norms. Increase in the concentration of PM10 and heavy metals was observed in the ambient air of Delhi in 2015 as compared to 2006 level with increase in human activity, vehicular emission due to increased traffic and construction activities [1]. The category of air pollution based on AQI (PM10) was observed to be "severe" category in winter and summer, and "heavy" to "severe" in Monsoon and post-monsoon in 2015. The heavy metal pollution by cadmium and Nickel was observed to be "High Pollution". The Environmental Pollution Control Authority (EPCA) for NCR in their 2014 report recorded that from 2002-2012, particulate matter in Delhi has increased by 75% and number of vehicles on the roads have increased 97%. In the winter of 2013-2014, Delhi's air pollution increased to dangerous levels with PM2.5 remained 2-3 times the national standard and has reached 8-10 times the standards in high smog episodes.

3.5 Ambient Air During O-E Scheme

After implementation of O-E Scheme, the data collected showed increase in air pollution in the first week of January, but reducing trend in the second week. Delhi is known to be highly polluted and it might have been taken some time to show the impact of O-E scheme. Same observations have been recorded by Delhi Pollution Control Committee (DPCC) and Central Pollution Control Board (CPCB). For ease in comparison, the air pollution data for 12 to 15 January 2016 (second week) during O-E scheme period along with pre-scheme period (1-30 Dec, 2015) and post-scheme period (16-31 Jan, 2016) are presented in Table II and Figure 1. The PM2.5 was observed to vary in the range from 157 to 248.9 µg/m3 during scheme period, from 46 to 341 µg/m3 during pre-scheme period and from 124.9 to 439.2 µg/m3 during post-scheme period, showing higher peak of air pollution in pre-scheme period and post-scheme period. The reduction in peak air pollution level in O-E scheme period was observed to be 28.68% as compared to pre-scheme period and 43.42% as compared to post-scheme period (Table III). The polynomial trend line is U shaped in Figure 1, indicating that the PM2.5 is decreasing near second week of O-E scheme period. This observation is supported by the graphical presentation of air pollution in Delhi given by CPCB (Figure 2), wherein the PM2.5 showed increasing trend in the first week of O-E scheme, then decreasing trend till 16th January 2016, which is the end of O-E scheme period, then again showing increasing trend. Delhi has more traffic during 8 am to 1 pm and during 4 pm to 9 pm. The air pollution levels during post-scheme period at morning (**Figure 3**) and evening (Figure 4) were found to be higher than those recorded during second week of O-E scheme period. In both the figures, increasing trend line with low concentration of PM2.5 during O-E scheme period and higher concentrations during morning and evening period were recorded, indicating the decrease in air pollution level due to operation of O-E scheme.

The value of AQI based on PM2.5 indicates status of air pollution, health effect statement and cautionary statement due to air pollution (Table 1). The AQI ranged from 182 to 299 during O-E scheme period (*Unhealthy* to *Very Unhealthy* status), from 46 to 349 (G*ood to Hazardous* status) during pre-scheme period and from 187 to 460 (*Unhealthy* to *Hazardous* status) during post-scheme period. The air pollution in O-E scheme period did not have *Hazardous* status, while pre and post O-E scheme period had *hazardous* status.

The improvement in air quality during O-E scheme period was observed to be of small dimension. However, considering long term intense air pollution level in Delhi vs. small period of O-E scheme, unfavorable meteorological conditions of winter in Delhi and other sources of pollution, the results obtained are encouraging and predict that it would show considerable improvement of air quality during long periods of its implementation and fast recovery of air quality during other seasons of the year, as well as it would help in taking preventive steps during air pollution emergency.

The Figure 1, 3 & 4 shows wide fluctuations in data due to many other sources of pollution in Delhi namely poor roads, heavy traffic, diesel generator sets, incessant construction, dust containing high concentrations of metals like copper, manganese, nickel, barium, zinc, garbage burning piles of trash giving out particulate matter, mercury and other harmful chemicals. Burning trash produces nearly 30% of the world's particulate matter and 40% of its polycyclic aromatic hydrocarbons (PAHs). Another factor is highly unfavorable meteorological conditions during Delhi's winter, especially low mixing height or inversion layer height (Figure 5). The graphical presentation of CPCB's during December 31, 2015 to January 19, 2016 showed that higher wind speeds (Figure 6) and higher mixing height (Figure 7) in the second week of January 2016 resulted in better dispersion and lower pollution levels and the low wind speed and low mixing height in the first week of January 2016 resulted in increase in the air pollution. Higher humidity in first week as compared to December also led to an increase in the concentration of pollutants. These observations are supported by similar observations by System of Air Quality and Weather Forecasting and Research (SAFAR), CPCB and DPCC. CPCB concluded that while some reduction in air pollution is likely to happen due to O-E scheme, a single factor or action cannot substantially reduce air pollution levels in Delhi due to diverse sources of pollution. Therefore, a comprehensive set of actions following an integrated approach is required to make substantial improvement in air quality.

The air pollution data of PM2.5 for last year from 1-15 January 2015 (U.S. Embassy and Consulate in New Delhi) is presented in Figure 8. The data ranged from 37 µg/m3 to 449 µg/m3 with an average of 196.84 µg/m3, while in O-E scheme period, the PM2.5 ranged between 157 to 248.9 µg/m3, showing 44.57% reduction in peak PM2.5 concentration (Table III). The efficiency of O-E scheme is recognized by Deccan Chronicle (Saturday, Jan 30, 2016/11:29 pm) which reported that Delhi has lost the air quality gains of O-E scheme after the scheme was over. The first three working days after the end of the O-E scheme was back in '*Severe*' category. Despite being a windier day, the January 18 showed 35% greater build up of PM2.5 than the highest observed during O-E scheme period of 75 µg/m3 on January 11. This finding is also supported by the hourly graphs of SAFAR indicating better air quality on 9th January 2016; and DPCC recorded PM2.5 as 64 µg/m3, 51 µg/m3, and 74 µg/m3 at RK Puram, Punjabi Bagh and Anand Vihar respectively that is below National Standard of 60 µg/m3.

The Delhi government, which has been using portable machines sent around to monitor air quality at 200 locations, claim pollution is down by 50% compared to previous years, due to the highly successful O-E scheme [9]. However, DPCC do not have base data since this is the first time pollution readings with this method were

taken. So DPCC is relying on the average of the ambient air quality of last year to compare these pollution readings.

Centre of Science and Environment (CSE) stated that in spite of several severe smog episodes, the peak pollution during O-E scheme has been the lowest and this shows that despite hostile weather conditions – no wind, temperature dip and western disturbance - peak pollution during O-E scheme was much lower. This validates the importance of emergency action. The Green Body said January 15, which was the last day of the O-E scheme, was the "Cleanest " day of this winter when PM2.5 levels dropped to 155 µg/m3. The only day when lower levels were recorded earlier was on November 5, 2015 when it had rained in the city.

CSE referred to another assessment by a team of researchers from University of Chicago and University of Harvard, whose study found that the O-E scheme has helped improve air quality in Delhi by reducing particulate air pollution concentrations by 10-13% in the period.

3.6 Other Benefits of O-E Scheme

TERI has summarized considerable additional benefits of O-E scheme. These are high level of public cooperation, reduction on road congestion, increase of average car speed & reduced fuel use, increase in public awareness, adoption of car pooling, work from home, more use of public transport, and reduction in traffic counts. These benefits allow for the extending and enhancing the O-E scheme in future for air pollution mitigation. The scheme may be strengthened by following additional measures such as improvement in public transport systems, and resolving policy and regulatory issues related to car pooling on commercial or non-commercial basis.

4. CONCLUSION

The O-E scheme is found to be beneficial and it can be used as a measure for reducing air pollution more specifically during the days of high pollution episodes to cut down on the peak levels of air pollutants (TERI). This scheme may be applied to other polluted cities in India. The reduction in air pollution is small. However, this absolute reduction is important because there are other sources of pollution like buses, trucks, three wheelers, two wheelers, garbage burning, traffic congestion, windblown dust, winds blowing in from the Thar Desert in Rajasthan etc. The benefits of this scheme qualify this scheme to be implemented in future, but with supporting measures such as strengthening of public transport, car pooling on commercial and non commercial vehicles, along with measures to control dust emission from other sources. Actual effects of the O-E scheme will require some time to give results due to heavy pollution present over Delhi City.

5. ACKNOWLEDGEMENT

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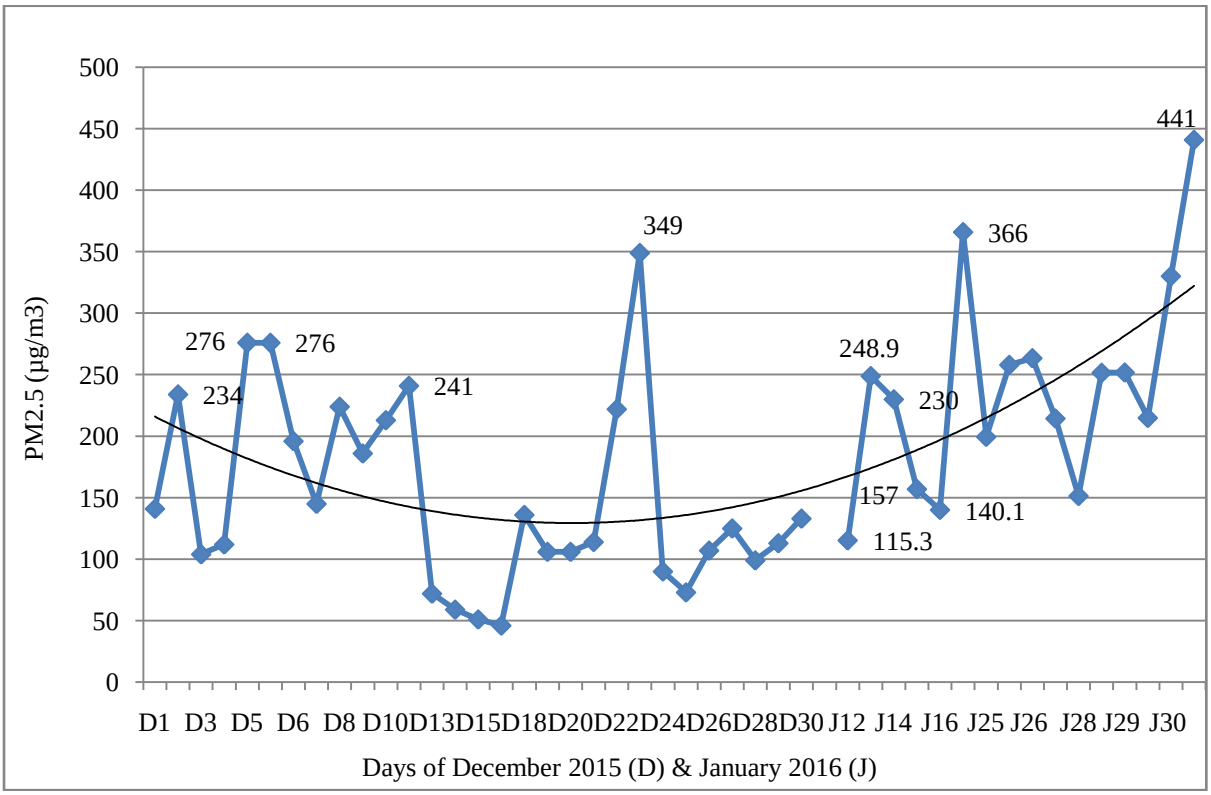

Figure 1: Dynamics of PM2.5 During Odd-Even Scheme (12-15 Jan, 2016) and Pre-Scheme Period (December 2015) and Post-Scheme Period (16 to 30 Jan; 1 pm to 3pm) (with Polynomial Trendline)

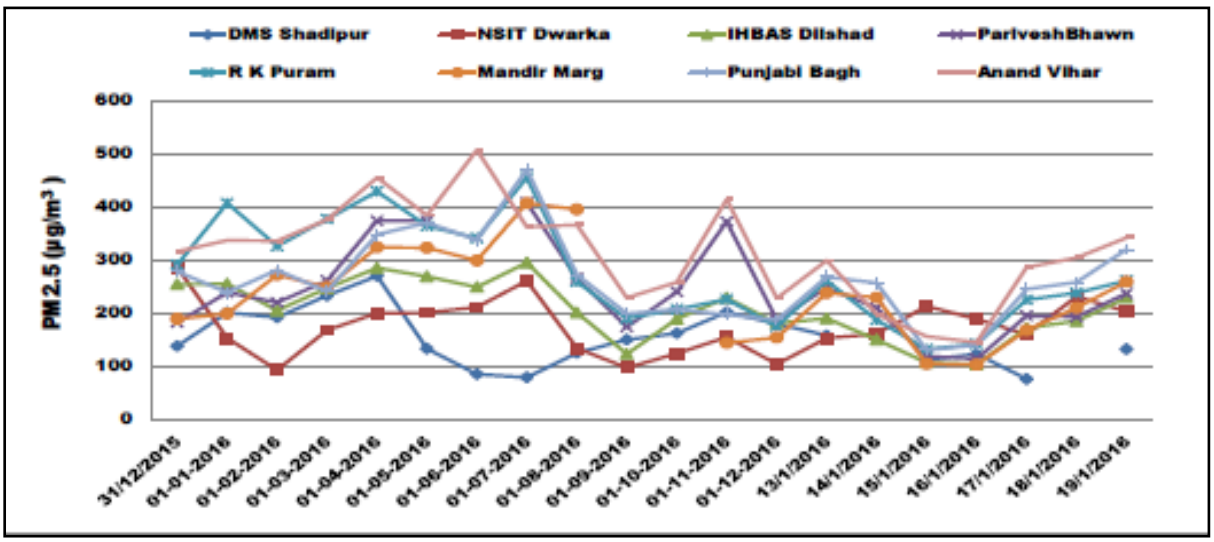

Figure 2: Daily Average PM2.5 on 31st December 2015 and During 1-15 January 2016

(CPCB, 2016, online)

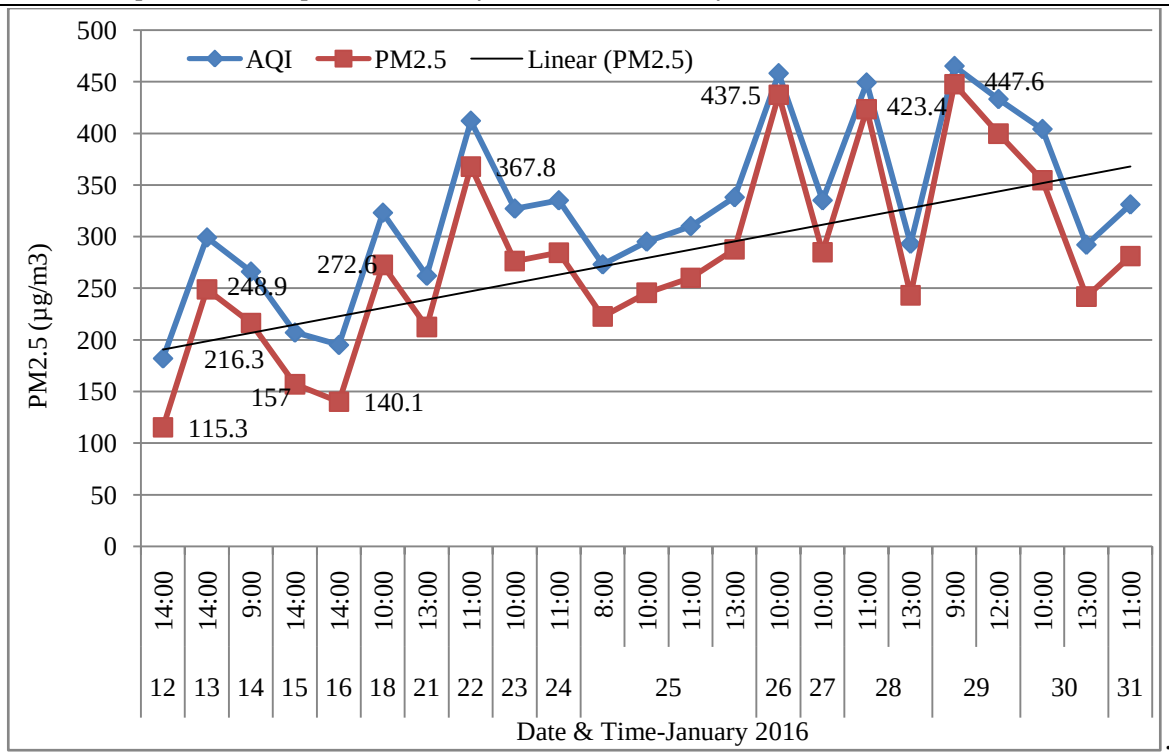

Figure 3: Dynamics of PM2.5 in Odd-Even Scheme (12 to 15 Jan) and Post-Scheme Period Morning Time (8 am to 1 pm) (16 to 31 January 2016) along with Trend line

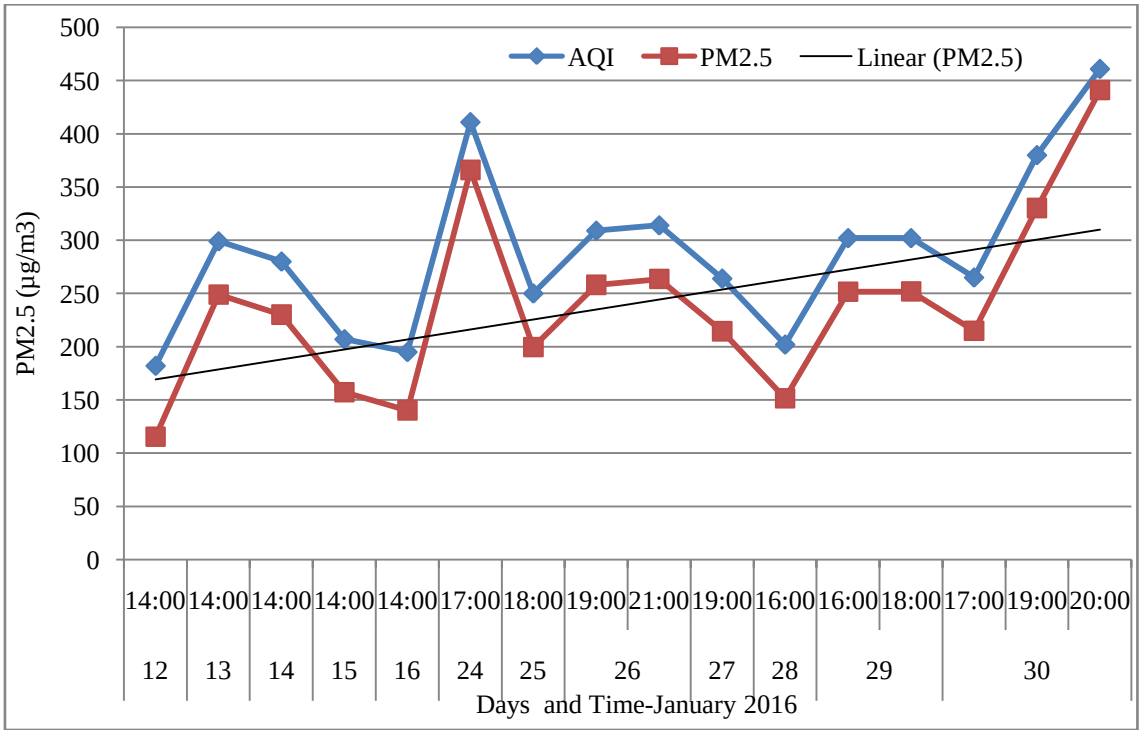

Figure 4: Dynamics of PM2.5 in Odd-Even Scheme (12-15 Jan) and Post-Scheme Evening Period (4 pm to 9 pm) (16 to 31 January 2016) along with Trend line

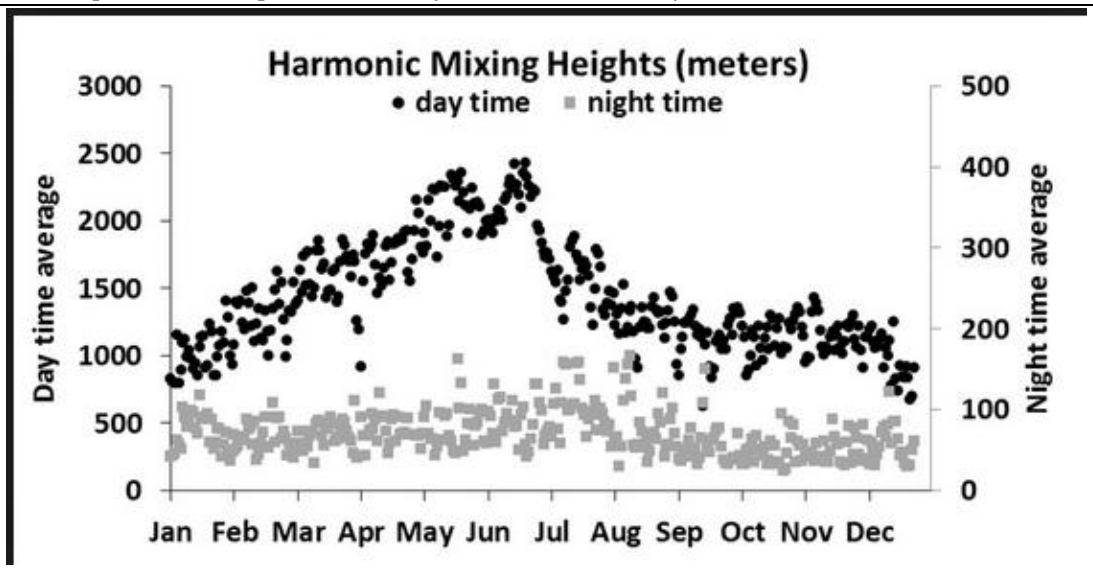

Figure 5: Mixing Heights or Inversion Layer Heights over Delhi
(Sarath Gguttikunda, urbanemission.blogspot.in/2014/01/mixing-heights-inversion-layer-heights.html, browsed on 02-02-2016)

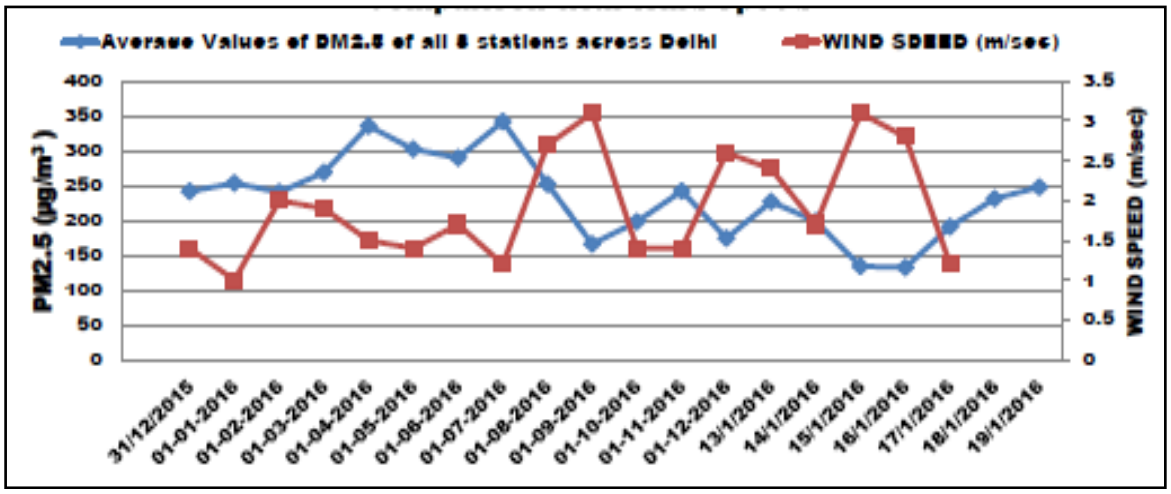

Figure 6: Correlation of PM2.5 Concentrations with Wind Speed

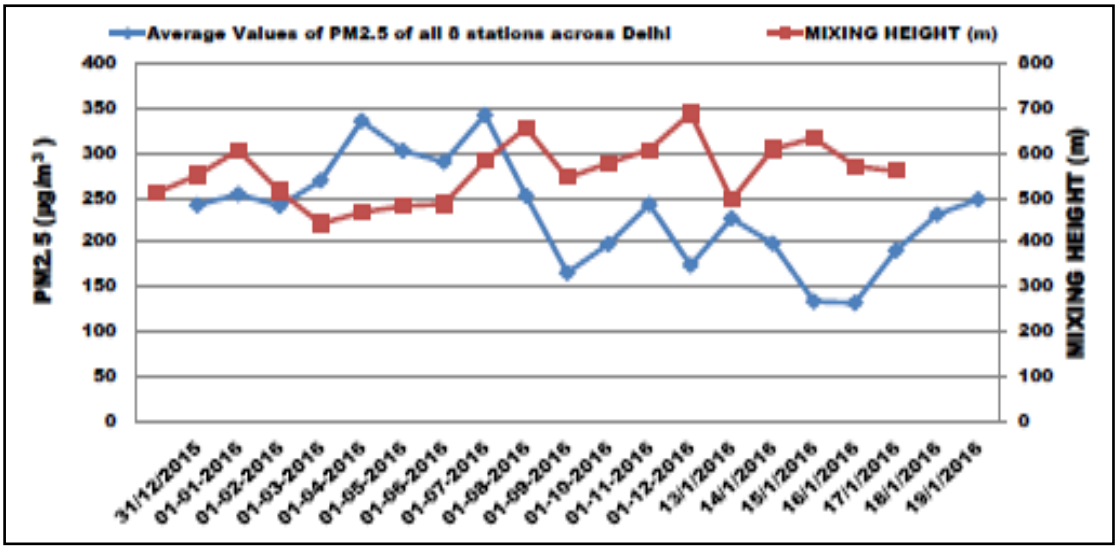

Figure 7: Correlation of PM2.5 Concentrations (31 Dec 2015 to 19 Jan 2016) with Mixing Height

(Compiled by CPCB)

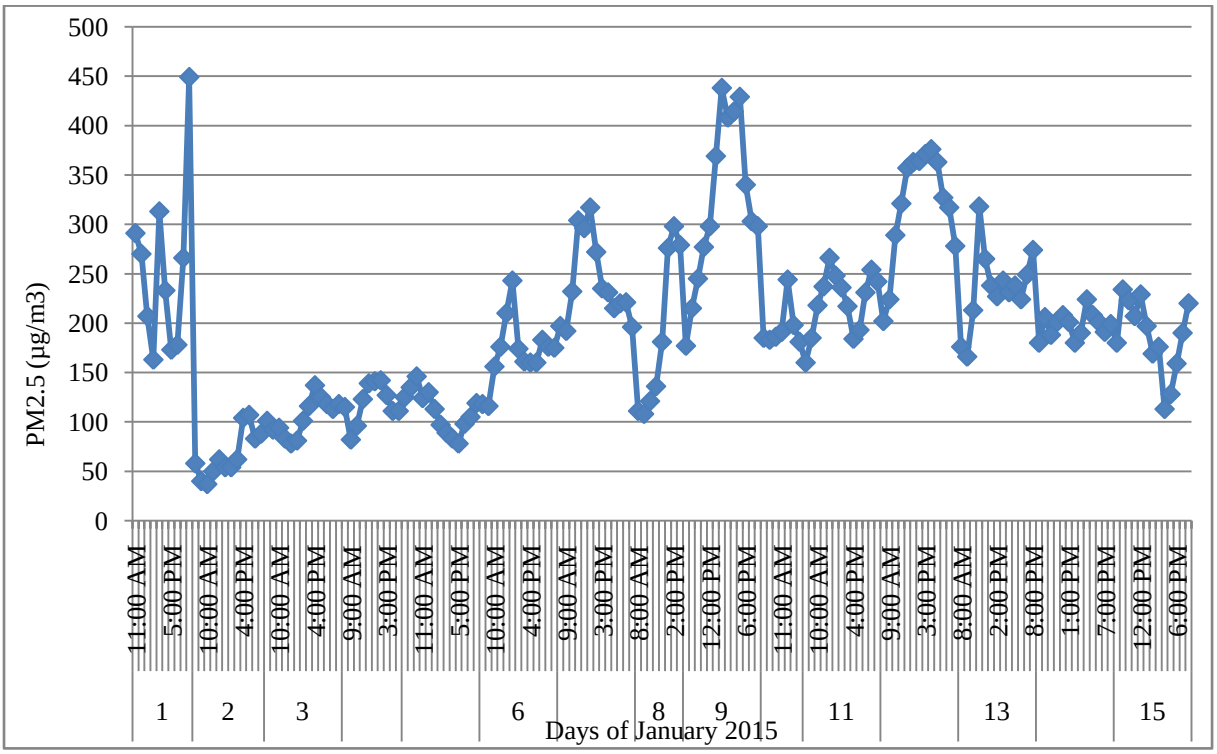

Figure 8: Dynamics of PM2.5 in The First Fortnight of January 2015 with Minimum 37 µg/m3 and Maximum 449 µg/m3 and Average 196.84 µg/m3

Table I: Classification of Air Quality Index (U.S.EPA) Based on PM2.5 Indicating Health Concern

Air Quality Index (AQI) Values	PM2.5 Health Effect Statement	PM2.5 Cautionary Statement	Colors
Good 0 to 50	PM2.5 air pollution poses little or no risk	None	Green
Moderate 51 to 100	Unusually sensitive individuals may experience respiratory symptoms.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Yellow
Unhealthy for sensitive groups 101 to 150	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.	Orange
Unhealthy 151 to 200	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population.	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.	Red
Very Unhealthy 201 to 300	Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population.	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	Purple
Hazardous 301 to 500	Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population.	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, and children should remain indoors and keep activity levels low.	Maroon

Table II: Air Quality (PM2.5) During Odd-Even Scheme (12 to 15 Jan, 2016) and Pre-Scheme Period (Dec, 2015) and Post Scheme Period (16 to 31 Jan, 2016)

December 2015	PM2.5 (µg/m3)	January 2016 Dates	Time of Observation (13:00 to 15:00 hrs)	AQI	PM2.5 (µg/m3)
1	141		Odd-Even Scheme Period (2nd week)		
2	234	12	14:00	182	115.3
3	104	13	14:00	299	248.9
4	112	14	13:00	280	230
5	276	15	14:00	207	157
5	276		Post-Scheme Period		
6	196	16	14:00	195	140.1
7	145	18	14:00	338	287.5
8	224	21	13:00	262	212.5
9	186	22	15:00	456	433.1
10	213	23	15:00	270	220.5
11	241	24	15:00	435	401.6
13	72	25	14:00	333	282.3
14	59	26	15:00	460	439.2
15	51	27	14:00	194	138.8
16	46		15:00	187	124.9
18	136	28	13:00	293	243.2
19	106	29	14:00	228	177.3
20	106		15:00	285	235.3
21	114	30	13:00	292	241.9
22	222		14:00	260	209.9
23	349	31	15:00	189	129.3
24	90				
25	73				
26	107				
27	125				
28	99				
29	113				
30	133				

Table III: Ranges of PM2.5 and Reduction in Peak levels during Odd-Even Scheme in Comparison with Same Period of 2015 and Immediate Pre- and Post- Scheme Period

Parameters	Air Pollution Status				Remark
	Odd-Even Scheme Period (1-15 January 2016)	Pre Odd-Even Scheme Period		Post Odd-Even Scheme Period	
		1-15 January 2015	December 2015	16-30 January 2016	
PM2.5 (µg/m3)	157 to 248.9	37 to 449	46 to 341	124.9 to 439.2	The data was fluctuating due to other impact factors; however the improvement indicates this scheme as one of the controlling methods to reduce air pollution due to vehicular emission.
% Reduction in Peak Level concentration during Scheme Period	--	44.57	28.68	43.42	