BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,

PRINCIPAL BENCH, NEW DELHI

Original Application No. 663/2023

In the matter of:

In re: News item published in Indian Express dated 07.10.2023 titled "GRAP Stage 1 kicks in as air quality dips to poor, condition likely to prevail till Sunday

NDOH: 20.11.2023

INDEX

Filed by

(K.S. Jayachandran)
Special Secretary-Environmental Department

Dated: 17th November, 2023
Place: Delhi

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PRINCIPAL BENCH, NEW DELHI
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ADDITIONAL ACTION TAKEN REPORT ON BEHALF OF GOVT. OF NCT OF DELHI.

MOST RESPECTFULLY SHOWETH:

1. That, the above mentioned matter was taken up by this Hon`ble Tribunal on 20.10.2023 on the basis of the various news reports and pleased to issue notice to Commission for Air Quality Management (CAQM), Chief Secretary-Delhi, Member Secretary-Delhi Pollution Control Committee, Commissioner-Municipal Corporation of Delhi, Member Secretary-Central Pollution Control Committee and Ministry of Environment, Forest and Climate Change.

2. That in compliance with this Hon`ble Tribunal order 20.10.2023, the GNCTD has filed a detailed report on 07.11.2023.

3. That this Hon`ble Tribunal considered the report of various respondents during the hearing on 08.11.2023 and pleased to direct:

(2)

I. *CPCB to file the report on the technical interventions suggesting ways to regulate and control pollution.*

II. *The concerned agencies are required to review their strategy and come out with effective solution to ensure that the AQI in Delhi and NCR is maintained within the permissible limits. In this regard during the course of arguments, following suggestions have been made by Counsel for the parties:*

- *Under GRAP, all kinds of Government constructions have been permitted, whereas at the stage of invoking GRAP-IV only the urgent and time bound government construction activities should be allowed and other should be deferred till the air quality improves.*
- *There are lapses on the part of implementing agencies in implementation of GRAP, therefore, effective steps should be taken to ensure its proper and full implementation.*
- *The Ministry of Petroleum should consider imposing ban on supply to petrol and diesel to unregistered and non-compliant vehicles by the petrol pumps.*

III. *Since no visible improvement in the air quality has been witnessed, therefore, the respondents are directed to take stringent measures so that the air quality index in Delhi and NCR improves.*

(3)

4. That, the present action taken report is being filed on the additional action taken and proposed to be taken by Government of NCT of Delhi for air pollution control.

4.1. To address the issue of air quality and to ensure and maintain satisfactory air quality in whole of Delhi, a detailed order for mitigation of air pollution in Delhi with special focus on Hotspots during the winters has been issued on 13.10.2023 with following major directions:

(i) all Dy. Commissioners of MCD as well as Secretary NDMC have been directed to intensify targeted and specific mitigation measures across Delhi with special focus and intensity at the 13 Air Hotspots, such as mechanical road sweeping, water sprinkling, smogging with static/ mobile anti-smog guns, repair of broken roads, paving of unpaved shoulders, traffic decongestion, etc., in coordination with all responsible departments / agencies to ensure improvement in the quality of air in Delhi and especially the hotspots;

(ii) In order to further strengthen the monitoring at ground level, a Monitoring Committee for each Revenue District has been constituted with immediate effect to ensure that targeted and specific measures for mitigation of air pollution is taken in Delhi on a mission mode during the winter months till 31st January, 2024. Such 11 Monitoring Committees shall comprise of concerned officers, details of which are as under-

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a. Coordinator;

b. District Magistrate;

c. Deputy Commissioner of Police (Traffic) / Addl. DCP (Traffic);

d. Deputy Commissioner, MCD or Secretary NDMC, as the case may be;

e. Chief Engineer, DDA;

f. Chief Engineer, PWD;

g. Concerned DCF/DFO;

h. DANICS Probationer;

i. Sub-Divisional Magistrates;

j. JE (Env.), DPCC;

k. Enforcement Officer of the Transport Department;

l. Representatives of DISCOMs (equivalent to the rank of Chief Engineer)

(iii.) Keeping in view of the deteriorating ambient air quality in the NCR and invoking of actions envisaged under Stage-III 'Severe' Air Quality (AQI ranging between 401-450) and Stage-IV ('Severe +' Air Quality (AQI >450) of Graded Response Action Plan (GRAP) vide CAQM order dated 02.11.2023 and 05.11.2023 and to further strengthen ground enforcement of various actions, additional 26 DANICS Officers have been appointed for ensuring Air Pollution control at the 13 Hotspots.

(iv) DPCC and other agencies have deployed 591 enforcement teams to ensure strict compliance of dust control norms as well as to stop illegal C&D waste dumping, for day and night patrolling. 611 enforcement teams have been deployed for identification and challaning of biomass and

(5)

solid waste burning incidences. 385 enforcement teams have been deployed for checking polluting vehicles.

5. That the Cabinet Secretary Government of India had taken a meeting on 08.11.2023 with all stakeholders in compliance with the directions passed by the Hon'ble Supreme Court of India dated 07.11.2023 regarding Air Quality Management in Delhi & NCR. Mentioned below is the action taken by GNCTD as per directions of the Cabinet Secretariat since 08.11.2023:

S. No.	Directions	Action taken report
1	Enforcement done on Fire cracker ban	Directions had been issued by DPCC vide dated 06.10.2023 under section 31 (A) of Air (Prevention and Control of Rule 20 Pollution) Act, 1981, read with (A) (6) of the Air (Prevention and Control of Pollution) (Union Territories) Rules, 1983, to Delhi Police for ensuring compliance for 'Complete Ban' on all kinds of firecrackers on manufacturing, storage, selling (including delivery through online marketing platform) and bursting upto 01.01.2024 in the territory of Delhi. Enforcement data (Since 16.10.2023 till 12.11.2023): a. No. of fire crackers sale violation observed / identified : 136 b. Quantity of fire crackers seized for

<table>
<tr><td></td><td></td><td>storage/sale : 12,365.148 kg
c. Quantity of fire crackers seized for bursting : 11.400 kg
d. No of violation observed/identified for bursting firecrackers: 10</td></tr>
<tr><td>2</td><td>Rationalizing parking fees</td><td>Due to ongoing Air pollution, NDMC has doubled the parking fees in 91 surface parking run in NDMC.
Rationalization of parking fees is under consideration in MCD.</td></tr>
<tr><td>3</td><td>Strict control on burning of municipal solid waste</td><td>Enforcement data (Since 08.11.2023 till 13.11.2023):
<table>
<tr><th>Action Points</th><th>Data</th></tr>
<tr><td>No. of inspections conducted</td><td>2380</td></tr>
<tr><td>No. of open burning sites addressed sites</td><td>274</td></tr>
<tr><td>No. of notices/ challans issued</td><td>274</td></tr>
<tr><td>Fine imposed (in Rs)</td><td>2,55,000/-</td></tr>
</table></td></tr>
<tr><td>4</td><td>Enforcement of ban on DG Sets</td><td>1. CAQM Direction no. 73 and Direction no. 76 have been circulated to all concerned. Appropriate emission control mechanism shall be put in place on or before 31.12.2023 in respect of DG Sets used in</td></tr>
</table>

<table>
<tr>
<td></td>
<td></td>
<td>
<table>
<tr><th>Action Points</th><th>Data</th></tr>
<tr><td>No. of inspections conducted regarding unauthorized DG sets at construction sites</td><td>302</td></tr>
<tr><td>No. of sites found using unauthorized DG sets</td><td>0</td></tr>
</table>
emergency services.
2. Enforcement data (Since 08.11.2023 till 13.11.2023):
3. Total 3022 DG sets are working in Delhi (Industrial units, Hospitals, etc.) Industrial associations have been sensitized regarding installation of retrofit emission control devices (RECD) on DG Sets.
</td>
</tr>
<tr>
<td>5</td>
<td>Plying of only Delhi registered taxis</td>
<td>The Govt. of NCT of Delhi has considered this and exempted only Delhi registered Taxies during Odd-Even Scheme and plying of outside Delhi registered Taxies may be restricted based on fuel type/number during Odd-Even Scheme, as it is not desirable to totally restrict the outside Delhi registered taxis during ODD-EVEN Scheme. Order to this effect is yet to be issued.</td>
</tr>
</table>

(8)

6. That apart from above, detailed below is the action being taken by GNCTD for Air Quality Management on other action points in Delhi. It is submitted that ground enforcement has been intensified for controlling air pollution.

S. No.	Action points	Action taken report
1	Enforcement of C&D norms at construction sites	1. Web portal for Construction and Demolition sites of 500 Sqm and above plot area in the National Capital Region launched by DPCC in Sep, 2021. 2. As on 14th Nov 2023, Around 1114 construction sites of more than 500 Sqm registered on C&D web portal (out of which 495 C&D sites: construction completed) to help project proponents self- audit their own dust mitigation measures. 3. 233 Anti-Smog Guns deployed at large construction sites. 4. Enforcement of C&D norms at construction sites (Since Sep 2023 to 13 Nov 2023) a) No. of inspections conducted: 16427 b) No. of sites found defaulting: 1111

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		c) Fine imposed: 229.65 lakhs 5. Dedicated 591 patrolling teams for inspecting violations at C&D Sites& open areas for dust violation (under winter action plan). 6. C&D waste processing capacity increased from 3150 TPD to 5150 TPD to cater to processing of approx.. 6000 TPD generated in Delhi. a. 1000 TPD proposed at Tehkhand Existing operational C&D Waste Processing Facilities - 5No. (Capacity 5150 TPD) [at Rani Khera – 1000 TPD, Shastri Park- 1000 TPD, Bakkarwala– 1000 TPD, (Mundka) – 150 TPD, Jahangirpuri Burari- 2000 TPD}
2	Prevention and Control of Road Dust	▪ 85 Mechanized Road Sweeping (MRS) in place and 18 under procurement. ▪ 375 water sprinklers/tankers in place for road dust mitigation. ▪ 262 (215 mobile and 47 static) Anti-Smog Guns deployed on roads and open areas to mitigate road dust re-suspension. ▪ Last winter Anti-smog water guns were installed at the top of 90 high-rise buildings

		(Govt. + Private). This year also similar direction issued to departments for deploying ASGs on top of high rise buildings. So far ASGs have been installed at 48 Govt. high rise buildings.
3	Prevention and Control of stubble burning	1. Out of 4350 Acres of non-basmati paddy area to be sprayed of liquid Bio decomposers in agricultural fields of Delhi, so far 2450 acres of fields have been sprayed since 28.10.2023 in the fields at North, North-West, West, Central and South-west districts and further spraying is being continued. 2628 acres is left to be sprayed and spray in the field will be completed by 30th November, 2023. 2. Eighteen monitoring teams for Day (13) & Night (5) patrolling have been constituted by the Development Department, GNCTD to keep watch/to prevent probable incidences of crop residue / stubble burning in NCT of Delhi. In addition, 165 monitoring teams comprising of Tehsildars/ SDMs/ Patwari, under direct supervision of District Magistrates (Revenue) have been constituted by Department of Revenue. 3. Till date, no violation on stubble burning

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		has been observed in Delhi on part of farmers.
4	Vehicular Pollution Control	**1.** Compliance of ban on 10-Y-old diesel and 15-Y-old petrol vehicles. a) 317 old vehicles impounded from October till 12th Nov 2023 b) 45746 chalans without PUC from October till 12th Nov 2023 c) 7.19 lakhs PUCC issued from October till 12th Nov 2023 d) 13518 Non destined goods vehicles checked and out of them , 7700 Non destined goods vehicles returned from October till 12th November 2023 . **2.** 2,49,125 E-Vehicles registered till now. **3.** 3100 EV charging station having 4793 charging points and 318 battery swapping stations in place. **4.** Out of 60 bus depots 15 are electrified out of which 6 are operational. Remaining depots shall be electrified by 2024-25
5	Grievance Resolution	More than 90 % grievance resolution on Green Delhi Application and more than 80 % grievance resolution on MCD 311 Application.
6	Augmentation of	a) 7041 buses (DTC- 3992 (Active) and

<table>
<tr><td></td><td>Public Transport</td><td>Cluster-2953) in place including 902 E-Bus. Target to augment total fleet of 10,925 buses including approx.. 8000 E buses.
b) 1500 buses timeline:
• 602 buses are ready to operate.
• 898 buses will be engaged by Nov 2023.
c) One Delhi Application relaunched on 02.11.2022. (Live Tracking of Buses, Online Bus Ticket/ Pass and Electric vehicle charging stations locations).</td></tr>
<tr><td>7</td><td>Industrial Pollution</td><td>1866 industries converted to Piped Natural Gas (PNG) out of 1866 fuel-based industries, remaining 70 are running on approved fuel i.e. LPG and are in process of conversion to PNG too.</td></tr>
<tr><td>8</td><td>GRAP (Stage III and Stage IV) report action points</td><td><table>
<tr><td></td><td>Stage III (3-5th Nov 2023)</td><td>Stage IV (from 6th - 12th Nov)</td><td>Total</td></tr>
<tr><td>No. of BS III petrol/ BS-IV Diesel LMVs found plying on road and challaned</td><td>3451</td><td>9811</td><td>13262</td></tr>
</table></td></tr>
</table>

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		Action taken on project sites where construction was continued	122	555	**677**	
		No. of trucks and LCVs stopped at Delhi border entry points	-	9805	**9805**	
		No. of trucks and LCVs not carrying essential commodities that still entered Delhi and challaned	-	775	**775**	
		No. of HGCs /MGVs not carrying essential commodities found plying on roads and challaned	-	84	**84**	
		Action taken on	Physical	Physical		

		discontinuing physical classes.	classes in schools for children upto class V were suspended with option to schools to go for online mode of classes from classes VI onwards.	classes in schools for children of all classes were made online (with option for online / physical mode for class X and XII).	

7. **Implementation of GRAP orders**:

The Commission For Air Quality Management (CAQM) in National Capital Region and Adjoining Areas, in exercise of its powers conferred upon it under section 12 of Commission For Air Quality Management in NCR and Adjoining Areas Act, 2021 has issued direction No. 75 containing revised Graded Response Action Plan (GRAP) on 27.07.2023, which defines four stages of adverse air quality in Delhi viz. Stage I-Poor (AQI 201-300), Stage II-Very Poor AQI (301-400), Stage III-Severe (AQI 401-150), and Stage

IV-Severe+ (AQI > 450) respectively, thereafter followed by its amendment vide Direction No. 77.

As per CAQM orders dated 05.11.2023, necessary action as per actions envisaged under Stage IV under GRAP is being taken by the stakeholder departments in Delhi. Daily action taken report is being submitted to the Commission. Review meetings on implementation of GRAP were held on 07.11.2023, 13.11.2023 and 16.11.2023 under the chairmanship of Hon'ble Minister (Environment), GNCTD .

8. That, for stringent action against violators GNCTD has re-launched anti dust campaign from 14th November 2023 till 30th November, to reduce dust pollution in the City and launched one month Anti open burning campaign w.e.f 14th November 2023. All enforcement teams of stakeholder departments have been directed for effective ground enforcement of pollution norms and penalize the violators.

9. That, as an emergency measure GNCTD is proposing to undertake Pilot study on Artificial Rain through Cloud Seeding in Delhi in association with IIT Kanpur. A power point presentation regarding cloud seeding made by the team of IIT Kanpur and Confederation of Indian Industry (CII) before Hon'ble Minister is annexed at **Annexure 1**. A formal proposal from the organization is awaited.

10. **Control of Vehicular Pollution**

That, in reference to the observation of the Hon'ble Supreme Court in W P C 13029/1985 regarding implementation of Odd Even scheme in Delhi as an emergency action for air pollution control and

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permitting only *the taxis registered in Delhi during this period*, GNCTD placed on record methodology, restrictions and impact study of Odd Even Scheme.

10.1 In compliance of directions dated 13.08.2018 passed by the Hon'ble Supreme Court of India in WPC No. 13029/1985 followed by advisory issued by Ministry of Road Transport & Highways (MORTH) vide letter dated 01.10.2018, Transport Department-GNCTD had issued a notice for :

" *The hologram based colours stickers to be placed on the windshield of the vehicles to give an indication of the nature of fuel being used in the following manner:*

Orange - Diesel vehicles

Light Blue – Petrol & CNG vehicles

Grey – All other vehicles

BSVI emission norms shall have a 1 cm green strip at the top in the 3rd registration plate.

Thereafter, MORTH, GOI on 4th December 2018 (GSR 1162 (E) and 6th December 2018 (SO 6052 (E)) has also issued directions to implement colour coded stickers on old and new vehicles as the third sticker of High Security Registration Plates (HSRP). In compliance to these directions, new cars that are being registered in Delhi are provided with colour coded stickers.

Around 78,000 colour coded stickers were affixed since October, 2018 till 27.01.2019. As per notification issued by Ministry of Road Transport & Highways vide S.0.6052(E) dated 06.12.2018 from

01.04.2019, the type approved High Security Registration Plates including the third registration mark (i.e. hologram based colour sticker) are to be supplied by the vehicle manufacturers to their dealers, who shall place a mark of registration on such plates and affix them on the automobiles.

The sticker wise breakup of Delhi Registered vehicles since October 2018 is as under:-

Sticker's Colour	Fuel Type	No. of Registered Vehicles
Orange	Diesel (BSIV &below)	2,28,133
Orange with Green Strip	Diesel (BS-VI)	43,717
Light Blue	Petrol/CNG (BS-IV)	12,89,763
Light Blue with Green Strip	Petrol/CNG (BS-VI)	5,15,581
Grey	Electric	10,460

It is clear from above that total vehicles with orange sticker are 2,71,850 (2,28,133 + 43,717) out of which BS IV and below diesel is already banned in GRAP Stage-III which is 2,28,133 in number. The added effect of banning Orange stickered vehicle will be only on 43,717 vehicles, which are BS VI diesel vehicles. Therefore balance 18 lakhs vehicles will remain on the road due to ban only on orange stickered vehicles.

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As per Vahan database as on 08.11.2023, total number of motor cars registered except electric cars in Delhi as on date are 20,74,194 which will come under the impact of Odd Even System.

With the Odd Even system around 10 Lakhs cars will be off road on a particular day, addressing critical problem of congestion causing pollution.

The registration plates of the vehicle are easily recognizable with their colours i.e. White for private vehicles, Yellow for commercial vehicles and Green for Electric vehicles. The vehicles with yellow and green registration plates are considered for exemption under the odd even system. For effective enforcement in the left over vehicles with white registration plates, the last digit of its registration number will be prudent and easier for enforcing Odd and Even.

10.2 Odd Even System Impact Study:

As regards the directions of this Hon'ble Court to file the impact of Odd Even Scheme is concerned, this is to submit before this Hon'ble Court that the impact of Odd-Even scheme on air quality can be estimated only through a scientific evaluation that compares observed air quality during Odd-Even days with what the levels could have been in the absence of the programme. Meteorological conditions greatly influence how pollution levels vary from one day to the next, and, so, any reasonable evaluation needs to figure out a way to make like-to-like comparisons.

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In the first two implementations of Odd-Even scheme during 1-15 January 2016 and 15-30 April 2016, GNCTD did not carry out any such scientific evaluation. However, the Transport Department is relying on the findings of two independent and scientific evaluations of Delhi's Odd-Even scheme by globally reputed institutions namely Energy Policy Institute at the University of Chicago, Harvard Kennedy School, Indian Institute of Technology, Delhi, Indian Institute of Technology, Kanpur, Indian Institute of Tropical Meteorology, Pune, CSIR-National Physical Laboratory, New Delhi and The Energy Resources Institute, Delhi, to conclude that the policy works as an effective emergency measure.

The first of these impact evaluations was conducted by Energy Policy Institute at the University of Chicago, Harvard Kennedy School and covered both January and April rounds of Odd-Even. The study found that PM2.5 levels were lower by 13% on average during 8am-8pm during the odd-even scheme in January 2016. No impact was detected at night. No impact was detected when the programme was repeated in April, most likely because the warmer month of April is marked by greater dispersion of particulates. The researchers conclude that "Taken together, this suggests that the main value of an "Odd-Even" program is as an emergency measure during winter months when car emissions play a more prominent role in affecting air quality." (**Annexure 2**).

The second impact evaluation (2016) was conducted by Indian Institute of Technology, Delhi, Indian Institute of Technology, Kanpur, Indian Institute of Tropical Meteorology, Pune, CSIR-National Physical Laboratory, New Delhi and The Energy Resources Institute,

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Delhi. This study utilised satellite-based estimates of PM2.5 to examine the potential decrease due to fewer traffic emissions during odd-even. The study concluded that the traffic restriction between January 1-15 in 2016 reduced PM2.5 by 4-6% with a maximum of up to 10%, primarily at three local hotspots in Delhi. (**Annexure 3**)

On request of GNCTD, a study on "Traffic Impact Assessment of Odd- Even Scheme in Delhi" was conducted by M/s DIMTS during odd even Scheme during 4^{th} -15^{th} November 2019 (except 10^{th} and 12^{th} November 2019) in Delhi.

The major conclusions of the study report (**Annexure 4**) are as under:

1) Traffic data analysis indicated that during Odd-Even Scheme about 30 % personal car traffic was reduced on road. However, there was increase of 6.5% in 2 wheeler traffic, 19.5% in Taxi, 7.5% in Auto and 4.7% in Buses.
2) Estimated average increase in the daily Bus ridership during scheme was about 2.8 Lakhs amounting to about 5.39% increase. Similarly, average increase in the daily Metro ridership was recorded about 1.7 Lakhs amounting to about 3% increase in Metro journeys. Overall, total increase in the daily Public Transport ridership was about 4.5 Lakhs amounting to 4.2% increase in PT journeys during the Odd Even period.

3) Number of congested spots (having less than 5 kmph speed) were also analysed during and post scheme. It has been determined that incidences having speed less than 5 kmph

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reduced from 13.7% to 12.4% and incidences having speed between 5- 10 kmph reduced from 13 % to 11.3 %. On the other hand, incidences having speed more than 30 kmph increased from 21.2% to 24.1% showing lesser congestion and lower duration of congestion during odd-even scheme implementation.

4) The analysis of traffic queue length at major intersections during and post scheme indicated that traffic queue length at junctions were substantially lower during odd-even compared to normal days.

5) It has been estimated from analysis that there was a decrease of about 6% vehicle kilometres travelled (VKT) during the Odd Even Scheme period amounting to 37.80 lac vehicle - km/day.

6) Reduced vehicle km travelled would also result in reduced fuel consumption. It has been estimated that there was about 15% decrease in fuel consumption on average day during Odd Even Scheme implementation.

That, it is stated that the findings of the above stated report by M/s DIMTS broadly indicated positive impact in reduction of the air pollution contributed by the vehicles, besides reduction of congestion on Delhi roads as well as increase in share of public transport during the period of Odd-even drive.

10.3 With regard to permitting only Delhi registered taxis, the Govt. of NCT of Delhi has considered this and proposes to exempt only

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Delhi registered Taxies during the period of Odd-Even Scheme and plying of outside Delhi registered Taxies may be restricted based on fuel type/number, as it is not desirable to totally restrict the outside Delhi registered taxis during ODD-EVEN Scheme. Order to this effect is yet to be issued.

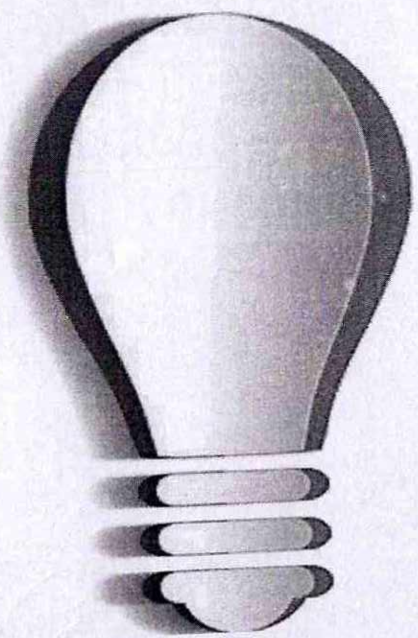
11. It is requested to this Hon'ble Tribunal that the present status report may kindly be taken on record.

K. S. Jayachandran
Special Secretary (Environment)
Government of NCT of Delhi

Place: Delhi
Dated: 17th November, 2023

Annexure - I

Confederation of Indian Industry



Artificial Precipitation through Cloud Seeding

Presentation by :
Dr. Manindra Agrawal & Team
Indian Institute of Technology Kanpur

08 November 2023

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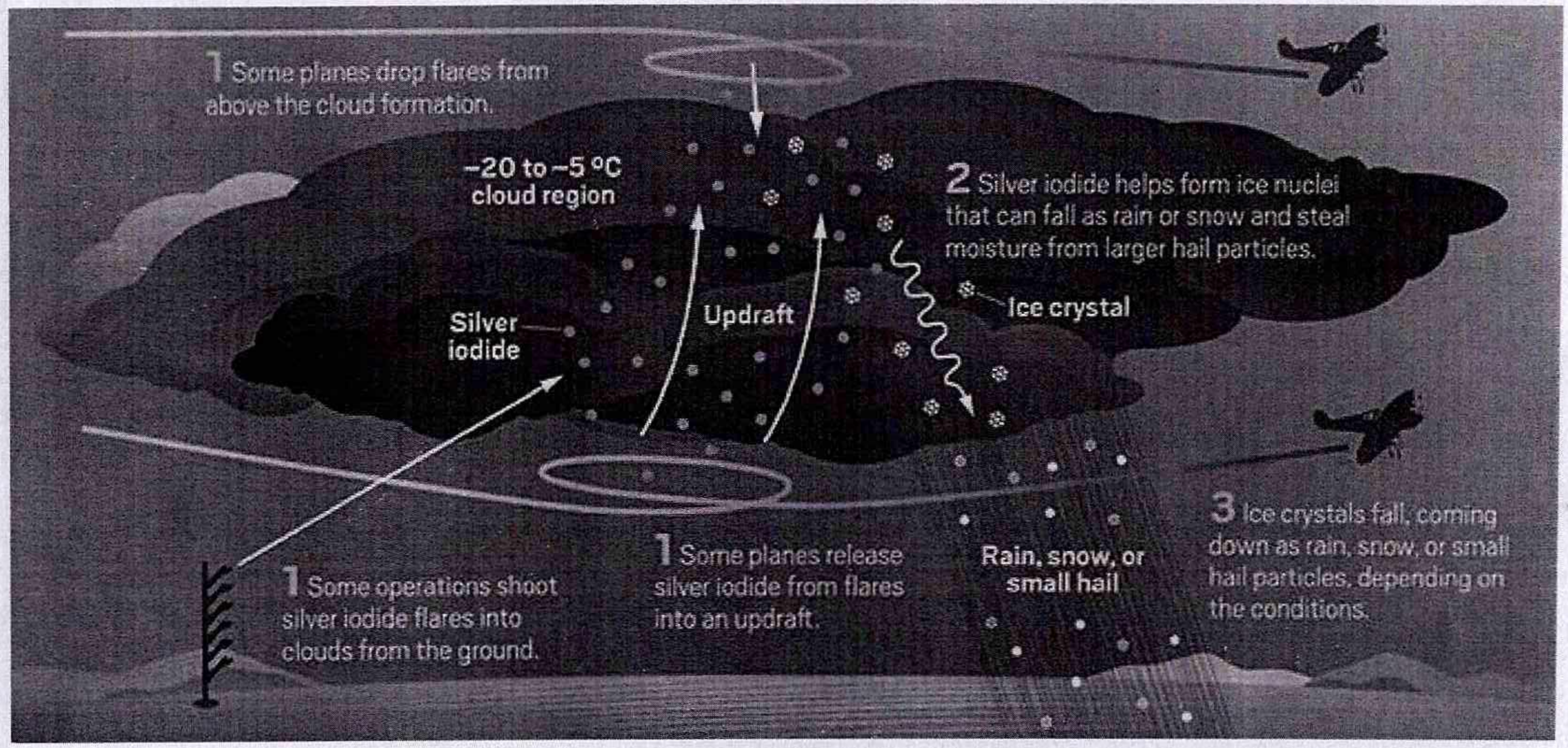
Discussion Agenda

1. Artificial Precipitation
   Weather modification is a reality
2. Important Pre-Requisites
   Should be in place for successful seeding
3. Rough Estimate
   Budgetary & action planning

Cloud seeding: process of releasing specific compounds into clouds with sufficient moisture content to create precipitation to suppress fog, hail, smog, or clear particulate matter in air

Ways of Cloud Seeding



1. Utilize "updraft" under clouds to disperse heated seed particles (already tested)
2. High above the clouds and drop seeding mixture from above (highest chance)
3. Shoot flares containing seeding mixture to the clouds (lowest chance)

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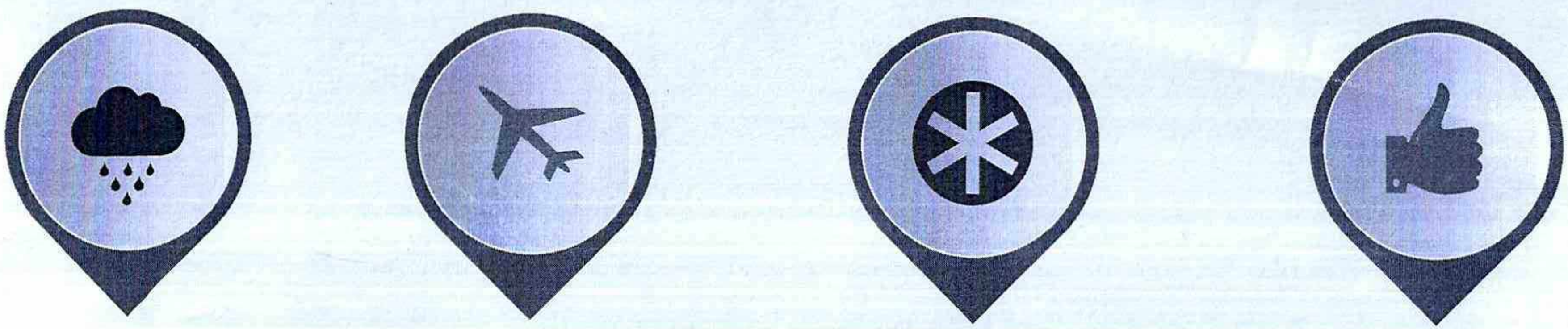
Cloud-Seeding Critical Factors



Clouds with Moisture

- Mandatory requirement
- Higher moisture content, better success

Aircraft & Setup

Seeding Material

Permissions

- Flying permissions are required
- Safe location for aircraft operations
- Approval from various government bodies
- Financial support

Important Agencies

1. Directorate General of Civil Aviation (DGCA)
2. Ministry of Defense (MoD)
3. Ministry of Home Affairs (MHA)
4. Special Protection Group (SPG)
5. Ministry of Environment, Forest, and Climate Change (MoEFCC)
6. Government of Delhi (GoD)
7. Airports Authority of India (AAI)
8. Government of Uttar Pradesh (GoUP)
9. Indian Meterological Department (IMD)
10. Central Pollution Control Board (CPCB)
11. Archaeological Survey of India (ASI)
12. Bureau of Civil Aviation Security (BCAS)

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Major Clearances

Government of National Capital Territory of Delhi

रक्षा मंत्रालय MINISTRY OF DEFENCE

नागर विमानन महानिदेशालय DIRECTORATE GENERAL OF CIVIL AVIATION

गृह मंत्रालय MINISTRY OF HOME AFFAIRS

BCAS

भारतीय विमानपत्तन प्राधिकरण AIRPORTS AUTHORITY OF INDIA

GNCTD	MoD	DGCA	MHA	BCAS	AAI
Operational	Operational	Operational	Security	Security Clearance for Airport Usage	Operational

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Budget

A Estimated costs: 1,00,000 per km^2

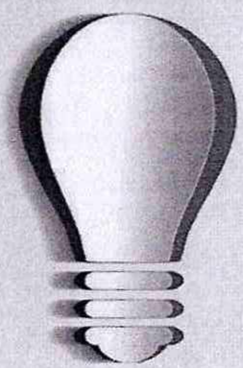
B Costs are estimated per km^2 with minimum of 100 km^2, and including five sorties (cloud seeding attempts)

Suggested Action Plan

A. Rain of over 300 km^2

B. Clearances from Agencies

C. Funding Support



Thank you

We are open for comments, suggestions, and discussions!

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Annexure - II

Clearing the air on Delhi's odd-even program

Michael Greenstone, Santosh Harish, Rohini Pande, Anant Sudarshan[1]

Abstract

In January and April 2016, the government of Delhi piloted an "odd-even" traffic rule which mandated that only cars with odd (even) numbered license plates could ply on odd (even) dates. We use high frequency measures from air quality monitoring stations to estimate the program impact. Relative to surrounding satellite cities, fine particle concentrations in Delhi's air were lower by 13% during the January pilot. In contrast, the program did not affect Delhi's air quality during the warmer month of April. Taken together, this suggests that the main value of an "odd-even" program is as an emergency measure during winter months when car emissions play a more prominent role in affecting air quality.

1.Introduction

Delhi, India's capital, is the third largest city in the world and India's largest city. It also routinely features among the world's most polluted cities. For instance, in 2015 Delhi's average concentration of fine particulates was 110 $\mu g/m^3$, 11 times the WHO prescribed annual average; and this fact led the Delhi High Court to compare Delhi to a "gas chamber" (The Times of India, 2015).

In December 2015, the government of Delhi announced a series of emergency measures including a pilot 'odd-even' scheme to ration driving (The Hindu, 2015; The Indian Express, 2015). The scheme worked as follows: first, cars were classified into odd and even categories on the basis of the last digit of car licensing plates. Next, it was mandated that only vehicles with odd numbered license plates could ply only on odd numbered dates and even numbered plates on even dates. The scheme was effective during the hours of 8 am and 8 pm for the first 15 days of January 2016. [2] A second round of the odd-even program was implemented between April 15-30, 2016.

This paper estimates the impact of the odd-even program on air quality. To do so, we use high frequency data from monitoring stations to compare fine particulate concentrations in Delhi (where the odd even policy was implemented) to that reported for the neighboring towns of Faridabad and Gurgaon (where the policy was not implemented). Our analysis period spans the six months between November 2015 and April 2016.

[1] We would like to thank Bhavna Rai for excellent research assistance.

[2] Vehicles driven by women or cars with more than two passengers were exempt from the policy.

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We find that, relative to its neighboring cities, fine particulate concentrations in Delhi's air were lower by roughly 24-36 μg/m^3 during the January odd-even scheme. These reductions were largest in the mid-morning (11am - 2pm) and we see no gains in air quality at nights (when rationing was not in effect).

In contrast, Delhi's air did not show any quality gains relative to its neighboring cities during the April phase of the program. A likely cause is that the warmer month of April is marked by greater dispersion of particulates, a fact that is reflected in Delhi's lower particulate concentrations during summer relative to the winter (Figure 2). In contrast, the winter month of January is marked by thermal inversion, a phenomenon where a layer of hot air covers cold air near the ground. This, in turn, causes air pollution to be trapped near the ground.

The paper is structured as follows. In Section 2, we present a brief background on air pollution in Delhi and the pollution mitigation programs introduced by the Delhi government or ordered by Supreme Court judgments. Data used for our analysis is outlined in Section 3, with methods described in Section 4. The concluding Section 5 discusses the results and its implications on the efficacy of the odd-even program as an air pollution measure in the city.

2.Background

Particulate Matter (PM) refers to tiny particles, either solid or liquid, which are suspended in the air.[3] Within this broad category, PM10 refers to particles that are smaller than 10 microns in diameters and PM2.5 to particles smaller than 2.5 microns in diameter. Smaller particles more easily penetrate human lungs and, therefore, present greater health risks. While there is no obvious `safe' level for particulates, the World Health Organization and the Indian Government set preferred norms for air quality - at present, these are 40 micrograms per cubic meter for PM10 and 60 micrograms per cubic meter for PM2.5.

Indian cities, however, routinely exceed these norms. Greenstone et al ,(2015) estimated 660 million Indians (or 54.5 % of the population) live in regions exceeding the national standards and reducing the pollution levels just to meet standards could increase life expectancy by 3.1 years on average. In this paper we focus on air quality in Delhi and neighboring cities and below we provide some background on Delhi's air quality as a precursor to our quantitative analysis.

2.1 Delhi: Sources of Pollution

Figure 2 shows the time-trend in Delhi's pollution over a 12-month period from May 2015 to April 2016. We see a sharp uptick in pollution in October, which corresponds to widespread crop burning in Delhi's neighboring agricultural states.

[3] PM comprise organic and inorganic substances, and originate from many different sources. Sources of PM2.5 include combustion of fuels in various processes in industries, automobiles, cook-stoves as well as in the burning of solid wastes, concrete batching and construction activities, and abrasion of road surfaces.

PM concentration levels then remain high in the colder winter months – reflecting meteorological conditions, and increased inefficient winter heating. Pollution levels decline starting in the months of March and April with summer.

Source apportionment studies for Delhi's pollution typically offer a wide range of estimates on vehicular contribution to particulate matter, going from 8.7% (CPCB, 2011) to 62% (Srivastava, 2008) for PM10[i]. There are relatively fewer estimates for PM2.5. All studies, however, suggest that vehicular emissions form a larger fraction in winters. For instance, a recent comprehensive study commissioned by the Delhi government estimate vehicular contribution to PM2.5 at 6% during summers and 25% during winters (Sharma and Dixit, 2016). Vehicular traffic also affects resuspension of road dust; the same study estimates that resuspension of road dust accounts for 4% of PM2.5 concentrations in summers and 28% during winters (Sharma and Dixit, 2016).

2.3 Odd-Even Program

On Dec 1, 2015 Delhi government announced that the odd-even program for privately owned cars would be launched as a pilot during January 1-15, 2016. The program would be effective between 8 am in the morning to 8 pm in the evening, apart from Sundays. Cars with registration plates from outside Delhi were also required to comply.

Around the time the odd-even program was being introduced, the
Delhi government also announced other measures to reduce air pollution

- November 6, 2015: Environment Compensation Charge charged for commercial vehicles (light diesel vehicles and three-axle vehicles) entering the city limits. (Supreme Court, 2015a ; Department of Environment, 2015) On December 16, 2015, the Charge was doubled (Supreme Court, 2015 b)
- On December 16, 2015, Supreme Court banned the registration of new diesel cars (larger than 2000 cc) till March 31, 2016 (Supreme Court, 2015 b)
- From January 1, 2016, Delhi government increased the restriction on entry of trucks during the day. Entry hours were pushed from 9 PM to 11 PM (Department of Environment, 2015)

However, the odd-even program witnessed unparalleled media coverage and scrutiny regarding its impact on air quality. Disentangling the impact of the odd-even scheme from other policy measures therefore requires careful analysis. We examine both the hours during the policy implementation when impacts were most clearly observed and consider periods both before and after the odd-even scheme. As a short-term policy measure the effects of odd-even should exist only during the 15 day period in question.

If the program witnessed compliance with odd-even, vehicle volumes would mechanically reduce. The reduction of cars on the road would mechanically reduce vehicular exhaust emissions. However, the impact on ambient concentrations, which

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is a function of several other factors, was unknown before the program. One source of skepticism about the program has been the extent to which vehicular restrictions in the city affect air pollution. We seek to answer this question here.

3. Data

Our analysis uses data from ten ambient air quality monitors in Delhi and three satellite cities just outside Delhi. Figure 1 shows the location of these monitors which are operated by the Central Pollution Control Board for Delhi and by the Haryana State Pollution Control Board for the neighboring towns of Faridabad, Gurgaon and Rohtak.

We compile hourly monitoring data for the six months spanning November 2015 to April 2016. Table 1 describes data availability for each monitor entering our sample.

Figure 2 shows significant variation in PM concentrations over the course of a single day: Concentrations are typically high in the early morning and forenoon hours, lower in the afternoon, and then increase again in the evening hours.

Figure 3 shows significant temporal variation in concentrations across days, reflecting weather conditions. Low atmospheric mixing heights and low wind speeds, for instance, increase concentrations. We also observe significant seasonal variation with improved air quality in summer and monsoon months.

Finally, Figure 4 shows significant within-city variation such that the seven monitors in Delhi typically show significant differences in air quality at the same time.

4. Empirical Strategy

Temporal and spatial variations in PM2.5 levels imply that a simple comparison of air quality before and during the program may be misleading. We, therefore, focus on difference-in-differences analysis where we examine how difference in air quality in Delhi and neighboring cities changes during the program relative to the time period before and after. We also consider a `triple difference' variant where we additionally examine whether during program days the impact is concentrated during hours that the program is effective (i.e. between 8 am and 8 pm)

More formally, we estimate a regression model that takes the form

$$Y_{tm} = \alpha + \beta.\ 1(m \in \text{Delhi}) + \gamma.\ 1(t \in \text{oddeven}) + \delta.\ 1(m \in \text{Delhi}) \text{ X } 1(t \in \text{oddeven}) + \lambda_m + \eta_t + \mu_h + \varepsilon_{tm}$$ **.Model 1**

Y_{tm} is the particulate ($PM_{2.5}$) concentration at time t (on hour h and day d) for monitor m. Explanatory variables include an indicator variable for the treatment area (*Delhi*), an indicator variable for the days that the odd-even program was in place (termed *oddeven*), and their interaction term. β and γ are the coefficients for

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the treatment area and period indicator variables. The interaction coefficient δ estimates the program impact on particulate concentration..

This is the triple difference specification because the interaction term is the product of the indicator variable for Delhi, the indicator for days when the program was implemented and the indicator for the hours during which the restrictions were in force

We use monitor fixed effects to control for different average levels of particulate matter at each monitor. We use time fixed effects to account for differences in average levels across time of day, and from one day to the next.

In addition, we have introduced several finer variants to the specifications in Model 1. These include models with

- Time fixed effects at the day level, indicator variable for each hour of day to account for average hourly trends, and an interaction variable between the daily indicators and the times when the restrictions were in force. (Model 1-Table 2)
- Time fixed effects at the hourly level (Model 2 in Table 2, and the models in Table 3)

Standard errors are clustered at the monitor level. To address the challenge of gaps in air pollution data from the monitors at different points of time, and therefore potential artifacts of this changing composition of the panel on the estimates themselves, we use bootstrapped standard errors with 200 repetitions.

Our empirical analysis is premised on the assumption that that in the absence of the program, pollution in delhi and neighboring cities would have evolved similarly. The relatively unexpected nature of the program and short program duration, combined with the geographic proximity of the satellite cities to Delhi, makes this a plausible assumption. As a robustness check, we also report a variant of model 1 with time fixed effects at the hourly level and with an interaction between Delhi and a linear time trend variable[ii].

In addition, we run 24 models for each hour of the day to get hourly estimates for impact on the concentration of particulates. The specifications are nearly identical to Equation 1. However, running 24 models in this manner relaxes the assumptions and reduces the sample size, thereby creating a more stringent test.

For each hour of the day, *h*,

$$Y_{dm,h} = \alpha + \beta.\ 1(m \in \text{Delhi}) + \gamma.\ 1(d \in \text{oddeven}) + \delta_1.1(m \in \text{Delhi})\ X\ 1(d \in \text{oddevenJan}) + \delta_1.1(m \in \text{Delhi})\ X\ 1(d \in \text{oddevenApril}) + \lambda_m + \eta_{d,h} + \Omega.W_{dm.h} + \varepsilon_{dm}$$

. Model 2

This model is run over the 6-month period with separate estimates for January and April rounds. Inclusion of the Delhi-time trend interaction has no effect on the

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coefficient for the triple difference. The coefficient of the interaction is not significant for the results for the 6-month period, validating the parallel trends assumption. These results remain consistent with several different timeframes and specifications, and suggest that the model successfully identifies the impact of the program on pollution concentrations.

5. Results and Discussion

5.1 Regression results

The results (in Tables 2 and 3) show that there was a statistically significant and substantial reduction in PM2.5 concentrations during the days and hours that the odd-even program was implemented in New Delhi in the January round. The estimated reduction from the many specifications we cover in Section 4 ranges from about 24 $\mu g/m^3$ to 37 $\mu g/m^3$. In percentage terms, we estimate a reduction of 13%[iii].

From the hourly models, we find large, statistically significant reductions in concentration between 11 am – 2 pm, which could be attributed to reduction in traffic during the morning peak hours. During other times of the day, our estimates are noisy and we cannot rule out the possibility that they are zero. This may be due to dispersion (wiping out any local improvements in air quality) and other sources of PM2.5 (reducing the significance of reductions from traffic alone). Importantly however, no impacts were observed at night when the odd-even rationing was no longer in force.

This reduction in concentrations could be attributed to three factors: one, reduction in PM from vehicular exhaust of the cars taken off the road; two, reduced congestion and consequently, reduced idling and emissions from all the vehicles (allowed cars as well as buses and other vehicles) on the road; three, reduced resuspension of road-dust due to reduced vehicular volumes. [iv]

One concern here is that road traffic outside Delhi may also have reduced during odd-even because of significant commuter traffic from Delhi to the satellite cities and from these cities to Delhi. To the extent this occurs, our results will under-estimate the impact of the rationing, both in January and April.

On the other hand, the results in April look very different. We observe significant reduction during both the night and the day in the second (April) round of vehicle rationing. At the very least this underscores that while an initiative such as odd-even can work (over a short period), it will not always be useful. This is important to keep in mind and it is possible that in Delhi this type of policy mechanism is useful only during parts of the winter.

It is possible that one or more of the other interventions introduced by the government in December may have also contributed to the reductions in Delhi. We may be concerned that restrictions on trucks – on the volumes entering the city and on the hours they could enter— may have confounded the impact of the program. Two factors make this unlikely. First, we find the impacts of odd-even restricted to the days it was in force. The restrictions on truck traffic continued beyond this period. Secondly, from the hourly model results (Figure 5), the conspicuous dip around noon is likely due only to car driving restrictions, and we do not observe significant reductions late in the night.

5.2 Differences between January and April

5.2.1 Meteorological factors

It is possible that despite similar compliance and similar reduction in *emissions*, concentrations may have been affected less in April than January. A plausible reason for this is greater dispersion during warmer months. Dispersion is faster when atmospheric mixing heights[v] are greater, as is the case in the summers compared to winters (Guttikunda and Gurjar, 2012). For this reason, modest increases and decreases in emission sources on-ground may disperse upwards and not translate into observable changes in pollution concentrations near the ground. On the other hand, in winter when dispersion is minimal, these changes are immediately noticeable. This suggests a limitation of the program itself: it is perhaps more appropriate as an emergency measure during the winters, than as a long-term pollution reduction measure, even if compliance rates are high.

5.2.2 Lower compliance and/or use of alternative vehicle

Alternative explanations for the differences in results between January and April could include lower compliance to the restrictions, and greater use of an alternative vehicle (an unrestricted second car, a taxi or a two wheeler) in the second round compared to the first. We discuss these together because they have similar measurement challenges, as will be explained shortly.

The first hypothesis is lower compliance in April. With a program of the scale of odd-even in Delhi, police enforcement is bound to have constraints; public enthusiasm plays a large role too. Were public participation to decline, these schemes may become largely ineffective.

The second hypothesis is that commuters were better prepared for the second round, in terms of alternative private modes of transport- a second car, a neighbor's unrestricted car or a two-wheeler. In the case of similar driving restrictions in Mexico City introduced in 1989, Davis (2008) compares vehicle registrations with new vehicle sales to show that the program there led to an increased adoption and use of used cars. Substitution to relatively older vehicles on restricted days for the principal vehicle may lead to a net increase in pollution.

Finding reliable data on non-compliance or substitution is difficult. For example, with traffic police records, a reduction in traffic *challans* from January to April could indicate improved compliance or reduced enforcement or both. As a result, these records form an unreliable way to understand compliance.

Instead, traffic volumes and travel times could offer insights. Primary traffic surveys by the School of Planning and Architecture along several junctions around the city find that traffic volumes were higher during the second round of the program than the first round, and that there was a large shift to two-wheelers (Hindustan Times, 2016). They contrast this with the January round when commuters chose to carpool or use the public transportation.

However, there is some contradictory evidence that suggests that compliance did not reduce. Kreindler (Indian Express, 2016) uses high frequency queries on travel times from Google Maps along several routes and found that the two rounds show consistent reductions in speeds in both rounds. Furthermore, from a survey of 960 male drivers from across Delhi, Kreindler writes in the same article that there was little to distinguish participation between the two rounds.[vi]

5.3 Concluding remarks

The challenges in estimating the impact of this program stress the need for more carefully designed pilots, with reliable data collection and analysis. The limited number of air quality monitors in and around Delhi, and the low levels of data availability (Table 1) impede effective air pollution regulation in the city.

Even if the program resulted in reductions in traffic congestion and air pollution in the city, the odd-even program may not be a good long-term measure to reduce air pollution in New Delhi. As the program in January was known in advance to be a short-term pilot, commuter response may not be typical of what is expected over the longer term. In other cities where such a program has been implemented there is some evidence that commuters purchased and used a second car (Davis (2008) for Mexico City) or "cover or borrow license plates" (Wang et al. (2014) in the case of Beijing).

A more sustainable option to reduce vehicular usage and traffic congestion could be to institute congestion pricing in Delhi. Congestion pricing may be more equitable, and well targeted to parts of the city especially vulnerable to congestion and high local pollution levels. Such a program could also generate additional revenues that could then be redirected to other urgent traffic interventions in Delhi, including greater investments in public transportation as well as making the streets friendly to pedestrians and cyclists.

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Figure 1: Map with locations of the monitors in Delhi (blue) and in Haryana (yellow), which are used for analysis in this study.

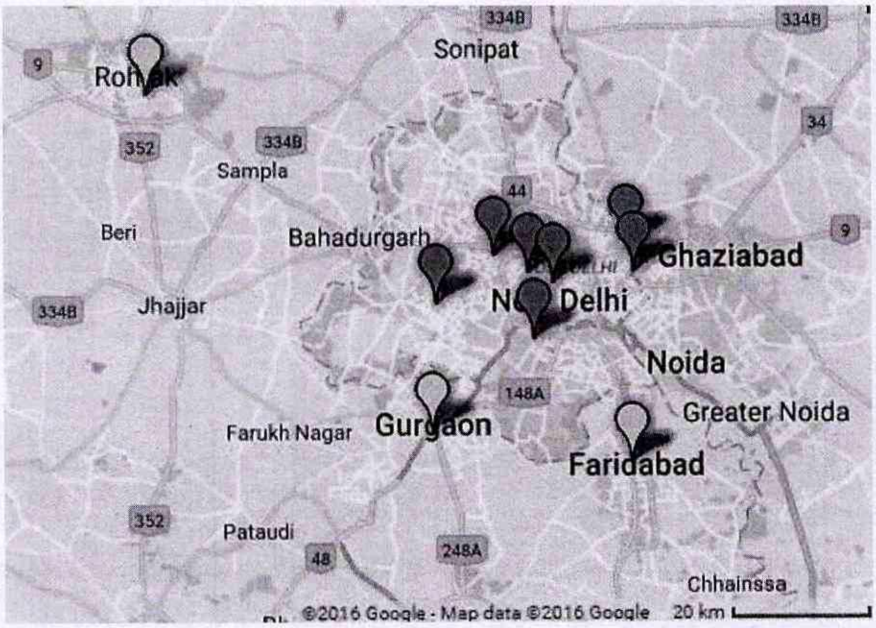

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Table 1: Data availability for the 10 monitors during November 2015- April 2016, and in particular for the two months where the odd-even pilot took place.

	January '16	April '16	November '15 - January '16	February '16- April '16
Delhi monitors				
Anand Vihar	98%	63%	96%	0%
Dwarka	96%	71%	90%	81%
IHBAS	27%	52%	62%	32%
Mandir Marg	81%	61%	92%	89%
Punjabi Bagh	90%	58%	92%	89%
RK Puram	99%	77%	95%	98%
Shadipur	95%	77%	98%	96%
Haryana monitors				
Faridabad	60%	59%	83%	82%
Gurgaon	10%	60%	3%	64%
Rohtak	52%	.	17%	.

1. Data availability= Number of hours of data available from each monitor for the period divided by number of hours during this period that satisfy the conditions below.

I. At least 1 monitor from Haryana (comparison group)

II. At least 4 monitors from Delhi (treatment group)

III. PM2.5 levels between 10 and 1000 ?g/m³

2. Four other monitors in Delhi (Civil Lines, DCE, ITO and IGI Airport monitors) have zero data availability on the CPCB website for the entire period.

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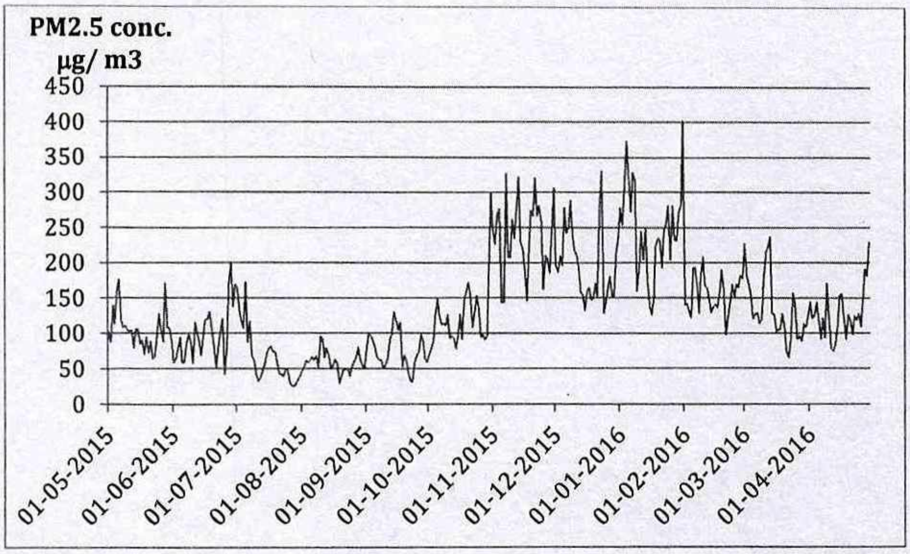
Figure 2 Average concentrations in Delhi over the course of the year (from May 2015- April 2016).



1. This uses data from air monitoring station in Delhi with availability of 50% or higher. Stations included here are Anand Vihar, Dwarka, Mandir Marg, Punjabi Bagh, RK Puram and Shadipur.
2. Daily averages have been computed by controlling for monitor fixed effects

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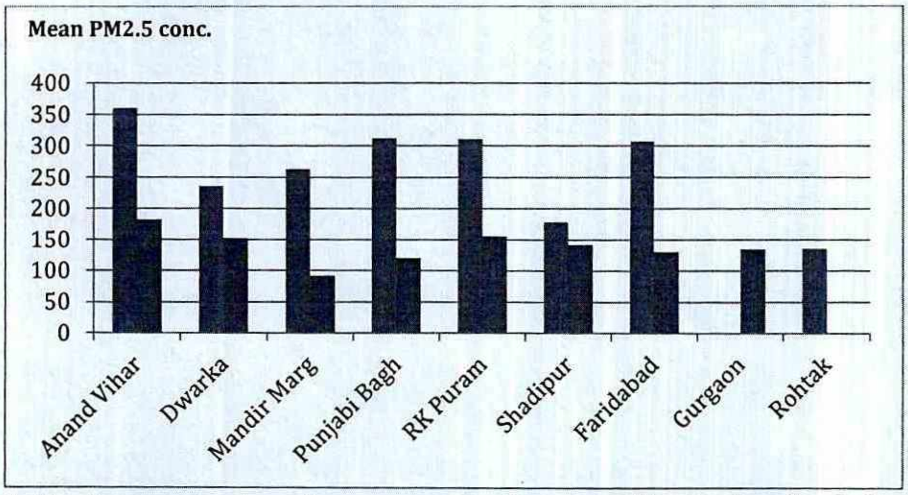
Figure 3 Averages across the monitors Average PM2.5 levels in the 10 ambient air quality monitors.



1. Monitor averages have been computed after controlling for time fixed effects

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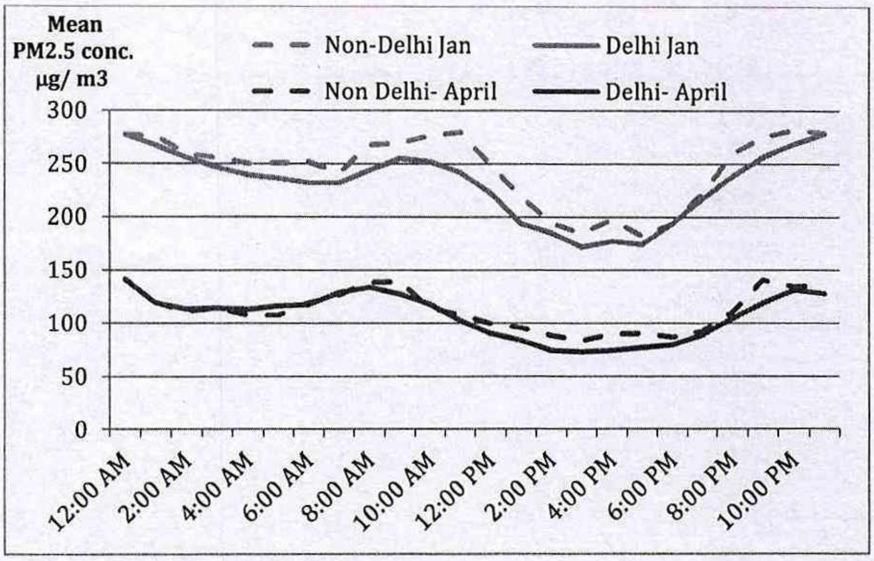
Figure 4: Average fine particulate matter levels in the months of January and April 2016 for the Delhi and Haryana monitors.



These have been computed by controlling for monitor fixed effects and time fixed effects (for every hour of observation) and by regressing concentrations on indicator variables for Delhi and for hour of day, and the interaction of the hour indicator variables with the Delhi indicator variable. This has been done to control for compositional variations.

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Table 2 Results of regression models for the two rounds separately. The triple difference coefficient is significant for the January round, and not significant for the April round.

VARIABLES	January- (1)#	January- (2)	January- (3)	April- (1)#	April- (2)	April- (3)
Delhi X OddEvenDates	15.58	13.77	31.82	-4.000	-8.361	12.04
	(24.09)	(21.63)	(17.68)	(12.53)	(12.81)	(12.74)
DelhiX OddEvenDatesX OddEvenHours	-37.66*	-32.77**	-33.45**	-1.801	0.635	-0.642
	(22.21)	(10.37)	(10.83)	(15.20)	(9.283)	(8.920)
Delhi X Timetrend			1.112			-1.723
			(2.357)			(1.286)
Observations	3,667	3,667	3,667	3,438	3,438	3,438
R-squared	0.313	0.488	0.489	0.332	0.472	0.473
Number of monitors	8	8	8	9	9	9
Monitor FE	Y	Y	Y	Y	Y	Y
Day FE	Y	Y	Y	Y	Y	Y
Hour of Day FE	Y	Y	Y	Y	Y	Y
Day FE X OddEvenDates FE	Y			Y		
Day FE X Hour of Day FE		Y	Y		Y	Y

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

#- Bootstrapping with 200 repetitions, stratified on the Delhi indicator variable. Model 3 has hourly fixed effects and therefore controls for compositional differences effectively.

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Table 3 Results of the regression model when run on a single pooled dataset with monitor and time (each hour of observation) fixed effects. Results are summarized below for the six month period of November 2015 - April 2016.

VARIABLES	(1) Six months joint estimate	(2) Six months separate estimates	(3) Jan and April joint estimate	(4) Jan and April separate estimates
Delhi X OddEvenDatesJan		-14.96		-6.020
		(21.54)		(24.29)
Delhi X OddEvenDatesApril		-3.940		12.84
		(17.15)		(13.01)
Delhi X OddEvenDatesJanX OddEvenHours		-24.42***		-31.69**
		(6.446)		(12.93)
Delhi X OddEvenDatesAprilX OddEvenHours		11.60		-6.794
		(12.27)		(15.53)
DelhiXOddEvenDatesBoth	-8.945		5.702	
	(13.56)		(13.65)	
DelhiXOddEvenDatesBothXOddEvenHours	-7.072		-18.59*	
	(8.371)		(9.234)	
Observations	21,197	21,197	7,105	7,105
R-squared	0.472	0.473	0.486	0.489
Number of monitors	8	8	10	10
Monitor FE	Y	Y	Y	Y
Day FE	Y	Y	Y	Y
Hour of Day FE	Y	Y	Y	Y
Day FE X OddEvenDates FE	Y	Y	Y	Y

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The triple difference is highly significant only for the January round, and is not significant for the combined model (1). If January and April months are pooled together, the combined coefficient (in 3) is significant, but if separate coefficients are included in the specification, only the January triple difference is significant.

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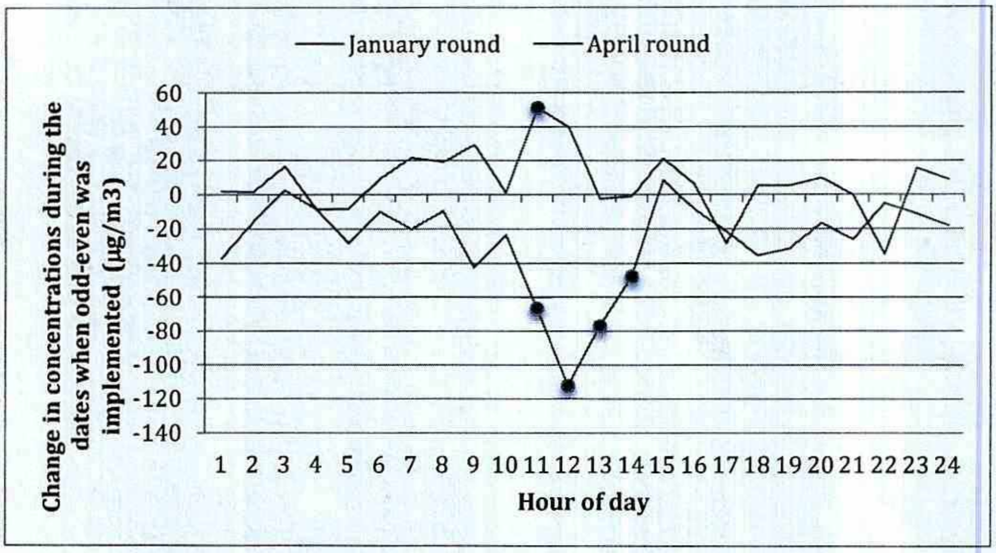
Figure 5: Results of the hourly models when run over the six-month period. The difference-in-difference coefficient has been plotted for each hour of the day with the hours with statistically significant results shown as a circled point on the graphs



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[i] These studies provide a wide range of estimates for vehicular contribution to PM10 ranging from 8.7% (in industrial locations)- 20.5% (residential locations) (CPCB, 2011), 27-31% (Khillare and Sarkar, 2012) and 62% (Srivastava et al, 2008). Goel and Guttikunda(2015) estimate that cars alone account for 19% of vehicular PM2.5 emissions.

[ii] If the pollutant concentrations within and outside Delhi are systematically changing relative to each other (for example, pollution in Delhi is going down due to multiple local mitigation efforts), the Delhi- time trend interaction should be significant. We include a linear time trend (days since November 1st) and an interaction term between the *Delhi* variable and the linear time trend to Model 1.

$$Y_{tm} = \alpha + \beta.\,1(m \in Delhi) + \gamma.\,1(t \in oddeven) + \delta.1(m \in Delhi) \text{ X } 1(t \in oddeven) + \lambda_m + \eta_t + \tau.\, days + \rho.\, Delhi \text{ X } days + \varepsilon_{tm}$$

[iii] Percentage reduction is estimated using a variant of the regression models described in the paper with the dependent variable as natural logarithm of PM2.5 concentrations. With these specifications the coefficient of the triple difference can be directly interpreted as the percentage change. Specifically, this estimate of 13% comes from a model using the combined 6 month data, with separate estimates for the two rounds.

[iv] With reduced congestion and hence, improved average speeds, it is possible that there is an increased resuspension of road dust. However, the net impact of reduced traffic is almost certainly going to be reduced emissions.

[v] There are several definitions for mixing heights. This height need not necessarily be the same as the height at which inversion happens, which is primarily a nocturnal phenomenon. One definition as per Seibert et al: "The mixing height is the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence within a time scale of about an hour"

[vi] Kreindler finds that the April round marginally less effective along a few dimensions: a larger percentage of drivers used other four-wheelers (including taxis) than their principal vehicle on restricted days and fewer moved to public transportation (Indian Express, 2016)

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Annexure - III

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"Traffic intervention" policy fails to mitigate air pollution in megacity Delhi

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ABSTRACT

Megacity Delhi has been ranked amongst the top most polluted cities in the world consistently over the last few years (WHO, 2016). As a desperate and emergency measure, the administration implemented 'traffic intervention' mitigation effort by instigating 'odd-even' policy as a trial for 15 days in January (1–15) 2016. During this period, odd and even numbered private cars were restricted to respective odd and even days. Here we examine the impact of this policy intervention on ambient particulate matter smaller than 2.5 μm ($PM_{2.5}$) through a combination of in-situ, satellite and model data. Traffic restriction reduces $PM_{2.5}$ by 4–6% (maximum up to 10% in three local hotspots) which is within the uncertainty range of satellite-based estimates (and hence not detected). This is not a significant result considering the fact that such step was taken as an emergency measure when $PM_{2.5}$ exposure exceeded 250 μg/m^3 during the winter season. The failure is attributed to stable meteorological conditions (winds are not strong enough to disperse $PM_{2.5}$ away) during the period and there was no control over $PM_{2.5}$ outside the periphery of the city. A more comprehensive inter-sectoral and inter-state action plan is required to address this alarming issue in this region.

1. Introduction

$PM_{2.5}$ exposure in Delhi is a menace earning the capital of India, the second most populous country in the world, a dubious tag of being one of the top most polluted cities in the world. Ambient $PM_{2.5}$ concentration exceeds the national air quality standard by more than 300% (Central Pollution Control Board, Delhi Central Pollution Control Board, 2016; Dey et al., 2012; Guttikunda and Goel, 2013) in Delhi. $PM_{2.5}$ exposure not only results in morbidity and significant years of life lost(Greenstone et al., 2015) but also translates into estimated burden of ~12000 premature deaths per year in the Indian capital (Chowdhury and Dey, 2016). Air pollution problem in Delhi was recognised long time back and several measures were taken to curb the pollution. The sulphur content of diesel and petrol was reduced by 50 ppm during 1996–2010 and around 1328 industries categorized as 'hazardous' were shut down in this region (Narain and Krupnick, 2007). Following a court order, commercial vehicles older than 15 years were gradually phased out after 1998 and the public transport vehicles were converted to compressed natural gas (CNG)(Narain and Krupnick, 2007). Though the conversion to CNG was initiated around 2002, the intervention was found to have no profound positive impact on reducing pollution over Delhi with exception of CO (Chelani and Devotta, 2005; Kathuria, 2005).

Despite of all these efforts, $PM_{2.5}$ concentration remains alarmingly high in Delhi national capital region (NCR). Annual average $PM_{2.5}$ levels have consistently remained within the range of 110–120 μg/m^3 during 2011–2015 (SAFAR, IITM data). In response to various reports showing adverse effects of PM on health, the Government of Delhi initiated a bunch of policies and public measures following the National Green Tribunal Act, 2015 (http://www.greentribunal.gov.in/) which banned the use of diesel vehicles (10 years old) within the city. More recently, the Government introduced 15-days (1st to 15th January 2016) odd-even traffic restriction that allowed odd and even numbered cars (based on the last digit of the license plate) to ply on odd and even days, respectively within the city from 8 am to 8 pm with an exception on Sunday with no restriction. The restriction was only imposed on private vehicles (four wheelers) excluding the two wheelers, public vehicles, school buses and vehicles for public officials and administration. Women were also exempted from the scheme. Though this type of vehicular restriction is new to the residents of Delhi, and was met with

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mixed responses from the public, vehicular rationing or driving restrictions are not uncommon in other parts of the world. Vehicles in Mexico City, Sao Paolo, Bagota, Beijing, Tianjin and Paris have all been under the hammer of the traffic restriction laws, although there have been no clear evidence of its success (Lin et al., 2011). It was found that during and before the 2008 Olympic Games at Beijing, when the traffic restrictions were enforced by the Chinese Government, levels of sulphate and nitrate content of $PM_{2.5}$ increased while ambient concentrations of vehicle related NO_x and volatile organic compounds (VOC) decreased (Wang et al., 2010). Few published reports on the odd-even traffic restriction over Delhi show that there have been slight improvement of average vehicle speed of about 9% between 11 am and 5 pm and also the odd-even policy was able to reduce the number of private cars by only 35% against the expected reduction of ~50% (Goel and Pant, 2016). A study (Li and Guo, 2016) concerning the traffic restriction during 2008 Beijing Olympics found that traffic volume reduced by only 20–40% during the odd even restriction, another study (Wang et al., 2014) found that 47.8% of the regulated car owners did not follow the traffic restriction rules and illegally drove their cars, which may also be a matter of concern for Delhi traffic restriction. Therefore, a comprehensive analysis is required to understand the impact (success or failure) of such desperate policy measure.

Winters (Dec-Feb) in Delhi typically witness very high levels of $PM_{2.5}$ concentration due to calm condition, inversion, and shallow mixing layer height that favour pollution to accumulate near surface (Kar et al., 2010). The recently published report by the Delhi Pollution Control Committee(Sharma and Dixit, 2016) estimates the average daily concentration of $PM_{2.5}$ in winter remains about 375 $\mu g/m^3$ against the permissible limit of 60 $\mu g/m^3$. The main contributors to total $PM_{2.5}$ in winter are secondary particulate particles (~25–30%), vehicular emissions (~23–28%), biomass burning (~17–26%), municipal solid waste burning (~9%), and suspended soil and road dust(Sharma and Dixit, 2016). An attempt by the Government of Delhi to restrict on-road private vehicles on odd-even basis is expected to cut off about 50% emission from private vehicles. However, a variety of other sources in the surrounding areas of NCR also contribute to total emissions(Sharma and Dixit, 2016).

Here, we examine the spatial heterogeneity in the magnitude of change in $PM_{2.5}$ across Delhi NCR by analyzing Terra-MODIS 3 km Collection 6 (MOD04_3k) aerosol optical depth (AOD) retrievals, converted to $PM_{2.5}$ using daily conversion factor (η) from Goddard Earth Observing System chemical transport model (GEOS-CHEM)(van Donkelaar et al., 2010). $PM_{2.5}$ estimates were bias-corrected(Dey et al., 2012) against coincident in-situ $PM_{2.5}$ data collected by Central Pollution Control Board (CPCB) and validated against System of Air Quality and Weather Forecasting And Research (SAFAR) data. We compute the anomaly of $PM_{2.5}$ during the pre-intervention, intervention and post-intervention periods with respect to corresponding 13-year statistics (2003–15) derived from satellite-based estimates as in-situ data are not available throughout (details are provided in the methods section). ERA-Interim derived meteorological parameters are used to check whether the meteorological conditions acted in unison with the traffic restriction in suppressing the $PM_{2.5}$ concentration over Delhi. We also use a modelling approach to simulate expected reduction in $PM_{2.5}$ concentration due to traffic intervention at similarly high resolution of 4×4 km^2.

2. Methods

2.1. Satellite-based $PM_{2.5}$ data

MODIS on board EOS-Terra satellite has been remotely sensing aerosol optical depth (AOD) since March 2000. MODIS level 2 data provides AOD at both 10 km and 3 km spatial resolution, with the later (MOD04_3k) was recently introduced as a part of the Collection 6. The 3 km product differs from the older 10 km product in terms of the treatment of surface reflectance in the aerosol retrieval algorithm (Remer et al., 2013). The finer product resolves delicate aerosol features like smoke plumes over land and ocean and could also be retrieved over regions where the 10 km product can barely retrieved. However, the uncertainty in the 3 km product is larger than that of 10 km product(Livingston et al., 2015; Remer et al., 2013).

In view of these pros and cons of finer resolution data, we tried to capture the spatial gradient of $PM_{2.5}$ within the city of Delhi NCT and the larger National Capital Region (NCR) using 3 km AOD product. Our region of interest constitutes the districts of New Delhi, North Delhi, North East Delhi, North West Delhi, Central Delhi, West Delhi, East Delhi, South Delhi and South West Delhi (NCT of Delhi), Rohtak, Panipat, Sonipat, Jhajjar, Rewari, Gurgaon and Faridabad (Haryana), Gautam Buddha Nagar, Bulandshahar, Faridabad, Meerut, Ghaziabad and Baghpat (Uttar Pradesh) making up the NCR region. Though the odd-even traffic restriction rule was implemented only within the districts of NCT, we extend our analyses up to NCR region to capture intervention effects on surrounding regions as well. We extracted the Dark Target C6 AOD product at 3 km from the MODIS Terra Level 2 at Atmospheric Archive and Distribution System (http://ladsweb .nascom.nasa.gov) for the years 2003–2016 (for a period from 15th Dec to 30th Jan of each year) within the region of our interest. Further, we gridded the geo-located AOD data at 3 km resolution by taking the median AOD for all the geo-located retrievals of AOD that fall within each 3 km grid box. We estimate the daily $PM_{2.5}$ by using the spatially varying daily estimates of conversion factor (η, which is the ratio of $PM_{2.5}$ to columnar AOD) at $0.1° \times 0.1°$ resolution estimated from the GEOS-CHEM chemical transport model. More details about the estimation of η are provided elsewhere(van Donkelaar et al., 2010). The daily η estimates are interpolated at 3 km resolution and are applied to the MODIS Terra AOD to estimate satellite derived $PM_{2.5}$ for a period of 45 days for each winter starting from 2003 to 2016. MODIS-$PM_{2.5}$ is supposed to be biased low over the Indian landmass as has been evidenced in the earlier studies (Dey et al., 2012; van Donkelaar et al., 2010). We compared MODIS-$PM_{2.5}$ with the available coincident measurements of $PM_{2.5}$ over Delhi by the Central Pollution Control Board (CPCB) at eight stations, viz. IHBAS, AnandVihar, Civil Lines, IGI Airport, ITO, Mandir Marg, Punjabi Bagh and R.K. Puram. Due to large spread in data while comparing MODIS-$PM_{2.5}$ and in-situ $PM_{2.5}$, we group MODIS-$PM_{2.5}$ and the corresponding measurements of in-situ $PM_{2.5}$ in every 2nd percentile to minimize the noise in the 3 km MODIS-$PM_{2.5}$ estimates (Mishra et al., 2016; Schutgens et al., 2016). Fig. S1a depicts the comparison between MODIS-$PM_{2.5}$ and in-situ $PM_{2.5}$ and also depicts that the MODIS-$PM_{2.5}$ is biased low. We quantify the bias in the MODIS Terra data as ($\Delta PM_{2.5}$ = In-situ $PM_{2.5}$–MODIS-$PM_{2.5}$) which may be represented by the relation:

$$\Delta PM_{2.5} = -28.71 + 0.55 \times [InsituPM_{2.5}], \quad (R = 0.8, \text{ at } 99\% \text{ CI}) \qquad (1)$$

The resulting bias was corrected for MODIS-$PM_{2.5} > 28.71$ $\mu g/m^3$ to avoid negative $PM_{2.5}$ values. The bias corrected $PM_{2.5}$ for the period from 1st December 2015 to 16th January 2016 was validated against coincident SAFAR $PM_{2.5}$ data (The SAFAR observational network of Air Quality Monitoring Stations (AQMS) and Automatic Weather Stations (AWS) established within city limits represents selected microenvironments of the city including industrial, residential, background/cleaner, urban complex, agricultural zones etc. as per international guidelines which ensures the true representation of city environment, http://safar.tropmet.res.in/MONITORING%20SYSTEM-10-3-Details)) obtained from six measurement stations located respectively at CRRI, Delhi University, IITM, IMD Ayanagar, IMD Lodhi Road and IGI Airport (Fig. S1c). The validation yields satisfactory results with slope 0.88 and R = 0.78. The satellite is able to estimate $PM_{2.5}$ with ~26% uncertainty (estimated with the error in the regression coefficients). Such high uncertainty in satellite retrieved $PM_{2.5}$ estimates can be scaled down by improving the quality of the available in-situ data used for bias-correction. The 3 km MODIS AOD product is also susceptible to be slightly erroneous over regions with high reflectivity and over cities.

Our period of interest commences from 16th December, 2015 and extends up to 31st January 2016. As our interest is to estimate the effect of traffic restriction on the prevailing air quality over Delhi, which was active for 15 days from 1st January, 2016 to 15th January 2016, we subdivide our period of interest to 3 segments, the pre-intervention period (16th December, 2015 to 31st December 2015), the intervention period (1st January, 2016January 2016 to 15th January, 2016) and the post-intervention period (16th January, 2016 to 31st January, 2016). We also estimate the $PM_{2.5}$ for the same three segments for the preceding 13 years to inspect the anomaly of bias-corrected MODIS-$PM_{2.5}$ during the period of traffic restriction.

2.2. Meteorological analyses

Meteorology plays an important role in modulating the $PM_{2.5}$ concentration over a region at all-time scales i.e. seasonally, daily and diurnally (Chelani, 2013; Mishra et al., 2015). Meteorology often modulates the $PM_{2.5}$ concentration by perturbing the ventilation rate (wind speed and mixed layer depth), precipitation induced wet scavenging, dry deposition, controlling the transport of anthropogenic and natural species and the emission of naturally emitted species (Daniel and Winner, 2009). To account for the effect of meteorology on the inflected $PM_{2.5}$ concentration during the pre, post and during the odd-even intervention period, we analyse meteorological variables such as wind speed, wind direction and the stability parameter. The stability parameter is defined as the difference between the temperatures at 1000 hPa and 850 hPa. Relatively higher value of stability parameter represents less stable atmosphere. We used the ERA Interim data at 0.125° × 0.125° resolution, for analysing the mentioned meteorological variables of our interest from 16th December, 2016 to 31st January, 2016 in three time segments (pre, post and during odd-even intervention). We also analyse long term (2003–2016) climatology of these meteorological parameters to account for the anomaly of the meteorological parameters during the period of intervention.

2.3. Analysis using chemical transport models

Impact of the odd-even rule was also estimated using a parallel modelling approach. Multi-sectoral emission inventories were fed into the air quality model along with meteorological inputs to assess air quality in two scenarios – a) with odd-even rule, b) without odd-even rule. The difference in air quality in the two scenarios was ascertained as the impact of the intervention. In this study, we used weather research forecasting (WRF) model (version 3.4.1.) for carrying our meteorological simulations for the study domain covering Delhi and surrounding regions in National Capital Region (NCR). Thereafter, the meteorological fields were fed into the CMAQ model (Ching and Byun, 1999) version 4.7.1 for simulating $PM_{2.5}$ concentrations in the study domain. The CMAQ model takes into account the interactions of different pollutants in the atmosphere and has been used for air quality research across the world and also in India (Chen et al., 2007; Sharma et al., 2016, 2013; Sokhi et al., 2016)

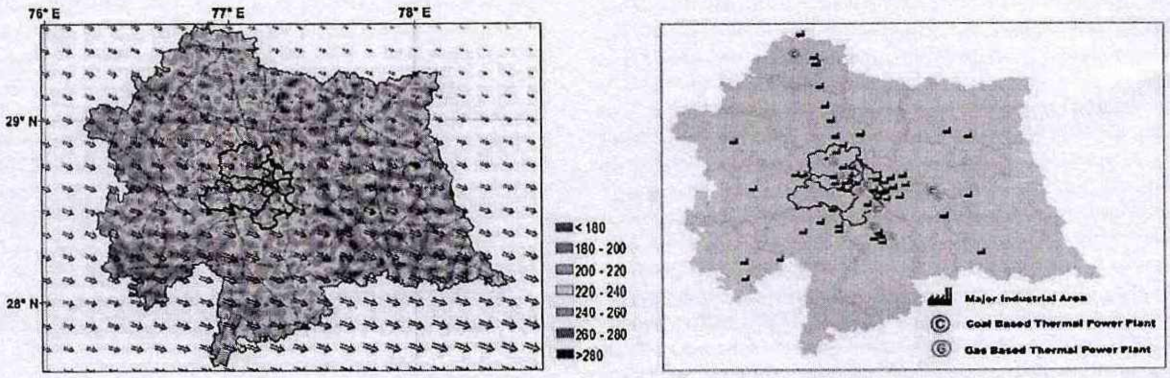
The CMAQ model was fed with a baseline emission inventory for the Delhi–NCR region at a resolution of $4 \times 4\,km^2$. Emission estimates have been originally made for the year 2012 and were projected for the year 2015 based on growth rates prevailing in different sectors. Emission factor approach was used and indigenous emission factors were used wherever possible to derive emission inventory for the region for different contributing sectors like transport, industries, power, DG sets, agricultural burning, refuse burning, residential fuel consumption, etc. Meteorological simulations were carried out using the WRF model for the period December 2015 to January 2016. First 15 days of the simulations were not used in the analysis considering it as the model spinoff period. The model generated 3-dimensional meteorological fields at a resolution of $4 \times 4\,km^2$ were fed into the CMAQ model along with the emission inventory. Boundary conditions for $PM_{2.5}$ concentrations for the study domain were taken from Indian scale runs carried out in (Sharma et al., 2016). This was to account for long range transport of pollutant towards Delhi. 24-hourly $PM_{2.5}$ concentrations were predicted for all the grids in the domain. The model performance was validated by comparing the model predicted values at 10 locations in Delhi where PM2.5 concentrations were measured in the city under the SAFAR monitoring program.

On satisfactory validation of the model, emission inventories were reduced considering the odd-even rule presumably resulting in 50% reduction in cars on-road. We assume 50% reduction in car population as a conservative approach to assess the maximum potential of the odd even traffic restriction, we understand that the actual reduction may be less than 50% (Goel and Pant, 2016) due to various issues as has been observed in similar analyses elsewhere (Wang et al., 2014) and different exemptions given to certain categories during the odd-even rule in Delhi. Both reductions in tail-pipe emissions and road dust re-suspension due to movement of cars were taken into account while estimating the impact of the intervention. The difference in $PM_{2.5}$ concentrations in the baseline and odd-even scenario was ascertained as the impact of the odd-even scheme.

3. Results and discussions

3.1. Change in ambient $PM_{2.5}$ during pre-intervention to post-intervention period in delhi NCR

Fig. 1(a) depicts the average concentration of $PM_{2.5}$ overlain on



(a) (b)

Fig. 1. (a) 13 year average winter time $PM_{2.5}$ (in $\mu g/m^3$) over the National Capital Region (NCR) of Delhi, the arrows indicate the wind direction and the size of the arrows indicate the wind speed. The dotted lines indicate major highways. (b) Major point sources of emission (major industrial clusters, coal and gas based power plants) in NCR.

wind vectors over Delhi for 45 days (16th December to 31st January) for the period 2003–2016 during winter. The analysis is restricted within the boundaries of Delhi NCR consisting of 13 districts from Uttar Pradesh and Haryana and 9 districts of the National Capital Territory (NCT, where the odd-even traffic restriction was implemented). It can be seen that MODIS Terra derived $PM_{2.5}$ is higher in the districts on the eastern flank of NCR with respect to the districts which lie on the western NCR. Westerly wind may be held responsible for transport of PM pollution towards the eastern flanks of NCR resulting in the concentration in most of the eastern districts of NCR being almost twice of the districts on the western flanks. Fig. 1(b) depicts the major industrial areas in the NCR as well as the major coal and gas based power plants. There are 3 gas-based power plants and 2 coal-based power plants within the limits of NCT and there are in total 6 gas based and 6 coal based power plants within the boundaries of the NCR. These power plants and large industrial areas mostly emit huge amount of PM, CO_2, CO, SO_2, NO_x apart from large amount of hazardous chemicals and trace elements like lead, cadmium and mercury(Mittal, 2010). These primary pollution sources along with vehicular emissions and other emissions as discussed above are contributing to the large loading of $PM_{2.5}$ over Delhi.

Fig. S2 (Supplementary material) depicts the thirteen years mean $PM_{2.5}$ concentration and the meteorological parameters during the three time segments. It depicts that the meteorological factors (both wind speed and the stability parameter) are conducive for stagnation of the pollutants during the pre-intervention and intervention periods (Fig. S2 a) resulting in high concentration of $PM_{2.5}$. On the other hand, the meteorology in the post intervention period is climatologically more conducive for dispersion of the pollutants, resulting in relatively low $PM_{2.5}$ concentration during the post intervention period. The stability parameters (temperature difference between 1000 hPa and 850 hPa pressure levels) and wind vectors for the three time segments i.e. pre-intervention (16th to 31st December 2015), intervention (1st to 15th January, 2016) and post-intervention (16th to 31st January, 2016) periods are depicted in the Supplementary Fig. S3 and S4 . The anomalies for these two parameters are depicted in Fig. S5. Fig. 2 shows the anomaly maps of $PM_{2.5}$ for the respective time segments. Relatively increased mean wind speed and decreased mean stability during pre-intervention period make it favourable for dispersion of pollutants. However, the anomaly map of $PM_{2.5}$ during pre-intervention period (Fig. 2a) shows an increased $PM_{2.5}$ concentration (relative to 13 years mean) over most parts of Delhi. Although the concentration over most of the NCT region is observed to decrease with respect to the 13 year climatological mean during the traffic intervention period, higher $PM_{2.5}$ concentration (positive anomaly) over the western flanks of NCR combined with westerly wind may have responsible for increased $PM_{2.5}$ over the western side of NCT (Fig. 2b). This indicates traffic restriction may not be effective in reducing $PM_{2.5}$ if applied only within the limits of NCT given that neighbouring districts (located in NCR) of NCT have equally dirty air. Further, restricting 50% of the private cars which contribute to just about 3% of the total $PM_{2.5}$ emission(Sharma and Dixit, 2016) would not be effective due to prevalence of other factors that contribute to emission of $PM_{2.5}$ in and around the NCT periphery. During the post intervention period (16–31 January, 2016), the absolute $PM_{2.5}$ concentration is much lower than the previous periods. However, some scattered positive anomaly with respect to 13 year climatological mean could be attributed to meteorology that was favourable for pollution to be more stagnant than in the previous years (Fig. S3 & S4). In spite of regulations imposed on the traffic count, the change in $PM_{2.5}$ concentration has remained within the uncertainty range of the satellite-based $PM_{2.5}$ with respect to the pre and the post intervention period perhaps due to transport of pollution from the western districts. Same conclusion can be drawn from the analysis with only SAFAR data.

3.2. Simulation to assess the change in $PM_{2.5}$ concentrations in Delhi due to odd-even scheme using WRF-CMAQ models

The observed $PM_{2.5}$ change discussed previously does not quantify the possible reduction in $PM_{2.5}$ as a result of lower vehicular emission and re-suspended dusts due to traffic restriction. This is addressed by carrying out modelling exercise using the emission inventory presented in Supplementary Table S1. Emission inventory (at a grid resolution of 4×4 km^2) is prepared for the NCR including Delhi for various sources e.g. transport, residential, power, industries, open burning etc. The approach used for emission estimation was based on sectoral activity data and emission factors (Eq. (2)).

$$E_k = \sum_l \sum_m \sum_n A_{k,l,m}.ef_{k,l,m}.(1 - \eta_{l,m,n}).\ X_{k,l,m,n} \quad (2)$$

where *k, l, m, n* are region, sector, fuel or activity type, abatement technology; *E* denotes emissions of pollutants; *A* the activity rate; *ef* the unabated emission factor; η the removal efficiency; and *X* the actual application rate of control technology *n* where $\Sigma X = 1$ (Klimont et al., 2002).

Table S1 presents the emission estimates of $PM_{2.5}$ for Delhi and whole NCR. Emission estimates are compared with previous inventories for $PM_{2.5}$ as reported in Sharma and Dixit (2016), and were found to be in close agreement. Sectoral distributions of emissions are shown in Supplementary material Fig. S5. The primary $PM_{2.5}$ emissions along with inventories of other gaseous pollutants (which contribute to secondary particulate formation) were fed into the Community Modeling and Analysis System (CMAQ) model for air quality simulations. The $PM_{2.5}$ concentrations were simulated by the WRF-CMAQ modelling approach(Sharma et al., 2016) for pre-intervention, intervention and post-intervention periods. The modelled average $PM_{2.5}$ concentrations were found to be about 5% higher during the intervention in comparison to the pre-intervention period. This was mainly due to lower PBL and wind speed in January than in December as also reproduced by WRF meteorological simulations. We note that the model simulated $PM_{2.5}$ may be under-estimated slightly (Fig. S7, Supplementary material) due to uncertainties in emission inventories, unaccounted emission sources and error in simulated meteorological simulations. However, the objective here is a relative assessment of maximum possible reduction in $PM_{2.5}$ when the emissions corresponding to lesser vehicles that were taken off the road are reduced in the model. We consider that a decrease of cars by 50% due to the odd-even rule resulted in a reduction of 0.25 T/day of tail-pipe and 8 T/day of road dust $PM_{2.5}$ emissions in Delhi. However, in absence of any information, no additional emissions due to possible increase in two-wheelers/buses or any other modes of transport is assumed in the model. The model was rerun with reduced emission inventory and $PM_{2.5}$ concentration was simulated. The percentage difference in $PM_{2.5}$ in baseline and reduced emissions (due to odd-even rule) scenario is shown in Fig. 3.

A reduction of 1–10% is estimated across different parts of Delhi due to 50% reduction in cars assuming a full compliance of the 'odd-even' policy. Central part of the city with higher vehicular activity shows higher reduction than the outskirts. It is to be noted that main part of the reduction is coming due to reduction in the road dust re-suspension with less number of cars on road, and only a small effect is attributed to reduction in tail-pipe emissions. This reduction is not detected in the analysis of satellite data because of two reasons. In reality, exemptions were given to women and VIP categories and there is no available count of vehicles actually operated during the intervention period. Moreover, there could be a rise in number of two-wheelers due to shift from cars to other modes of road transport.

4. Conclusions

In this study we attempt to quantify the effect of traffic restriction during 1st to 15th of January, 2016 on the $PM_{2.5}$ concentration over

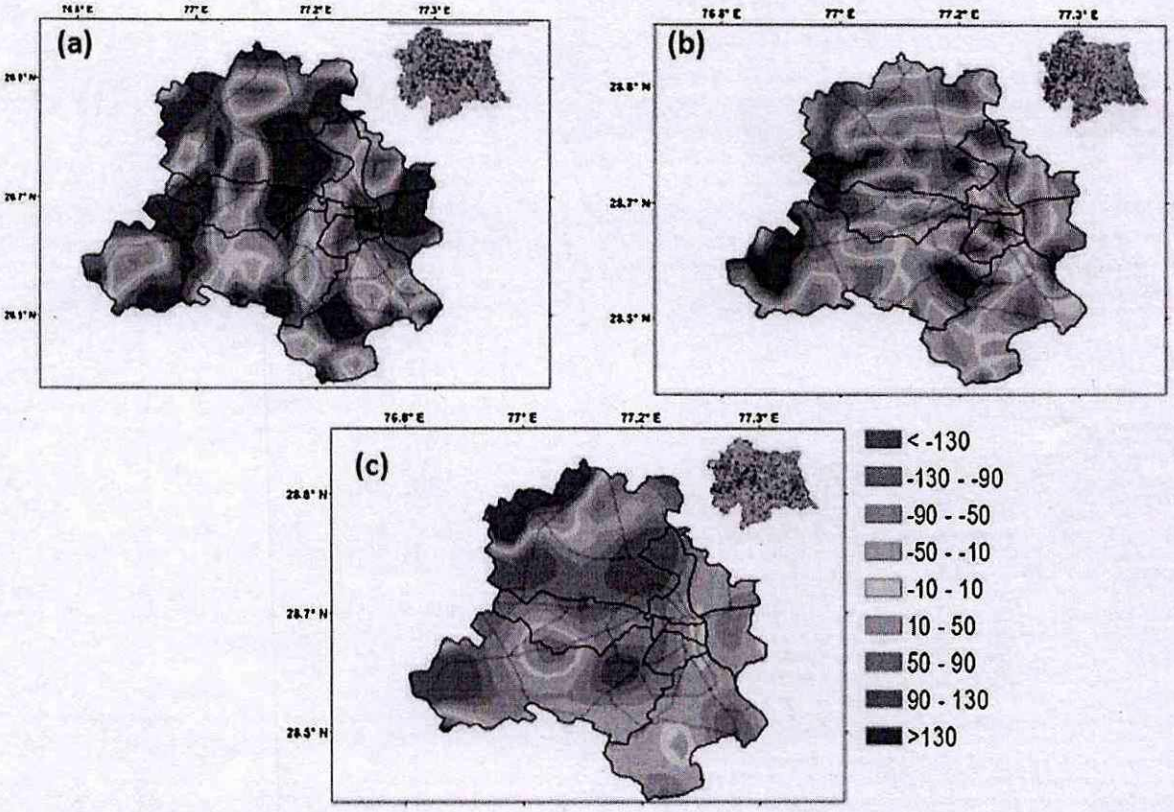


Fig. 2. Anomaly of $PM_{2.5}$ (Deviation of $PM_{2.5}$ in the 3 time segments from 13 year average concentration) in the (a) pre-intervention (16th December 2016–31st December 2016), (b) intervention (1st January 2016–15th January 2016) and (c) post-intervention (16th January 2016–31st January 2016) periods with respect to 13 year mean in Delhi NCT. The same for larger NCR is shown as inset.

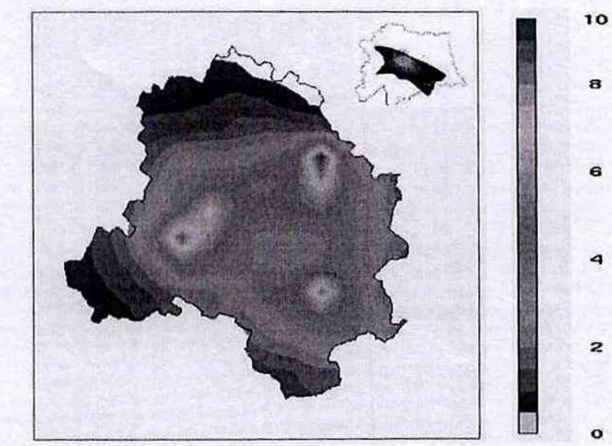


Fig. 3. Percentage change in PM2.5 concentration (during 1–15 Jan 2016) due to reduction in emissions due to the odd-even rule.

New Delhi. The change of $PM_{2.5}$ due to traffic restriction remains small and within the uncertainty range of the satellite-based $PM_{2.5}$ estimates. Simulations employing the WRF-CMAQ model reveal a decrease of $PM_{2.5}$ by 8–10% in three pockets of Delhi; while in remaining parts of Delhi NCT, it decreases by only 2–3%. It can be concluded that restricting traffic volume alone cannot control the $PM_{2.5}$ concentration over Delhi, where there are multiple other sources contributing towards making the city's air dirty. What we estimate is the maximum benefit the odd-even traffic restriction will achieve in short duration. However, we expect that the efficacy of the scheme will further go down in long run as people may opt for alternative vehicles in absence of access to a proper public transport system which will kill the objective of the intervention. Therefore, in the current circumstances, this intervention will continue to fail to deliver the expected benefit. We also feel that the bulk of pollution that lingers outside the NCT limits will not be contained outside the boundaries of the city if the traffic interventions are applied only within the NCT. The study of the Health effects Institute under the Public Health and Air Pollution in Asia project over Delhi (Health Effects Institute Research Report, 2011) revealed that a 10 $\mu g/m^3$ decrease in PM_{10} resulted in a discounted risk of 0.15% in all-cause mortality (non-accidental). It is evident that bulk of PM_{10} in Delhi during the winter is contributed by $PM_{2.5}$(Tiwari et al., 2012). Based on these two studies, we perceive that significant health benefit cannot be expected from this short-term traffic intervention. However, this provides an opportunity to explore the health benefit using retrospective data. A long-term inter-sectoral and inter-state action plan is required to deal with this critical environmental problem. In addition to few studies over Delhi attempting to identify sources of air pollution (Sharma and Dixit, 2016), a comprehensive source profiling study over Delhi should be performed to identify further detailed information about major sources and components of $PM_{2.5}$. Performing such detailed study is also expected to provide us informative knowledge about identifying the sources on which restrictions may be applied to achieve maximum benefit in terms of pollution mitigation and social acceptance.

Author contributions

S.D., S.N.T., A.K.M. and S.C. designed the research, S.C., A.K.M. and S.S. carried out the analysis, S.C., A.K.M., S.D., S.N.T., S.S. and G.B. prepared the draft.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2017.04.018.

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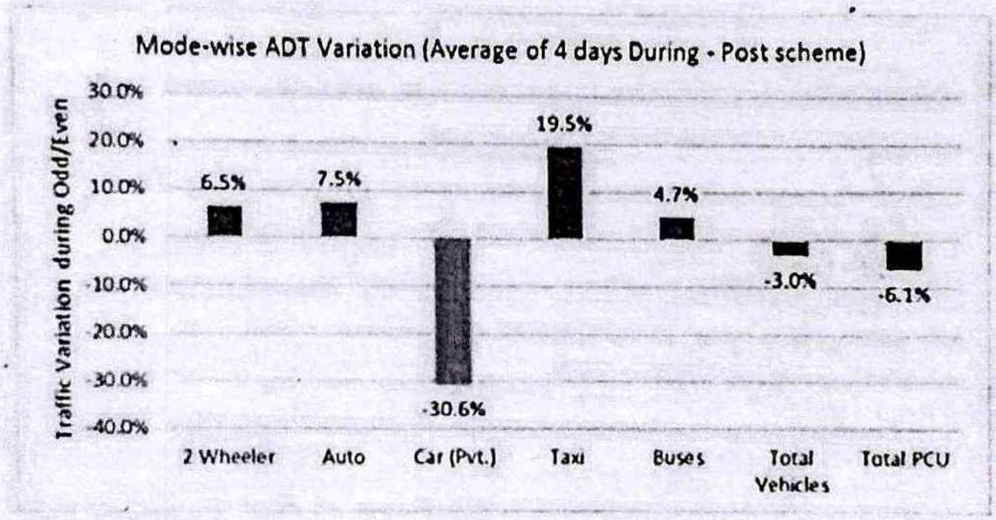
5 Summary and Conclusions

As part of Odd – Even study, data was collected by conducting various traffic surveys during and post scheme. In addition opinion surveys of people were taken to assess impact of road rationing scheme on traffic and travel behaviour of user. Major conclusions are as under:

- Traffic data analysis indicated that during Odd – Even Scheme about 30 % personal car traffic reduced on road. However there was increase of 6.5% in 2 wheeler traffic, 19.5% in Taxi, 7.5% in Auto 4.7%% in Buses. This is shown in figure below for typical location



- The analysis indicates that net impact of traffic reduction on various roads in terms of total volumes (PCU) ranges from 1 % to18% as shown below. Highest impact of traffic reduction was seen on GT road (-18.1%) followed by Noida Link road (-15.4%)

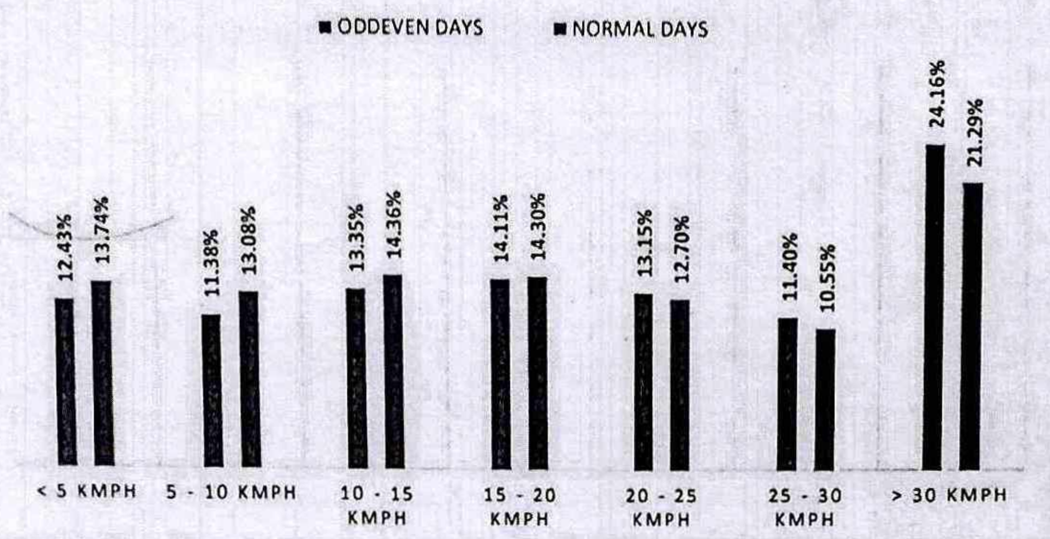
Day Wise % PCU Reduction (During-Post Scheme)					
S. No	Location	Day			
		Wednesday	Thursday	Friday	Average day Traffic
1	Lal Bahadur Shastri Marg, Chirag Delhi	-4.3%	-7.5%	-6.0%	-6.2%
2	GT Karnal Road near GTK Depot	-2.3%	-3.0%	-3.8%	-3.5%
3	ITO-Indraprastha Marg	-0.1%	-3.7%	-4.1%	-2.8%
4	NH-8 near Mahipalpur	-7.1%	-7.4%	-6.1%	-6.9%
5	Noida Link Road near Akshardham Metro Station	-11.2%	-15.4%	-13.4%	-13.8%
6	Ring Road Nigam Bodh Ghat	-4.9%	-6.3%	-7.9%	-7.4%
7	Ring Road South Extension	1.5%	-5.2%	0.6%	-1.1%
8	Shastri Park Junction	-16.8%	-18.1%	8.6%	-10.5%
9	Tagore Garden	-5.9%	-6.9%	-3.9%	-6.8%
10	Ashram Chowk	3.7%	2.0%	4.5%	2.7%

- It has been estimated that average increase in the daily Bus ridership during scheme was about 2.8 Lakhs amounting to about 5.39% increase. Similarly average increase in the daily Metro ridership was recorded about 1.7 Lakhs amounting to about 3% increase in Metro journeys. Overall, total increase in the daily Public Transport ridership was about 4.5 Lakhs amounting to 4.2% increase in PT journeys during the Odd Even period.

- For analysis of speed during and post scheme, more than 10 million GPS records of Auto/Taxi and Cars have been used. It is determined that due to reduction in traffic, average speed on road increased between 2 % 15% on various major roads in Delhi as shown below.

Road Name	Average Peak Hr. Speed During Odd Even	Average Peak Hr. Speed Post Odd-Even	% Speed Increase
Inner Ring Road	30.45	28.31	7%
Outer Ring Road	29.99	26.46	12%
Guru Govind Singh Marg | Karol baug to Ashok Park Metro	18.47	17.12	7%
Lal Bahadur Shastri Marg | Chirag Delhi to Ambedkar Nagar	22.49	21.40	5%
Mehrauli badarpur Marg | Tuglakabad to Mehrauli	18.53	18.02	3%
Radial 1 Najafgarh Road	16.83	16.76	0%
Radial 2 Rohtak Road	26.22	24.96	5%
Radial 3 Lala Jagath Narayan Marg	16.93	15.44	9%
Radial 4 GT Karnal Road	19.12	18.73	2%
Radial 5 Vikas Marg	21.92	20.15	8%
Radial 6 CRRI to Kashmere Gate	27.06	22.95	15%
Radial 7 shanker Vihar (NH 48) to Central Sec.	29.48	26.66	10%
Radial 8 Chatterpur to Central Sec.	22.56	20.82	8%

- Apart from speed variation, number of congested spots (having less than 5 kmph speed) were also analyzed during and post scheme. It has been determined that incidences having speed less than 5 kmph reduced from 13.7 % to 12.4 % and incidences having speed between 5- 10 kmph reduced from 13 % to 11.3 %. On the other hand incidences having speed more than 30 kmph increased from 21.2 % to 24.1 % showing lesser congestion and lower during of congestion during odd- even scheme implementation as shown below.



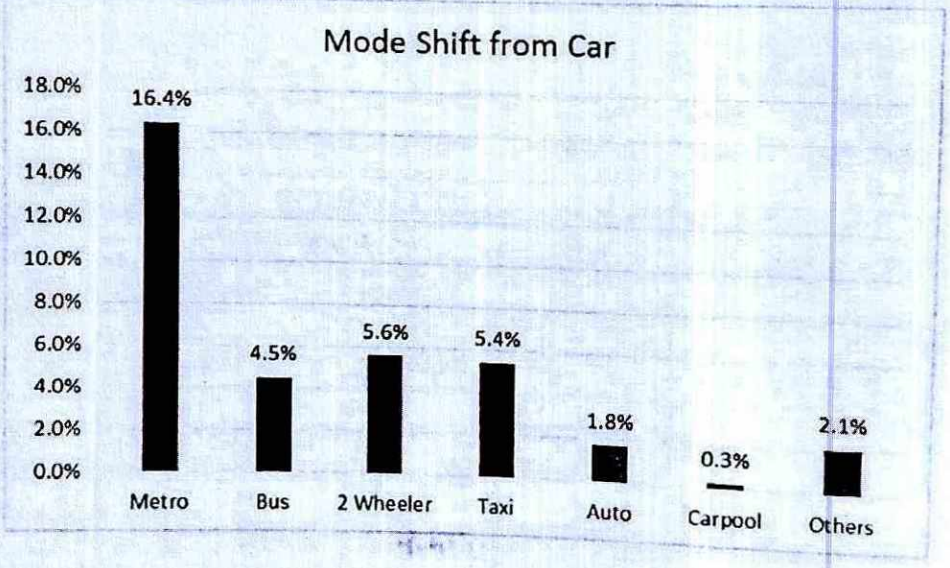
- The analysis of traffic queue length at major intersections during and post scheme indicated that traffic queue length at junctions were substantially lower during odd-even compared to normal days as shown below.

Traffic Queue Length at major intersections- Evening Peak Hour

S.No	Location	Directions	Queue Length (in meters) During Odd/Even	Queue Length (in meters) After Odd/Even	% Change
1	Ashram Chowk	From Badarpur	641	813	-21%
		From Bhogal	398	530	-25%
		From Lajpat Nagar	67	95	-29%
2	ITO	From Mandi House	194	252	-23%
		From Laxmi Nagar	340	516	-34%
		From Old Delhi	219	284	-23%
3	Moti Nagar	From Shadipur	43	53	-19%
		From Raja Garden	53	70	-24%
		From Jakhira	61	64	-5%
4	Karkar More	From Master Plan Road	99	96	3%
		From Laxmi Nagar	116	118	-2%
		From Shahadra	63	74	-15%
		From Karkardooma	69	73	-5%
5	Moti Bagh Junction	From Chanakyapuri	468	568	-18%
		From Munrika	356	454	-22%
		From Dhaula Kuan	127	206	-38%
6	IIT Gate Junction	From Chirag Delhi	108	130	-17%
		From AIIMS	142	406	-65%
		From Mehrauli	265	459	-42%

S.No	Location	Directions	Queue Length (in meters)		% Change
			During Odd/Even	After Odd/Even	
7	Chirag Delhi Junction	From Moolchand	192	495	-61%
		From Ambedkar Nagar	156	257	-39%
		From Nehru Place	67	79	-15%
8	Peeragarhi Chowk	From Paschim Vihar	77	125	-38%
		From Punjabi Bagh	248	247	0%
		From Pitampura	337	371	-9%
		From Peeragarhi Metro Stn	84	511	-84%

- The opinion surveys conducted as part of study indicated following:
    - 36% of people shifted from car to Metro , Bus, 2 wheelers, Taxi and Auto modes during odd –even scheme



- The perception user survey result indicated that 53% of people felt that there was reduction in travel time during scheme.
- Most of the users reported overcrowding in metro (40%) and buses (27%) as the biggest issue. Increase in travel time is reported by some users which have shifted to metro or buses from their own car. Increase in travel cost is reported by users shifted to taxis from cars.
- As part of the survey, users were asked about their opinion on future implementation of scheme. The overall analysis suggests that nearly half (46%) of the users want the scheme to be implemented permanently followed by 32 % people suggesting implantation of the scheme during high pollution days only. This response is mainly received as users of 2 wheelers, buses saw benefits of higher speed during scheme.Majority of the car users (37%) were in favour for temporary implementation of the scheme (during high pollution days only).

- As part of the survey, users were asked that how will they travel if odd-even is made permanent. The analysis results show that majority of the users (37%) have suggested that they will use metro followed by people (26%) stating that they will use buses. Nearly 10% of the people have stated their willingness of buying another car for travelling. Some others have stated that they will shift to 2-wheeler (17%) and Taxi/Cab (8%). Only around 1% of people have said that they will change their job location/move to another city.

- It has been estimated from analysis that there was a decrease of about 6% vehicle kilometres travelled (VKT) during Odd Even Scheme period amounting to **37,79,672** veh-km /day.

- Reduced vehicle – km travelled would also result in reduced fuel consumptions. It has been estimated that there was about 15% decrease in fuel consumption on average day during Odd Even Scheme implementation