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Air Pollution during Phase-1 and Phase-II of Odd-Even scheme in Delhi

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The latest WMO estimate shows that 13 of 20 most polluted cities in the world are in India, including the worst ranked city, Delhi. For the past couple of years, the level of pollutants in this city has been 3-4 times above the safe standards. The Hon'ble Supreme Court of India has directed the policy makers to take suitable steps to bring down the level of pollution to the safe standard. For reducing the pollution level, the Government of Delhi has taken several steps; one was vehicle rationing for the period 1-15 January 2016 and 15-30 April 2016. In this program, vehicles whose number end in odd like 1, 3, 5, 7, 9 were allowed to ply on odd days, i.e 1, 3 January etc. and vehicles whose numbers end in even like 0, 2, 4, 6, 8 were allowed to ply on even days, i.e 2, 4 January etc. Sundays were exempted. In this short communication, we are reporting the pollution level of Delhi during these two periods. The average values of PM2.5 and PM10 (particulate matter) during these periods were 205 μg/m^3 and 326 μg/m^3, respectively, during 1-15 January and 96 μg/m^3 and 179 μg/m^3 during 15-30 April which were much higher than the safe limit 60 and 100 μg/m^3. There was an increase in the pollution level during the event fortnight compared to the pervious fortnight which decreased in the next fortnight. The average values of surface ozone during phase-I and phase-II were 24 ppb (parts per billion by volume) and 46 ppb against the safe limit of 180 ppb. During phase-I, PM2.5, PM10 and O_3 showed a decreasing trend and during phase-II they show an increasing trend. We have also examined the effect of wind, humidity and temperature on pollution level. Pollutants do not appear to have been much affected by temperature and humidity, but their trend is in phase with the wind speed. Results are presented here.

Keywords: Odd-even fortnight, Air pollution, Particulate Matter (PM2.5 & PM10), Ozone, Wind

1 Introduction

The National Green Tribunal has recently said "It is undisputed and unquestionable that air pollution in Delhi is getting worse with each passing day". Tiny particles, PM2.5 and PM10 (particulate matter of radius 2.5 and 10 micrometer) that go inside the lungs are 3-4 times above the safe standards. Fine particles (radius <2.5 micrometer) are more hazardous than the larger ones. These particles cause cardiopulmonary effect (increase blood pressure and inflammatory mediators, C Reactive Protein produced by the liver increases and cause inflammation of arteries leading to cardiac attack), and lung cancer[1,2]. Surface ozone is another pollutant, whose concentration has been found to be much below the safe standard in Delhi. Long-term exposure of low concentration ozone reduces lung function[1,2]. In winter, (ozone value in Delhi is the lowest compared to other seasons) foul air coupled with fall in temperature, increases wheezing, chest constriction, short breath, bronchitis and severe asthma. Air pollution retards growth by causing people to die prematurely. In India it has reduced the life span by over three years. It reduces productivity at work, increases the incidence of sick days and raises the health care expenses. Many employees of MNC are not willing to work in Delhi due to high pollution level in this city. Many are demanding high salary for working in polluted city. As a result of constantly high pollution level above the safe limit, the Hon'ble Supreme Court of India has directed the policy makers to take steps to control this level. To decrease the pollution level, the Government of Delhi has taken several steps; one recent among them, as a test, is vehicle rationing. In this program, vehicles whose number end in 1, 3, 5, 7, 9 were allowed to ply on odd days, i.e 1,3 January etc. and vehicles with numbers ending in 0, 2, 4, 6, 8 were allowed to ply on even days, i.e 2,4 January etc. This program was done in two phases; phase-I was done during the period 1-15 January 2016 and the phase-II was done during 15-30 April 2016. Taking observations during these periods, the Government wanted to study if the pollution would decrease by vehicle rationing. In this short communication, we are reporting the pollution level of Delhi during these periods measured by India Meteorological Department, Government of India.

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2 Experiment Site

The experiment site was the campus of the India Meteorological Department (IMD) situated on Lodi Road in Delhi (28°N, 77°E). The population of Delhi is ~ 14 million, covering an area of ~1483 km^2. It is surrounded by four satellite towns, Faridabad, Gurgaon, Noida and Ghaziabad and is called the National Capital Region (NCR). The whole region is highly polluted by a large number of vehicular traffic, and small and big industries. The river, Jamuna, encompasses the eastern side of Delhi.

3 Experimental Method

Several methods are available to measure the characteristics of particulate matters of different size[3]. We have measured PM10 and PM2.5 using Beta Attenuation Monitor (BAM-1020; Met One Instruments, Inc, USA) which uses the principle of beta ray attenuation. The measurement principle involves emission by a small 14C (carbon-14) element of a constant source of high-energy electrons known as beta rays through a spot of clean glass fiber filter tape. These beta rays are detected and counted by a sensitive scintillation counter to determine a zero reading. The BAM-1020 automatically advances this spot of tape to the sample nozzle, where a vacuum pump then pulls a measured and controlled amount of dust-laden air through the filter tape loading it with ambient dust. This dirty spot is placed back between the beta source and the detector thereby causing an attenuation of the beta ray signal which is used to determine the mass of the particulate matter on the filter tape and the volumetric concentration of particulate matter in the ambient air. The instrument measures concentration of ambient aerosols with a resolution of 0.1 μg m^{-3} and lower detection limit of ~1 μg m^{-3}. Span check of the instrument is automatic and is verified hourly. Details of this method can be had from Being *et al.*[4]

Measurements of surface O_3 were made using O_3 analyzer (49i; Thermo Scientific, USA, precision ~1 ppb). O_3 analyzer works on the principle that O_3 molecules absorb ultraviolet (UV) light at a wavelength of 254 nm and produce a characteristic luminescence. Calibration of the O_3 analyzer was done on every alternate day using an inbuilt O_3 calibrator. Details of this method can also be had from Being *et al.*[4]

4 Results

PM:

Pollutants PM2.5 and PM10 originate from a variety of natural and anthropogenic sources. Oxides of nitrogen (NO_x) and CO are emitted from fossil fuel combustion and NMHCs (Non-methane hydrocarbons) are due to incomplete combustion in automobiles. Federico *et al.*[5] have recently reviewed the contribution of traffic to ambient air pollution. Traffic generates, in addition to vehicular emission, road dust that originates from the wear of road surface, brakes, clutches and tires. The construction and demolition of building also inject dust in the atmosphere. The pollutants are produced as a result of chemical conversion in gas phase, heterogeneous and multiphase reactions between different species[6,7]. Spindler *et al.*[8] have studied characteristics of long-term segregated particle PM10, PM2.5 and PM1. Studies have shown additive and more than additive effects especially for combination of PM and O_3 and PM (especially diesel exhaust) and allergens. During odd-even period, the number of vehicles on the road was (approx) half of those on non-odd-even days. As a result, pollution in the atmosphere is expected to have been reduced. IMD has been measuring concentration of PM2.5 and PM10 along with other pollutants since 2012. We have examined the concentration of PM2.5 and PM10 during phase-I and phase-II vis-à-vis their concentration in the previous and next fortnights to see if there is any effect of reduction of vehicle number on pollution?

Phase-I: Figure 1a shows the hourly average values of PM10 and PM2.5 for phase-I (1-15 January 2016). Day-to-day fluctuation in these values is seen. Also PM10 values are ~1.5 times higher than those of PM2.5 values. A decreasing trend for both PM10 and PM2.5 are seen during phase-I.

Phase-II: Figure 1b shows the hourly average values of PM10 and PM2.5 for phase-II (15-30 April 2016). As in phase-I, day-to-day fluctuation in these values was observed and PM10 values were also ~1.5 times higher than those of PM2.5 values. In contrast to phase-I, however, an increasing trend of both PM2.5 and PM10 was noticed during this period.

The number of vehicles on the road during phase-I and phase-II is nearly the same, but opposite trend of PM2.5 and PM10 in two events is seen in Fig. 1(a,b). To explain this feature, we examined the normal monthly variation of these two species during a year. The monthly variation of average values of PM2.5 and PM10 in Delhi is shown in Fig. 2. These are monthly average values of four years from January 2012 to December 2015. The lowest value is seen in August and the highest value in November. The lowest value in August is due to the monsoon rain

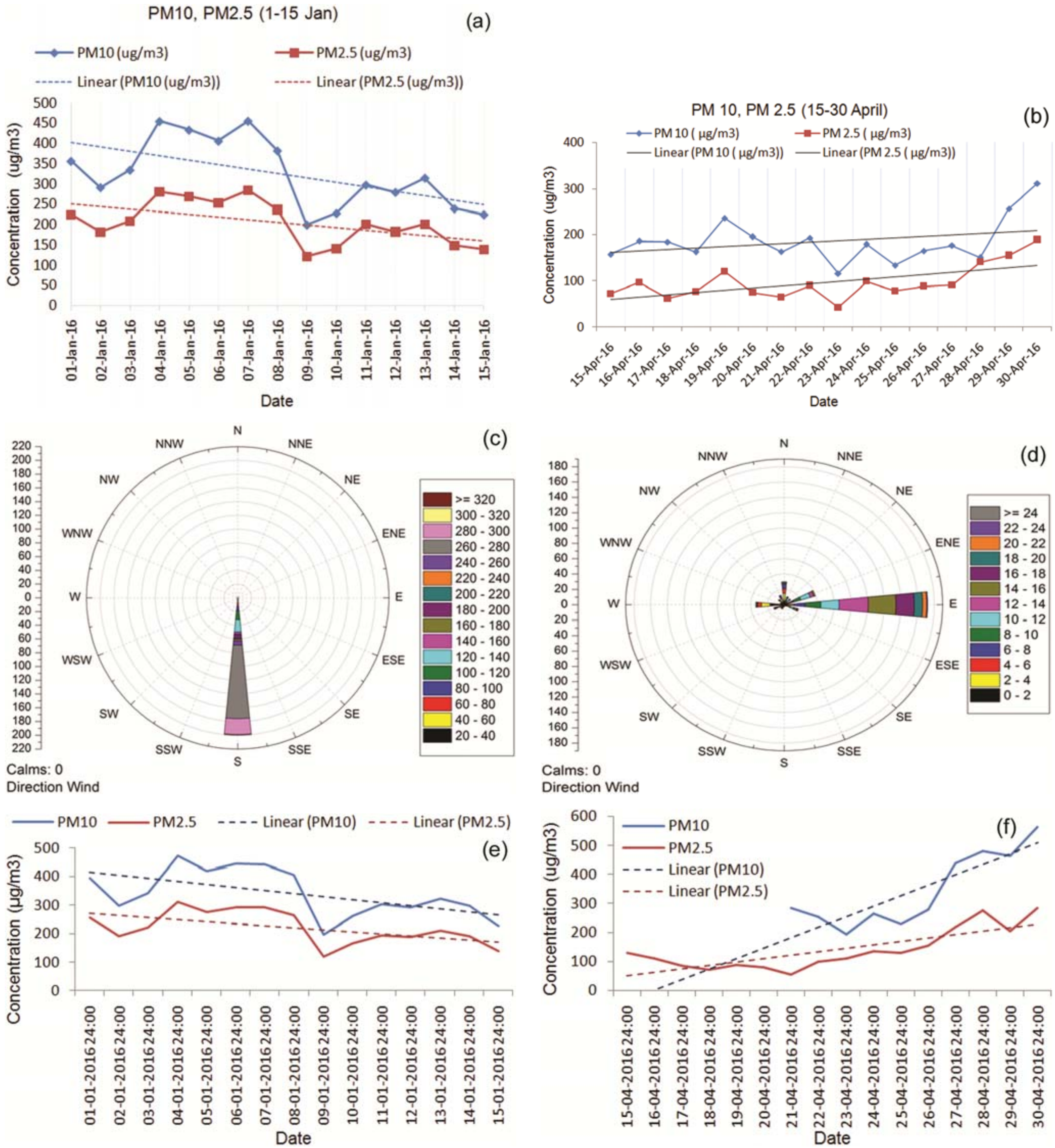

Fig. 1 — (a) Concentration of PM10 and PM2.5 during phase-I (1-15 January 2016) in Delhi, (b) concentration of PM10 and PM2.5 during phase-II (15-30 April 2016) in Delhi, (c) magnitude and direction of wind during phase-I (1-15 January 2016) measured at Delhi, (d) magnitude and direction of wind during phase-II (15-30 April 2016) measured at Delhi, (e) concentration of PM10 and PM2.5 during phase-I (1-15 January 2016) at Noida. The number "24" implies that the values are 24 hour average and (f) concentration of PM10 and PM2.5 during phase-II (15-30 April 2016) at Noida. The number "24" implies that the values are 24 hour average.

which washes away the pollutants. The highest value in November is considered to be due to bio-mass burning after the harvest season. The lowest values in August are 100.99 and 64.58 $\mu g/m^3$ and the highest values in November are 387.7 and 207.9 $\mu g/m^3$ corresponding to PM10 and 2.5 respectively. The

Fig. 2 shows a decreasing tendency of pollutants from January to February in which phase-I period falls. This explains the decreasing trend of PM2.5 and PM10 during phase–I and therefore, if at all a decrease in the pollution level had taken place during phase-I, that was not significant compared to the normal time variation. During April to May (in which phase-II period falls) there was an increasing trend in both PM2.5 and PM10 values (Fig. 2). This shows that if at all a decrease in the value of PM2.5 and PM10 had occurred during phase-II period, then that was not significant enough compared to the normal time variation.

The average values of previous, during and following fortnights of both the events are shown in Table 1. It is seen in this table that in phase-I (Table 1a), the average concentrations of PM2.5 and PM10 increased from 180 and 290 μg/m^3 in the previous fortnight to 205 and 326 μg/m^3 during the test fortnight and then decreased to 175 and 284 μg/m^3 in the next fortnight. In phase-II (Table 1b), the concentrations of PM2.5 and PM10 increased from 64 and 169 μg/m^3 in the previous fortnight to 96 and 179 μg/m^3 during the test fortnight and then decreased to 73 and 123 μg/m^3 in the next fortnight. In both the phases, the average value of the previous fortnight increased in the event fortnight and then decreased in the following fortnight. While the

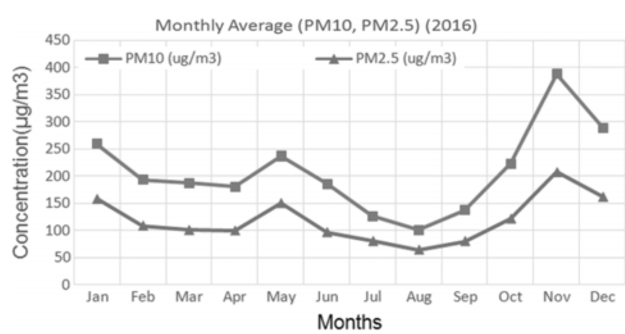

Fig. 2 — Average monthly variation of PM10 and PM2.5 from January to December in Delhi.

Table1a — Average values of PM10, PM2.5 and O_3 for three fortnights (the values of the phase-I fortnight are shown in red).

Date	PM10 (μg/m3)	PM2.5 (μg/m3)	O_3 (ppb)
15-31 Dec 2015	290	180	25
1-15 Jan 2016	326	205	24
16-31 Jan 2016	284	175	26

Table1b — Average values of PM10, PM2.5 and O_3 for three fortnights (the values of the phase-II fortnight are shown in red).

Date	PM10 (μg/m3)	PM2.5 (μg/m3)	O_3 (ppb)
1-15 April 2016	169	64	50
15-30 April 2016	179	96	46
1-15 May 2016	123	73	60

decrease in the following fortnight could be an after effect of vehicle rationing, increase during the event fortnight shows that there is no immediate effect of vehicle rationing on pollution. The average values of PM10 and PM2.5 during phase-I and phase-II were 326 μg/m^3 and 205 μg/m^3 and 179 μg/m^{3}and 96 μg/m^3, respectively, which are much higher than the safe limit 100 μg/m^3 and 60 μg/m^3. The average value during phase-II is ~50% lower than that in phase-I which is understandable from Fig. 2.

After the end of phase-I, web portal of India-Spend showed that air pollution level in the city went up by 15% during the 15 day period when the odd-even plan was in effect, when compared to the last 15 days of 2015 (source: INDIASPEND). Their average concentration of PM2.5 was 309 μg/m^3 (against our value 205 μg/m^3) during the odd-even period compared to the previous fortnight of 270 μg/m^3 (against our value 180 μg/m^3). These are the average values of three stations: Sarvodaya Enclave, India Habitat Centre and Munirka in Delhi. A TERI (Tata Energy Research Institute) study of four stations: Mandir Marg, R K Puram, Punjabi Bagh and Anand Vihar, during phase-I however, reported that there was marginal drop in pollution level. It appears therefore that the pollution level varies from place to place. Also there could be difference between the instruments of two institutions. After phase-II event, Central Pollution Control Board (CPCB) submitted a report to National Green House Court which stated that pollution did not decrease by vehicle rationing, it was the wind which controlled the pollution and brought the pollutants from the neighbouring cities. A recent report prepared jointly by TERI and University of California says that in-house source of Delhi contributes only 32% of air pollution in Delhi; NCR sources other than Delhi contribute 25% and the rest 43% is due to sources outside of NCR. According to this report, even if all emissions from Delhi were stopped, the PM level would still exceed the safe standard, mainly due to the higher contribution from outside Delhi by wind. Fig. 1c & 1d shows the wind value and its direction measured at Lodi Road, Delhi for both phase-I and phase-II. In phase-I, wind value is (approx) 260-280 m/sec (PM2.5 value 205) and wind is going from Delhi to towards south. In phase-II, wind value is less than 24 m/sec (PM2.5 value 96) and wind is going towards east. The magnitude and direction of wind in phase-I and phase-II are very much different, yet in both the events PM value has increased during the odd-even fortnight compared to the value of the previous fortnight. Also PM2.5 value in phase-II is low compared to phase-I value where as wind value in phase-II is high compared to phase-I value. Figs 1e and 1f show the values of PM2.5 and PM10 for Noida, for phase-I and phase II. A comparison of these two figures with Fig. 1a and 1b shows that the trend of variation of PM2.5and PM10 is identical and their concentration is nearly the same in both the cities.

To examine the effect of wind along with temperature and humidity on pollution, their values for both phase-I and II are shown in Fig. 3(a-d). It is seen in these figures that the trend of wind is the same as that of PM2.5 and PM10; the minimum temperature, the maximum temperature and the humidity do not show any significant trend.

If wind brings pollution from the neighbouring cities, then it will also drive the pollution away from Delhi. This is not an absolute loss process of pollutants; it shifts them from one region to other. Conventional loss process of PM is that that they will coagulate and become big and then sediment on the surface of the earth. (Studies[2], however, have also shown that bigger particles quickly break into a large number of small particles). The rate of change of concentration [C] of PM with time (t) can be expressed by the following equation:

$$d[\mathrm{C}]/dt = \mathrm{P} - \mathrm{L}.\,[\mathrm{C}] \quad \ldots (1)$$

Where P is its production rate and L is its loss coefficient. For equilibrium condition, $d[\mathrm{C}]/dt = 0$, then Eq. 1 gives:

$$[\mathrm{C}] = P/L \quad \ldots (2)$$

In both the phases, since C had increased and, if we assume that P had decreased, then that implies that L had decreased at a rate faster than that of P. This indicates that there could be some other kind of loss channel of PM which becomes slow during vehicle rationing as a result C increases. Interestingly, it has been found that along with high value of PM, surface ozone value in Delhi is also very low. Could there be any link between these two? Studies[5] of atmospheric chemistry have demonstrated that PM interacts with gases to alter its composition and toxicity.

O_3:

Surface ozone is also a dangerous pollutant which if not in right proportion, can cause vegetation injury, visible injury, pulmonary damage, asthma attacks and hazardous episodes to environment[1,2]. In Figs. 4a and b we have shown the values of O_3 during odd-even fortnights. As in PM, there is a decreasing trend in phase-I and an increasing trend in phase-II in the concentration of O_3. Seasonal variation of surface ozone in Delhi has been studied earlier[9]. Figure 5 shows the monthly averaged values of surface ozone for Delhi from January 1990 to December 2013. The data of all the years is averaged month wise. These

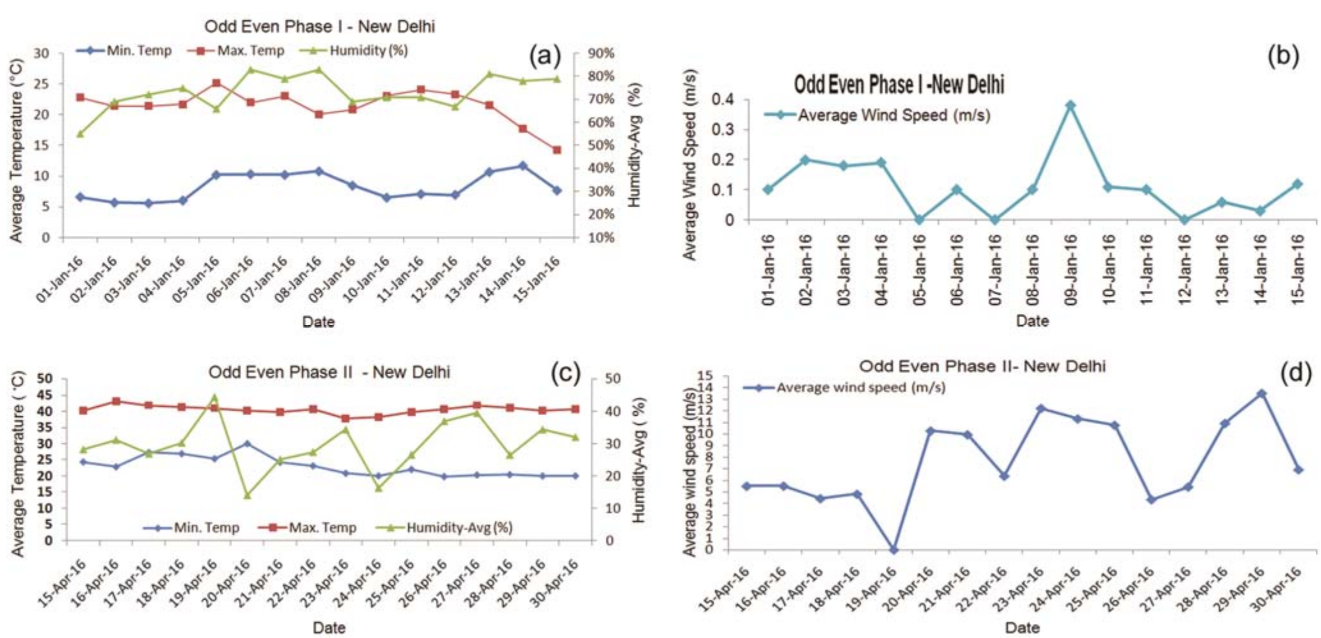

Fig. 3 — Variation of maximum temperature, minimum temperature, humidity and wind during phase-I and phase-II.

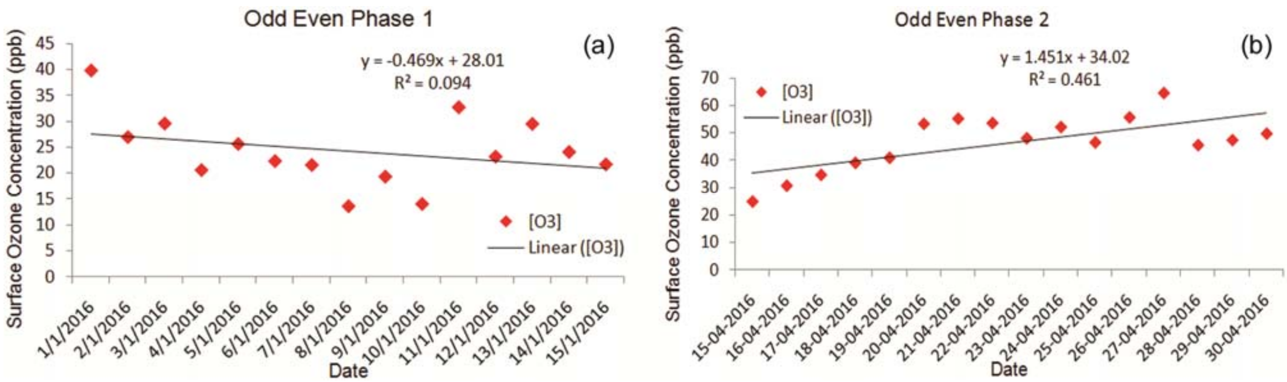

Fig. 4 — (a) Variation of surface ozone during phase-I and (b) variation of surface ozone during phase-II.

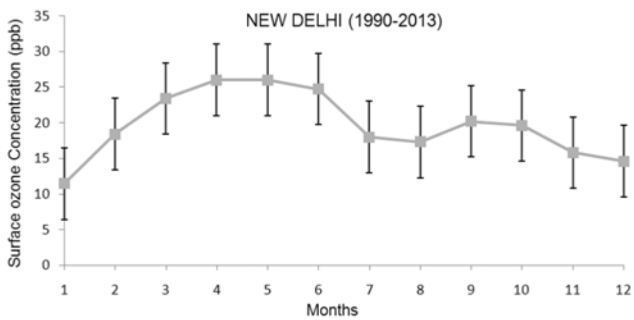

Fig. 5 — Average monthly variation of surface ozone from January to December in Delhi.

are shown in Fig. 5 from January to December. It is seen in this figure that O_3 value (11.5 ppb,) starts increasing from January (winter), becomes maximum (26 ppb) during April - May (summer), decreases to 18-17.3 ppb during July-August (monsoon season), increases to 20.2-19.6 ppb during September – October (post-monsoon period), and then decreases to 14.6 ppb in December (winter). There was an increasing trend from January to April (both in phase-I and II periods). Thus a decrease in O_3 during phase-I could be due to the vehicle rationing. However, this is not seen in phase-II. In Table 1 we have shown average fortnightly values of O_3, before, during and after the events. A minor decrease in the odd-even fortnight from previous fortnight and an increase in the next fortnight are seen. But the average O_3 is much lower than the safe standard value.

5 Conclusions and Remarks

Concentration of PM2.5, PM10 and O_3 were measured during, preceding and the following fortnights of two odd-even events in Delhi. Analysis of data shows a decreasing trend during phase-I period and an increasing trend during phase-II period in the concentration of PM2.5 and PM10. This trend is the same as the normal day trend of the year. There was an increase in the pollution level during the event fortnight compared to the pervious fortnight which decreased in the next fortnight. But the average fortnight values during the event are more than that of the previous and next fortnight values and their concentration is much higher than the safe limit. Pollutants are not affected by temperature and humidity, but they are in phase with the wind speed. An intriguing question is why was there no decrease in the pollution level during the event fortnight when the number of vehicles on the road was reduced by ~50%? In contrast, there was reduction in the levels of pollution when the buses were switched to CNG in 2011. One reason could be that with affluent economy, people purchased two cars of odd-even number plates; as a result, number of vehicles was not reduced during the odd-even periods. Besides, construction and demolition of building (which are in rampart in NCR after municipalities permitted to construct multistoried building) and injection of dust in the atmosphere by high speed running of vehicle (which are on increase), could be some other reasons. It seems ~5 lakh vehicles enter Delhi daily from other states for business. In addition, ~1000 new vehicles are launched on Delhi road daily. Traffic jam is also increasing day by day for which engines have to run for a longer time. Regarding surface ozone, there is no significant variation in its concentration during three fortnights of phase-I, but during phase-II, there has been a marginal decrease during the event fortnight and then significant increase in the following fortnight. Surface ozone value, however, is much lower than the safe limit. It appears, therefore, that the available sample data are insufficient to come to any conclusion about the effect of vehicle rationing on pollution. More measurements should be made in different months, when the meteorological parameters are different. This is also necessary to confirm the findings of TERI and other Institutes. A topic of academic interest is to study the PM-O_3 chemistry because PM value is constantly high and O_3 value is constantly low.

In many countries like, Sweden, Japan, USA and UK, pollution level is within the safe limit. One major step taken by them is to run city public transport by battery or electricity. Traffic jam is another reason of more pollution as vehicles engines run for a longer time. Fly-over is no solution to traffic jam; it only transfers congestion from one location to another. Construction of multi-tire roads, as in Japan, should be considered. India is a tropical country where a lot of solar power is available. Use of solar power should also be encouraged.

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