Odd–even traffic rule implementation during winter 2016 in Delhi did not reduce traffic emissions of VOCs, carbon dioxide, methane and carbon monoxide

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We studied the impact of the odd–even traffic rule (implemented in Delhi during 1–15 January 2016) on primary traffic emissions using measurements of 13 volatile organic compounds, carbon monoxide, carbon dioxide and methane at a strategic arterial road in Delhi (28.57°N, 77.11°E, 220 m amsl). Whole air samples ($n = 27$) were collected during the odd–even rule active (OA) and inactive (OI) days, and analysed at the IISER Mohali Atmospheric Chemistry Facility. The average mass concentration ranking and toluene/benzene ratio were characteristic of primary traffic emissions in both OA and OI samples, with the largest fraction comprising aromatic compounds (55–70% of total). Statistical tests showed likely increase ($p \leq 0.16$; OA > OI) in median concentration of 13 out of 16 measured gases during morning and afternoon periods (sampling hours: 07 : 00–08 : 00 and 13 : 30–14 : 30 IST), whereas no significant difference was observed for evening samples (sampling hour: 19 : 00–20 : 00 IST). This suggests that many four-wheeler users chose to commute earlier, to beat the 8 : 00 AM–8 : 00 PM restrictions, and/or there was an increase in the number of exempted public transport vehicles. Thus, the odd–even rule did not result in anticipated traffic emission reductions in January 2016, likely due to the changed temporal and fleet emission behaviour triggered in response to the regulation.

Keywords: Odd–even rule, pollution, PTR-MS, traffic, VOCs.

DELHI is the world's second most populous megacity with about 25 million inhabitants[1]. Rapid urbanization and increased use of motorized vehicles are among the major factors attributed to the increasing air pollution in the city[2–4]. Delhi has the highest number of personal vehicles in India, with a total registered fleet of 2.9 million cars/jeeps and 6.1 million two-wheeler motor vehicles which alone contributed to 93% of total registered vehicles (about 9.7 million), as on 31 March 2016 (ref. 5). From 2011 onwards, every year on an average about 150,000 cars/jeeps and 300,000 two-wheelers are being registered[5]. Concurrently, in recent times Delhi has experienced several air-pollution episodes in which criteria air pollutants exceeded both Indian regulatory and World Health Organization (WHO) standards for considerable periods[6]. In the past decade, significant initiatives such as conversion of three-wheelers and the bus fleet from petrol/diesel to compressed natural gas (CNG), construction of a 180 km metro rail system and fly-overs have improved air quality in Delhi[7,8], but the benefits rapidly receded with the overall increase in the number of vehicles and other urban emission sources.

Inspired by various road-use rationing schemes implemented in other megacities in the world such as Mexico city[9], Beijing[10] and Sao Paulo[11], as a measure against the severe wintertime air pollution in 2016, the State Government of Delhi implemented the odd–even rule on a trial basis for a period of 15 days from 1 to 15 January 2016. The rule entailed, that during the 15-day trial period, only odd license-plate private four-wheelers/cars could ply between 08 : 00 and 20 : 00 h local time on odd days and only even license-plate numbered private four-wheelers/cars could play on even days[12]. It is worth noting that public transport buses, two-wheelers, trucks, CNG-operated passenger cars and three-wheelers were exempted from the rule. All schools in Delhi were closed during the period, with school buses enlisted for enhancing the exempted public transport fleet. The rule was not applicable on Sundays.

Using the data obtained from the Central Pollution Control Board (CPCB) monitoring stations in Delhi, some studies investigated the impact of this rule on ambient concentrations of nitrogen oxides (NO_x), sulphur dioxide (SO_2), ozone (O_3) and particulate matter (PM_{10} and $PM_{2.5}$)[13–15]. However, as the ambient chemical composition at monitoring stations was controlled by mixed emission sources rather than primary traffic emissions and most of these criteria air pollutants are not unique and strong chemical tracers for traffic emissions, the question of whether traffic emissions had reduced as a result of the odd–even rule could not be addressed conclusively. In fact, contradictory surmises were presented concerning the impact of the odd–even rule on reduction of traffic emissions and air pollution within Delhi[13–15].

Volatile organic compounds (VOCs) are better suited as chemical tracers compared to criteria air pollutants such as sulphur dioxide, ozone and particulate matter, for constraining a variety of emission sources due to their shorter chemical lifetimes and better specificity as tracers

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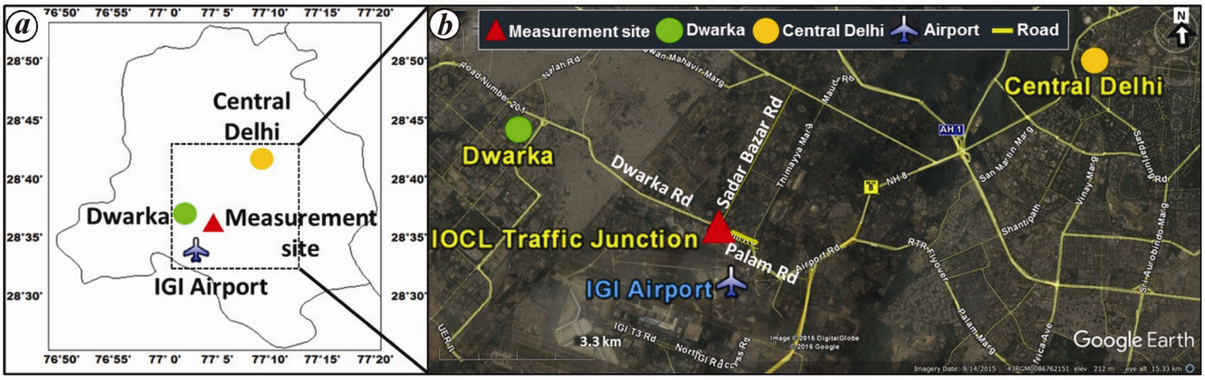

Figure 1. ***a***, Map of Delhi showing sampling location (red marker), airport (blue marker), Dwarka (green marker) and Central Delhi (yellow marker). ***b***, Google Earth image (obtained on 14 September 2015, 13 : 55 IST) showing zoomed view of the land use in the vicinity of the measurement site (IOCL traffic junction, Dwarka road, New Delhi).

of different types of emission activity and processes. Thus, VOCs such as toluene, sum of xylene and ethylbenzene isomers are excellent tracers of automobile exhaust emissions[16,17] and have been used as traffic emission tracers in numerous cities[18,19]. Additionally, VOCs play a significant role in the formation of fine-mode aerosol particles (PM$_1$) through photochemical reactions involving ambient hydroxyl radicals, and can have serious health effects when present at concentrations exceeding several tens of parts per billion[20]. Acetonitrile is a good tracer of biomass burning plumes[21], oxygenated VOCs such as acetaldehyde, acetone, methyl vinyl ketone (MVK) and methyl ethyl ketone (MEK) have strong photochemical sources[22], while daytime isoprene is a good tracer for biogenic emissions[23]. All the non-aromatic VOCs (except methane) are present in lower concentrations relative to aromatic compounds in vehicular tail-pipe exhaust emissions[24–26].

The objective of this study was to assess the impact of the odd–even rule implemented in Delhi during January 2016 on primary traffic emissions. Whole air samples were collected in pre-treated glass flasks at the Indian Oil Corporation Limited (IOCL) arterial road so as to sample primary traffic emissions during the odd–even rule active (OA) and inactive (OI) periods. A total of 27 ambient whole air samples were collected in the morning (07 : 00–08 : 00 IST), afternoon (13 : 30–14 : 30 IST) and night (19 : 00–20 : 00 IST) during periods when the odd–even rule was active (1, 2, 4, 11, 12 and 13 January 2016) and inactive (31 December 2015, 20 and 21 January 2016) respectively. Thirteen VOCs including toluene, and carbon dioxide, methane and carbon monoxide were analysed in the whole air samples at the IISER Mohali Atmospheric Chemistry Facility[27,28]. Data for the odd–even active and inactive periods were subjected to the Mann–Whitney *U* test for assessing statistically significant differences, if any. Moreover, total VOC, carbon monoxide, methane and carbon dioxide mass concentration and observed ambient variability were used to assess variance in the traffic emission intensity between the odd–even active and inactive periods.

All the whole air samples were collected in specially conditioned glass flasks at the IOCL arterial road (28.57°N, 77.11°E, 220 m amsl). This is a strategic arterial road which connects the residential colonies of Dwarka, the commercial and business centres of Sadar Bazar in central Delhi, the sub-urban residential colonies of Palam in southwest Delhi and the New Delhi International Airport. A mixed fleet of 35,000–40,000 diesel, petrol and gasoline-powered vehicles have been reported to ply on road during peak traffic hours[29]. Figure 1 *a* and *b* shows the location of the site on the map of Delhi (plotted using Pan Map GIS software). The red marker depicts the sampling site, whereas the yellow and green markers show Central Delhi and Dwarka respectively. The land use in the vicinity of the measurement site is shown in Figure 1 *b*, as a zoomed Google Earth image obtained on 14 September 2015; 13 : 55 IST. As can be seen there are no large industrial point sources in the vicinity. Hence, the site presented a suitable option for investigating the impact of the odd–even rule on primary traffic emissions.

Measurements of meteorological parameters were available at 10 m above the ground from a tower at the Indira Gandhi International Airport[30], which was 1.7 km away from our sampling site. Table 1 summarizes the average ambient temperature (°C) and relative humidity (%) measured during the respective morning, afternoon and night sampling hours during both OA and OI periods. Higher afternoon (30%) and night-time (25%) average ambient temperatures were observed during OA relative to OI periods, suggesting a higher mixed layer depth and stronger dilution effect at the sampling site, when the odd–even rule was in place.

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Table 1. Average ± 1σ ambient variability of ambient temperature and relative humidity during the periods when odd rule was active (1, 2, 4, 11, 12 and 13 January 2016) and inactive (31 December 2015; 20 and 21 January 2016)

	Morning (7 : 00–8 : 00 IST)		Afternoon (13 : 30–14 : 30 IST)		Night (19 : 00–20 : 00 IST)	
Met parameters	Active	Inactive	Active	Inactive	Active	Inactive
Temperature (°C)	12.6 ± 1.2	9.8 ± 1.1	22.2 ± 1.1	16.7 ± 4.5	18.1 ± 1.3	14.5 ± 3.9
Relative humidity (%)	72.4 ± 5.3	78.9 ± 4.9	36.2 ± 6.3	46.3 ± 17.4	54.6 ± 10.7	57.3 ± 16.4

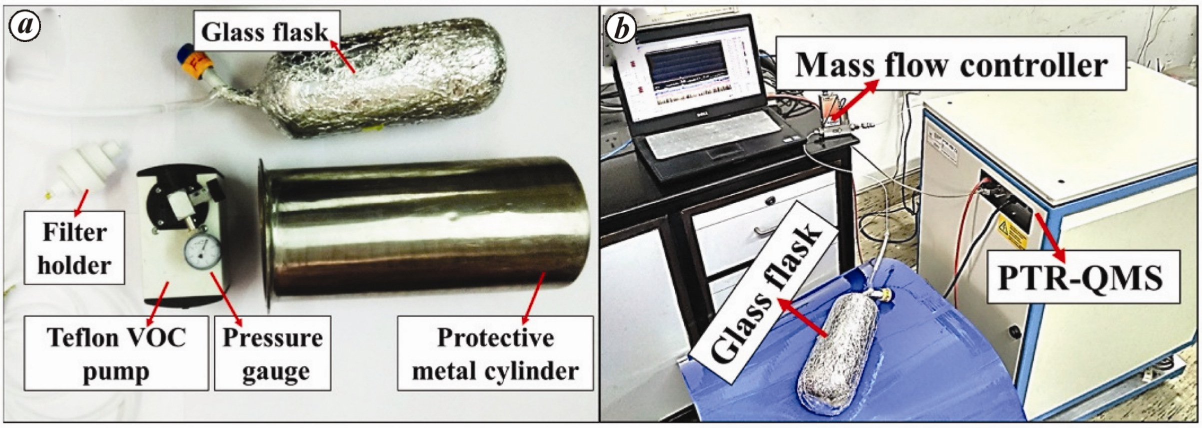

Figure 2. ***a***, Photograph of the equipment employed for the whole air sample collection using a custom-made borosilicate glass flask. ***b***, Photograph of volatile organic compounds (VOC) analysis set up for measuring VOCs from collected whole air samples using the PTR-QMS.

21 January 2016) respectively. Care was taken to ensure that the sampling was not biased by singular vehicles and direct tail-pipe emissions. This was done by sampling at a height of 1.5 m above the road on the divider and at a spot where vehicles were not allowed to stop at all. The sample collection time was about 2 min and from our experience during this time, at least 15–20 vehicles passed by the collection point. Thus, the samples we collected represent the emission signature of at least 15–20 vehicles and would not be biased by emission signatures of just one or two vehicles.

Figure 2 *a* shows a photograph of the equipment employed for whole air sample collection, namely a 2 litre customized borosilicate glass flask (Vensil Glass Works Limited, Bengaluru, India), Teflon sample inlet tubing (9.5 mm o.d.) with inline Teflon filter holder, and a Teflon VOC pump (model – N 86 104 KT.45.18; KNF pump), equipped with a pressure control valve. Prior to the collection of ambient whole air samples on-site, the glass flasks were cleansed and conditioned using the following protocol: (1) The flasks were cleaned with chromic acid to remove sticky organic material and rinsed with deionized water. (2) The flasks were then heated in an oven (Model-1210D/8; Jain Scientific Glass Works, Haryana, India) for 8 h at 180°C. (3) Thereafter, the flasks were filled with VOC-free zero air (~2 bar) produced using a gas calibration unit (GCU-A, Ionimed Analytik)[31] and evacuated and refilled (~300 mbar) at least thrice to remove potential residual effects. (4) Finally, the flasks were sheathed with aluminium foil to shield them from ambient radiation. The application of glass flasks for whole air grab sampling of VOCs, including storage stability of C2–C7 hydrocarbons, benzene and toluene has previously been validated[32,33].

During sample collection, air was sampled actively into the pre-treated glass flask using the Teflon VOC sampling pump and the glass flasks were pressurized only up to 2 bar. The sampling inlet was protected from floating dust and ambient particles using a Teflon membrane filter (pore size 0.45 μm). Once the desired pressure was reached, the Teflon screw on the flask was closed and the flask was stored in a dark container, until analysis within five days of sample collection at the IISER Mohali Atmospheric Chemistry Facility. A detailed technical description of this unique facility in India has been provided in our previous works[27,28,34]. Hence, only a brief description is provided here.

Figure 2 *b* shows the analysis set-up for VOC measurements from the glass flask using a high-sensitivity proton transfer reaction quadrupole mass spectrometer (PTR-QMS; HS Model11-07HS-088; Ionicon Analytik Gesellschaft, Austria). Within the PTR-QMS, analyte molecules undergo very soft chemical ionization with hydronium ions $(H_3O)^+$, which are the primary reagent ions, and the protonated ions are separated using a quadrupole mass analyser and detected using a secondary electron multiplier[27,28]. Each VOC was measured with a dwell time of 1 s in selected ion-monitoring mode. The 13 VOCs, namely methanol, acetonitrile, acetaldehyde, acetone, dimethyl sulphide (DMS), isoprene, MVK, MEK, benzene, toluene, sum of xylene and ethylbenzene isomers, sum of trimethylbenzene and propylbenzene isomers, and monoterpenes were detected at their respective protonated organic ions (MH^+): *m*/*z* 33, *m*/*z* 42, *m*/*z* 45, *m*/*z* 59, *m*/*z* 63, *m*/*z* 69, *m*/*z* 71, *m*/*z* 73, *m*/*z* 79, *m*/*z* 93, *m*/*z* 107, *m*/*z* 121 and *m*/*z* 137 respectively. These VOC identifications are in keeping with extensive validation experiments performed in a variety of ecosystems and have been reviewed in detail previously[35,36]. Due to isobaric contributions of furan to the signal at *m*/*z* 69 and potential minor isobaric contributions to MVK and MEK, our measurements represent an upper limit for isoprene, MVK and MEK concentrations[27,35]. The sample flow (~100 ml/min) from the glass flask was regulated using a mass flow controller (MFC: EL-FLOW; Bronkhorst high-tech; stated uncertainty 2%). Calibration experiments were performed on 2 December 2015 and 15 January 2016 to determine sensitivities, by dynamic dilution of a custom-ordered VOC gas standard (Apel-Riemer Environmental, Inc., Colorado, USA). The sensitivity factors (normalized counts per second/parts per billion (ncps/ppb)) and measurement uncertainties for the aforementioned 13 VOCs were determined according to the protocols detailed in our previous works[27,31,34]. All mixing ratios so obtained were converted to mass concentrations using the measured ambient temperatures and pressures relevant for the sample. The total measurement uncertainties were as follows: methanol, acetonitrile, acetaldehyde, acetone, benzene and toluene (<15%), acetonitrile, DMS, isoprene, MEK and MVK (<20%), and sum of xylenes and ethylbenzene isomers, sum of trimethylbenzenes and propylbenzene isomers and monoterpenes (<25%). The limit of detection (2σ noise while sampling VOC-free air) ranged between 0.03 and 0.15 $\mu g\ m^{-3}$, and was never an issue for any of the ambient air samples from Delhi.

Carbon dioxide (CO_2) and methane (CH_4) were measured using a cavity ring down spectrometer (CRDS; Model G2508, Picarro, Santa Clara, USA), whereas carbon monoxide (CO) was measured using a non-dispersive infrared (NDIR) filter correlation spectrometer (Thermo Fisher Scientific, Model No. 48i), as described in our previous work[27,28]. Calibration experiments were performed for the CRDS instrument by dynamic dilution of a gas standard mixture of CO_2 and CH_4 (Phoenix Gases Ltd, Navi Mumbai, India; traceable to NIST, USA) on 19 December 2015, and for the CO analyser on 12 December 2015 and 19 January 2016 by dynamic dilution of a gas standard (Chemtron Science Laboratories Pvt Ltd, Mumbai) respectively. The total uncertainty for the CO measurements was always below 6% and for the measurements of CO_2 and CH_4 it was <4% in each case. The limit of detection for CO_2, CH_4 and CO was below 0.5, 0.2 and 12 $\mu g\ m^{-3}$ respectively. Concentrations of CO_2 and CH_4 reported in this study were corrected for the dilution and broadening effect due to the presence of water vapour[37].

Figure 3 presents a summary of the average VOC fractional contributions to the total measured VOC mass concentration ($\mu g\ m^{-3}$) for the morning (7 : 00–8 : 00 IST), afternoon (13 : 30–14 : 30 IST) and night–time (19 : 00–20 : 00 IST) during both OA and OI periods. Also shown as red, blue and black histograms are the average measured mass concentrations ($\mu g\ m^{-3}$) of CO_2, CH_4 and CO respectively. Vertical bars on the histograms represent the 1σ measurement uncertainty. The average mass concentration ranking of measured species was characteristic of traffic plumes[38–40], the same in all the collected samples ($n = 27$) and as follows: CO_2 ($OA_{avg} = 997.8$ mg m^{-3}; $OI_{avg} = 930.7$ mg m^{-3}) > CO ($OA_{avg} = 3.9$ mg m^{-3}; $OI_{avg} = 4.2$ mg m^{-3}) > CH_4 ($OA_{avg} = 2.7$ mg m^{-3}; $OI_{avg} = 2.2$ mg m^{-3}) > toluene ($OA_{avg} = 90.7$ $\mu g\ m^{-3}$; $OI_{avg} = 71.3$ $\mu g\ m^{-3}$) > sum of xylenes and ethylbenzene isomers ($OA_{avg} = 77.6$ $\mu g\ m^{-3}$; $OI_{avg} = 61.6$ $\mu g\ m^{-3}$) > sum of trimethylbenzenes and propylbenzene isomers ($OA_{avg} = 45.5$ $\mu g\ m^{-3}$; $OI_{avg} = 36.3$ $\mu g\ m^{-3}$) > methanol ($OA_{avg} = 56.3$ $\mu g\ m^{-3}$; $OI_{avg} = 40.1$ $\mu g\ m^{-3}$) > benzene ($OA_{avg} = 40.0$ $\mu g\ m^{-3}$; $OI_{avg} = 34.3$ $\mu g\ m^{-3}$) > acetone ($OA_{avg} = 30.4$ $\mu g\ m^{-3}$; $OI_{avg} = 22.6$ $\mu g\ m^{-3}$) > acetaldehyde ($OA_{avg} = 30.4$ $\mu g\ m^{-3}$; $OI_{avg} = 22.6$ $\mu g\ m^{-3}$) > sum of isoprene and furan ($OA_{avg} = 16.7$ $\mu g\ m^{-3}$; $OI_{avg} = 12.0$ $\mu g\ m^{-3}$) > methyl ethylketone ($OA_{avg} = 9.8$ $\mu g\ m^{-3}$; $OI_{avg} = 6.2$ $\mu g\ m^{-3}$) > methyl vinyl ketone ($OA_{avg} = 7.9$ $\mu g\ m^{-3}$; $OI_{avg} = 5.6$ $\mu g\ m^{-3}$) > acetonitrile ($OA_{avg} = 4.0$ $\mu g\ m^{-3}$; $OI_{avg} = 3.0$ $\mu g\ m^{-3}$) > monoterpenes ($OA_{avg} = 2.5$ $\mu g\ m^{-3}$; $OI_{avg} = 1.7$ $\mu g\ m^{-3}$) > dimethyl sulphide ($OA_{avg} = 1.2$ $\mu g\ m^{-3}$; $OI_{avg} = 1.1$ $\mu g\ m^{-3}$). The total fraction of measured aromatic mass concentrations (105.0–351.6 $\mu g\ m^{-3}$; sum of benzene, toluene, sum of xylenes and ethylbenzene isomers and sum of trimethylbenzenes and propylbenzene isomers) accounted for 55–70% of the total measured VOC mass concentrations in all samples. It is worth mentioning that in ambient surface air at sites where the chemical composition is not controlled by primary traffic emissions, the sum of oxygenated VOCs such as methanol, acetaldehyde, acetone, MVK and MEK typically exceeds the sum of the concentration of aromatic compounds such as benzene, toluene, sum of xylenes and ethylbenzene isomers and sum of trimethylbenzene and propylbenzene isomers, as reported in previous studies[27,41]. Toluene and alkyl benzenes are major constituents of automobile exhaust[16,17], in part because of the use of such compounds and their derivatives as additives that improve the fuel octane rating and anti-knock properties. Table 2 shows a comparison of the average concentration ($\mu g\ m^{-3}$) acquired in the present study for benzene, toluene and sum of xylenes and ethylbenzene isomers and their concentration ranking (toluene > sum of xylenes and ethylbenzene isomers > benzene) with traffic sites in the UK[42], Algeria[43] and

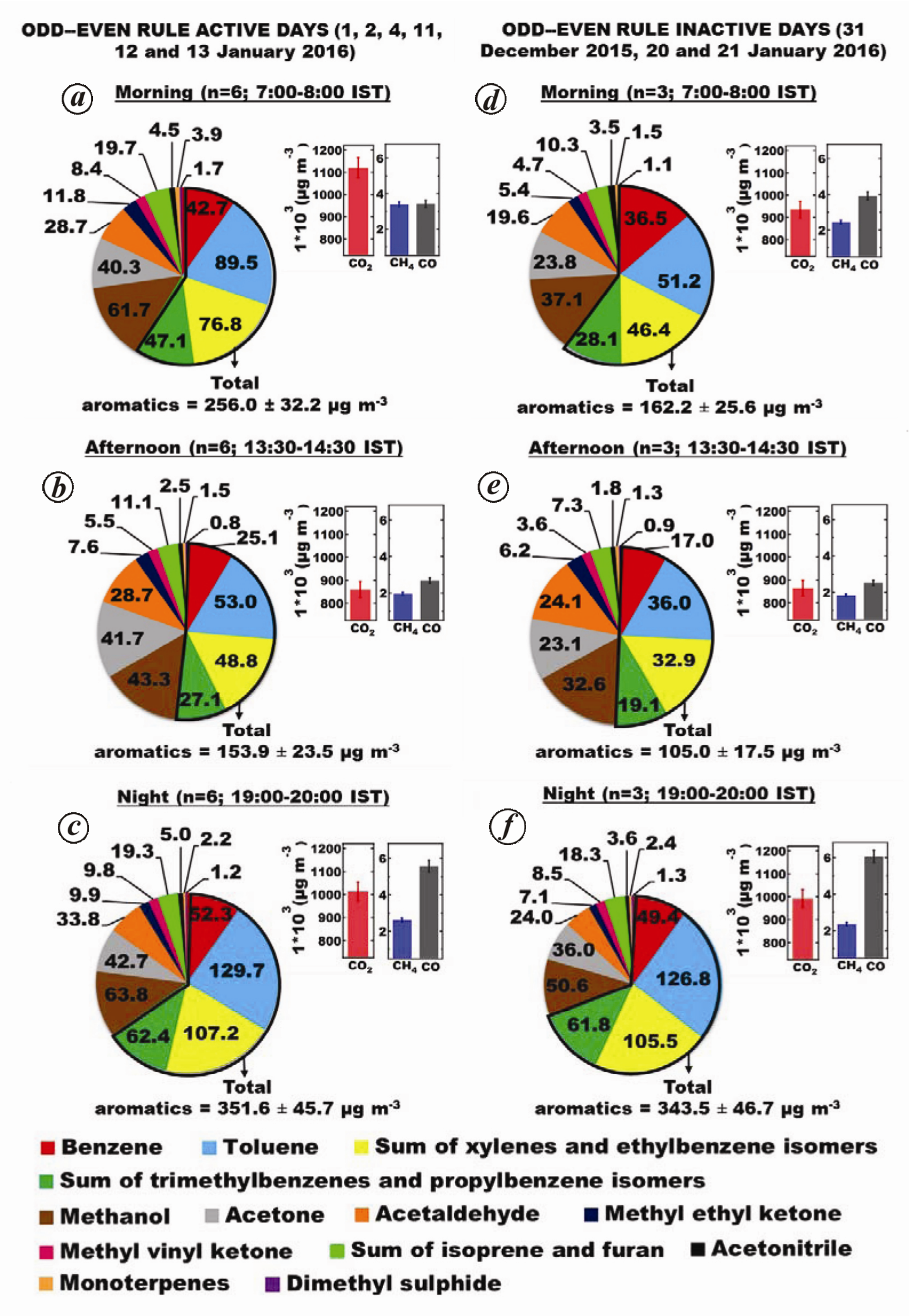

Figure 3 *a–f*. Pie charts summarizing VOC speciation during odd–even rule active days and odd–even rule inactive days derived from the measurements (*n*) at IOCL traffic thorough fare, New Delhi. Each fraction in each pie chart represents the respective averaged measured VOC mass concentration (μg m^{-3}). Highlighted fraction of each pie chart with a black line shows the total fraction of measured aromatic mass concentration in the total measured VOC mass concentration in μg m^{-3} ± 1 standard deviation (total measurement uncertainty). Inserted red, blue and black histograms are the average measured mass concentration of carbon dioxide, methane and carbon monoxide respectively. Vertical bars represent the total measurement uncertainty as standard deviation.

previous traffic emission studies in Kolkata[44] and Delhi[45]. Direct comparison of the absolute VOC concentration values in different studies should be treated with caution as the type of fuel, traffic density and meteorological conditions can induce large variability, but toluene (T) to benzene (B) concentration ratios are better indicators for characterizing traffic plume signatures. We note that the (T/B) concentration ratios greater than 1 are characteristic of traffic emission ratios, and considering ambient variability of individual datasets (T/B = 2.7 ± 0.2 during OA and T/B = 2.1 ± 0.8 during OI), comparable to the T/B ratios reported from traffic plumes in Birmingham, UK

Table 2. Comparison of average benzene, toluene and sum of xylene and ethyl benzene isomer concentrations (μg m^{-3}) and average ratio of toluene to benzene measured at sampling site (28.57°N, 77.11°E, 220 amsl) with road-side measurements at selected sites elsewhere in the world

Location	Benzene (B)	Toluene (T)	Sum of xylene and ethylbenzene isomers	Average *T*/*B* ratio
Birmingham, UK[a]	49.6	108.1	69.5	2.2
Algiers, Algeria[b]	27.1	39.2	33.1	1.5
Kolkata, India[c]	30.8	52.1	48.5	1.7
Delhi (Connaught Place), India[d]	97	180	144	1.9
Delhi (Okhla), India[d]	89	204	118	2.3
Delhi (AIIMS), India[d]	110	191	155	1.7
Delhi (IOCL traffic junction), India[e]	38.1	84.3	72.3	2.2

[a]Kim *et al.*[42], [b]Kerbachi *et al.*[43], [c]Som *et al.*[44], [d]Hoque *et al.*[45], [e]Present study.

(2.2)[42]; Algiers, Algeria (1.5)[43]; Kolkata (1.7)[44]; Connaught Place, Delhi (1.9)[45]; Okhla, Delhi (2.3)[45] and AIIMS, Delhi (1.7)[45].

The average mass concentration in morning samples collected between 7 and 8 a.m. local time for all measured VOCs during OA period was 436.6 ± 161.5 μg m^{-3} out of which aromatic compounds contributed 256.0 ± 32.2 μg m^{-3} (note numbers are: average ± 1σ ambient variability). These are 1.6 times higher than the average of all measured VOCs during the OI period of 269.2 ± 124.3 μg m^{-3}. This suggests that a large number of personal vehicle users may have opted to commute before the traffic restrictions were put in place (odd–even rule enforcement timings were 8 a.m.–8 p.m.). In the afternoon, during the OA period, the measured average total mass concentration of VOCs was 256.0 ± 32.2 μg m^{-3}, while that of the total aromatic compounds was 153.9 ± 23.5 μg m^{-3}, which is about 1.4 times higher compared to corresponding OI period values. Note that this is despite the OA period being characterized by warmer afternoons and hence potentially higher mixed depth layer and dilution ($T_{\text{avg,OA}}$ = 22.2°C versus $T_{\text{avg,IA}}$ = 16.7°C). Given the fact that during the OA period there was an overall increase reported in the number of vehicles that were exempt from the rule such as motorized two-wheelers (12%), three-wheelers (12%), taxis (22%) and buses (138%)[13], and the fact that two-wheelers have higher emissions per unit than cars fitted with latest emission control technology[4,46], the combination can explain the observed data. In the night-time, average measured mass concentrations of VOCs were comparable within the 1σ ambient variability range.

We further employed robust statistics (Mann–Whitney *U*)[47] to test for statistically significant differences, if any, for the median concentrations of the measured VOCs and trace gases in samples collected during the OA and OI periods. The results are as under:

(i) Median concentrations for the morning samples were significantly higher (confidence interval ≥84% or $p \leq 0.16$) during the OA period for all compounds, except benzene, CO and acetonitrile. It is worth mentioning that neither benzene nor CO nor acetonitrile has traffic as its dominant source.

(ii) Median concentrations for the afternoon samples were also significantly higher (confidence interval >90% or $p < 0.1$) during the OA period for all compounds, except methane, methanol and DMS.

(iii) Median concentrations for the night-time samples did not have statistically significant differences between OA and OI periods.

In view of the obtained experimental data and statistical test results, we conclude that the odd–even rule policy measure did not result in reduction of primary traffic emissions. Instead, it appears that there was an overall increase in traffic emissions, likely due to the changed temporal and fleet emission behaviour triggered in response to the rule. Two factors combined together can help explain the higher traffic emissions observed during the period when the odd–even rule was enforced. The first is that a large number of personal vehicle users seem to have opted to commute before the traffic restrictions were put in place. Secondly, there was an overall increase reported in the number of vehicles that were exempt from the rule, such as motorized two-wheelers, three-wheelers, taxis and buses by 12–138% (ref. 46). The emissions from the increased fleet of exempt vehicles therefore appear to have offset the reduction of emissions accomplished by controlling personal four-wheeler vehicles/cars. Another point worth considering is that the odd–even rule may have resulted in traffic decongestion during peak hours, which may certainly have benefited commuters. However, it must also be kept in mind that enhanced traffic emissions during times of the day when the dilution effect due to the atmospheric boundary layer is low (e.g. early morning before 8 a.m. and at night after sunset), could lead to higher peak concentration exposure for several health-relevant carcinogenic VOCs such as benzene.

While several important insights have been gained through this study, for future assessment studies, it would be advisable to deploy on-line VOC measurements of the kind reported here at multiple strategic sites as part of the experimental design. Further, combining measurements of tail-pipe emissions from key major vehicle types plying on the roads along with information about the number and type of vehicle (e.g. through webcam recordings at sampling points), would help provide more detailed information concerning the major emitters. Such an experimental design would also help address current uncertainties with regard to quantitative source apportionment of air pollutants in Delhi, similar to that demonstrated recently by some of us for the Kathmandu Valley[41,48], and enable air-pollution mitigation efforts for multiple urban sources rather than just traffic emissions.

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Effective weed control strategy in tomato kitchen gardens – herbicides, mulching or manual weeding

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Effect of weed control on tomato (*Solanum lycopersicum* L.) crop has been rarely explored in kitchen gardens for improving fruit yield and quality. Therefore, we studied the impact of manual weeding, herbicide application and mulching (using polyethylene sheet) on tomato crop improvement in kitchen gardens. The data show significant differences among different treatments in terms of weed density/m^2, weed fresh biomass and dry biomass and quality of tomato plants in terms of plant height, fruit-bearing (fruits/plant) and yield (tonne/ha). Highest weed density/m^2 (3.5 ± 0.84) was observed in plots with herbicide treatment and it was similar to that in control. Weed fresh biomass was significantly reduced in all treatments. Manual weeding resulted in the highest number of fruits/plant (33.75 ± 1.67), plant height (60 ± 1.01 cm) and yield of tomato (4.45 ± 0.18 tonne/ha). Therefore, manual control proved to be the most effective treatment in terms of weed suppression and yield enhancement of tomato crop. It was also observed that in crop production mulching must be encouraged in the future weed management strategies.

Keywords: Herbicide, kitchen gardens, tomato, mulching, weed control.

TOMATO (*Solanum lycopersicum* L., Solanaceae) is a popular and nutritive vegetable crop ranking next to potato in the world's vegetable production[1]. It is an important source of minerals and antioxidants, including carotenoids, lycopene, vitamins C and E, and phenolic compounds, which play a key role in human nutrition in preventing certain cancers and cardiovascular diseases[2]. Being one of the most favourite vegetables, tomato is consumed in many ways[3].

Several factors are responsible for low yields of tomato. Among them, weed infestation in cultivated fields is the major factor which also reduces quality and value of the crop by competing for light, space and nutrients. Thus the farmer ends up spending more on agronomic practices[4]. On the other hand, weeds provide a safe harbour to many insect pests of tomatoes.

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