Evaluation of Ozone Exceedances and NOx-VOC Regimes in Delhi using Ground Measurements and TROPOMI Satellite Extracts

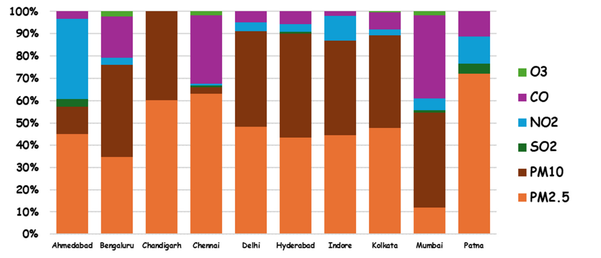
Sarath K Guttikunda [1,2] Sai Krishna Dammalapati [1], and Gautam Pradhan [3]

Affiliation: 1. UrbanEmissions.Info, New Delhi, India 2. Indian Institute of Technology, New Delhi, India 3. Earthmetry, Bengaluru, India

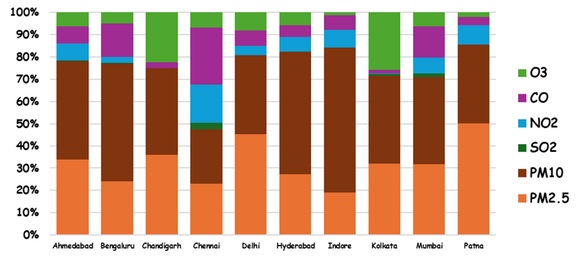
Average Air Quality Index (AQI) in Delhi (official data)

Avg. AQI	J	F	M	A	M	J	J	A	S	O	N	D
in 2015					242	192	138	147	194	264	358	301
in 2016	370	293	238	271	246	208	146	105	163	271	374	365
in 2017	304	267	211	227	249	174	98	103	139	285	361	316
in 2018	328	243	203	222	217	202	104	111	112	269	335	360
in 2019	328	242	184	211	221	189	134	86	98	234	312	337
in 2020	286	241	128	110	144	123	84	64	118	265	328	332
in 2021	324	288	223	202	144	147	110	107	78	173	377	336
in 2022	279	225	217	255	212	190	87	93	104	210	321	319
in 2023	311	237	170	180	171	130	84	116	108	219	373	348

Conditional pollutant shares in 2019



Conditional pollutant shares in 2023



Air Quality Index (AQI) methodology was formalized in India in 2014. Everyday, AQI is calculated using the average of all data per pollutant from regulatory continuous monitors in the city and includes information on the pollutant responsible for that day's AQI. Change in the presence of ozone as a conditional pollutant is noteworthy between 2019 and 2023.

Urban O_3-NO_x-VOC's Nonlinear Chemistry

- NO_x-limited regime means reducing NO_x emissions can effectively control O_3 levels while VOCs remain constant.
- VOC-limited regime means reducing VOC emissions reduces O_3 production; and in the presence of high NO_x (saturated conditions), reduction of NO_x emissions reduces O_3 titration and maintains/increases O_3 levels.
- Typically, at regional scales and in the rural areas, O_3 production is largely NO_x-limited and in urban areas is VOC-limited, as they are frequently NO_x-saturated
- Using TROPOMI's formaldehyde (HCHO) and nitrogen dioxide (NO_2) ratio (FNR) as proxy to explain this dependency over Delhi.

VOC's and CO competing for the free radicals

$VOC + OH^\circ \rightarrow R^\circ + H_2O$
$R^\circ + O_2 \rightarrow RO_2$
$RO_2 + NO \rightarrow RO^\circ + NO_2$

$CO + OH^\circ \rightarrow H^\circ + H_2O$
$H^\circ + O_2 \rightarrow HO_2$
$HO_2 + NO \rightarrow HO^\circ + NO_2$

$CH_4 + NO + OH^\circ \rightarrow HCHO + HO_2 + NO_2$
$VOC + OH^\circ \rightarrow HCHO + RO_2$
$HCHO + h\nu \rightarrow CO + O_2 + H_2 + HO_2$
$HCHO + OH^\circ \rightarrow CO + HO_2 + H_2O$

Free radicals are short-lived and denoted with a "dot"

Photo-stationary

O3 production

$NO_2 + h\nu \rightarrow NO + O^\circ$
$O^\circ + O_2 \rightarrow O_3$

O3 destruction

$O_3 + NO \rightarrow NO_2 + O_2$

$O_3 + h\nu \rightarrow O^\circ + O_2$
$O_3 + O^\circ \rightarrow 2OH^\circ$
$O_3 + OH^\circ \rightarrow HO_2$
$O_3 + HO_2 \rightarrow OH^\circ$
$O_3 + RO_2 \rightarrow RO^\circ$

NO_2 sink

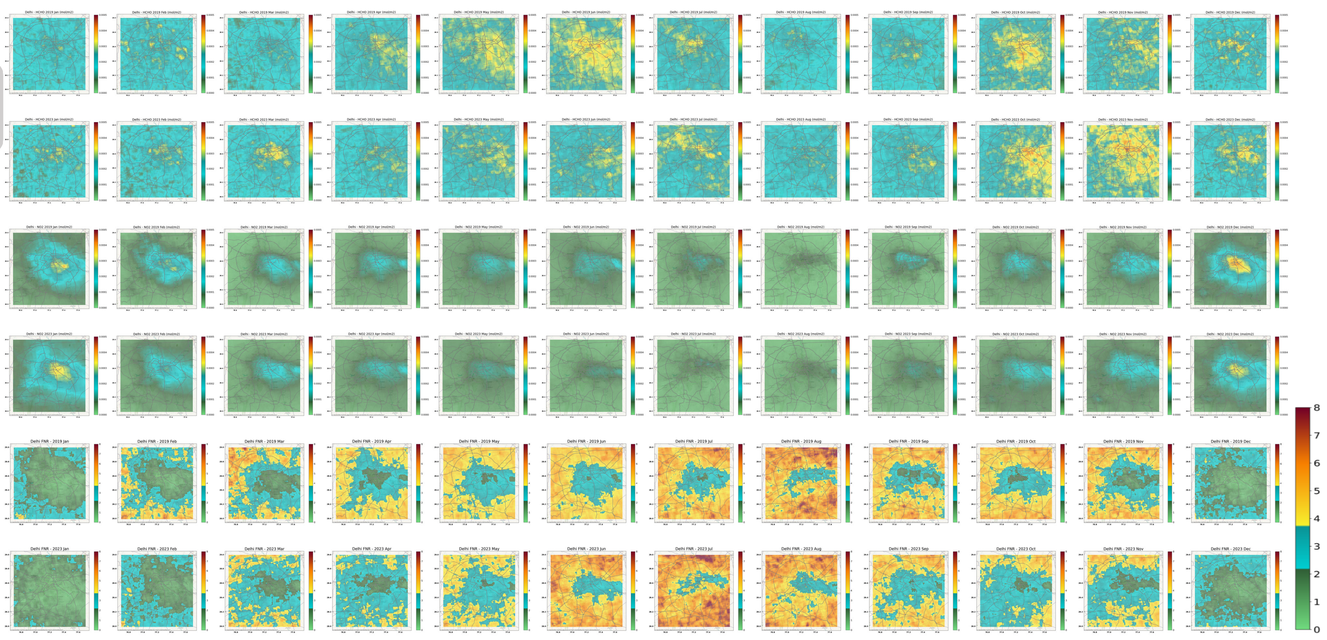
$O^\circ + NO_2 \rightarrow NO_3$ (to aerosols)
$O_3 + NO_2 \rightarrow NO_3$ (to aerosols)

TROPOMI data extracted from Google Earth Engine (cloud fraction 0.5) (extracts available by email and github)

TROPOMI HCHO 2019 and 2023

TROPOMI NO_2 2019 and 2023

Formaldehyde (HCHO) to NO_2 Ratio (FNR)



Summary of source apportionment studies for annual $PM_{2.5}$

All transport 10-30%
This includes all road, rail, and aviation modes and combustion of petrol, diesel, and gas.

All dust 10-30%
This includes dust from resuspension on the roads and construction activities.

All industries 10-30%
This includes all small, medium, and large industries, including power plants and brick kilns.

All Residential <10% in summer <30% in winter
This includes all cooking, lighting, and heating activities.

Waste burning 5-15%
This includes all open waste burning at kerb and residential sides, and at the landfills.

Power plants <7%
This is mostly from power plants outside the city limits.

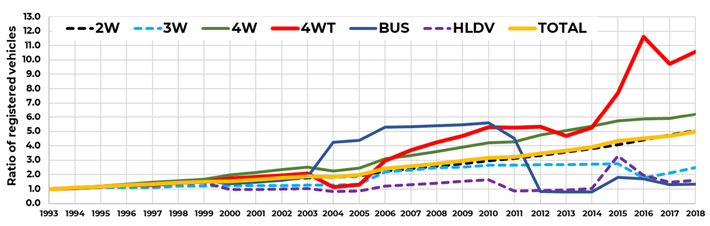
Dust storms <5%
This is a seasonal source.

Agricultural residue burning <3%
This is a seasonal source.

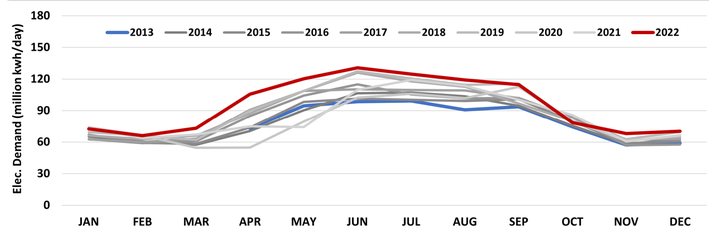
Firecrackers <1%
This is a seasonal source.

Earliest reported source apportionment results are from the 1997 White Paper on Delhi's air pollution by the Central Pollution Control Board. The latest results in this pool are from 2023 real time setup by the Delhi Pollution Control Committee on their premises. Majority of the results follow the filter sampling, chemical analysis, and receptor modeling method.

Growth in registered vehicles as a ratio to 1993



Monthly electricity demand 2013-2022



Emission scenarios to be evaluated which can alter the photochemical regimes in the city are (a) how mandating compressed natural gas (CNG) altered the emissions mix (b) how promoting electric vehicle usage can alter the emissions mix (c) how reduction in open agricultural fires pre-winter can alter the emissions mix and (d) what will be influence of 100% reduction in the use of biomass and coal for cooking and heating?

- Delhi averaged 35-40 continuous monitoring stations reporting ground level concentrations for $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and Ozone concentrations. In India, Delhi hosts the most number of stations, making it an ideal case study for this analysis.
- In 2023, O_3 concentrations exceeded the MDA8 limits (100 $\mu g/m^3$) for 90% of the days during the months of Mar-Apr-May and Oct-Nov.
- Based on the ground monitoring data and the satellite observations, core urban area can be designated as VOC-limited and most of the semi-urban area as transitional.
- As next steps, full chemistry chemical transport modeling will be conducted to understand the dependences better, along with scenario analysis built on results from the source apportionment.

All the data resources utilized for this analysis are documented for open-access @ https://www.urbanemissions.info, along with city air pollution analysis reports under the Air pollution knowledge Assessments (APnA) city program for 131 non-attainment cities of India's National Clean Air Programme (NCAP)