Uncertainty of Operating Smaller Number of Ambient Monitoring Stations Indian Cities from 2015 to 2023

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AQI Category (AQI value)	$PM_{2.5}$ 24-hours µg/m³	PM_{10} 24-hours µg/m³	SO_2 24-hours µg/m³	NO_2 24-hours µg/m³	CO 8-hours mg/m³	O_3 8-hours µg/m³
Good (0-50)	0-30	0-50	0-40	0-40	0-1	0-50
Satisfactory (51-100)	30-60	50-100	40-80	40-80	1-2	50-100
Moderate (101-200)	60-90	100-250	80-380	80-180	2-10	100-168
Poor (201-300)	90-120	250-350	380-800	180-280	10-17	168-208
Very Poor (301-400)	120-250	350-430	800-1600	280-400	17-34	208-748
Severe (401-500)	250+	430+	1600+	400+	34+	748+

Number of cities with... # stations →	1	2	3	4	5-10	10-20	20+
in 2015	17	2	1	0	2	0	0
in 2016	28	1	2	1	1	0	0
in 2017	47	1	2	2	1	1	0
in 2018	66	3	2	1	2	0	1
in 2019	99	2	5	4	4	0	1
in 2020	111	9	7	2	4	1	1
in 2021	139	9	8	4	8	1	1
in 2022	170	14	9	6	7	2	1
in 2023	215	18	16	7	11	2	2

	Number of unique cities listed	Number of reporting stations (avg.)	Number of reporting stations (max.)	Number of stations per unique city
2015	22	31	37	1.4
2016	33	53	54	1.6
2017	54	80	90	1.5
2018	75	129	137	1.7
2019	115	188	206	1.6
2020	135	238	258	1.8
2021	170	300	326	1.8
2022	209	338	396	1.6
2023	271	469	514	1.7
Number of stations recommended			4094	
Minimum number of stations per city recommended				5.0

- 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 a city, and bulletins are released at 4 p.m. as PDF reports.
- Total recommended number of stations (4094) in India is based on thumb rules defined by the Central Pollution Control Board in 2003.
- Minimum number of stations per city (5) is for spatial representation covering residential, traffic, industrial, commercial, and background sites.
- In 2023, 80% of the cities reported AQI using data from one station.
- Only 15 cities (6%) reported AQI using minimum 5 stations – Agra (6), Ahmedabad (9), Bengaluru (13), Chennai (8), Delhi (39), Hyderabad (14), Jaipur (6), Jodhpur (5), Kolkata (7), Lucknow (6), Moradabad (6), Mumbai (28), Navi Mumbai (7), Patna (6), and Pune (8)

% days $PM_{2.5}$ as conditional pollutant

	J	F	M	A	M	J	J	A	S	O	N	D
in 2015					47%	56%	47%	55%	51%	64%	68%	68%
in 2016	74%	64%	51%	54%	46%	44%	43%	40%	36%	50%	66%	60%
in 2017	64%	50%	45%	42%	35%	34%	31%	28%	33%	45%	56%	59%
in 2018	62%	52%	46%	36%	38%	32%	21%	22%	26%	43%	60%	65%
in 2019	66%	54%	42%	34%	31%	27%	22%	17%	18%	43%	61%	64%
in 2020	58%	48%	25%	19%	16%	14%	14%	12%	20%	41%	54%	55%
in 2021	59%	45%	31%	25%	18%	16%	14%	15%	11%	32%	56%	62%
in 2022	55%	43%	36%	25%	21%	19%	13%	13%	16%	31%	53%	57%
in 2023	59%	41%	32%	20%	16%	12%	11%	11%	13%	31%	53%	54%

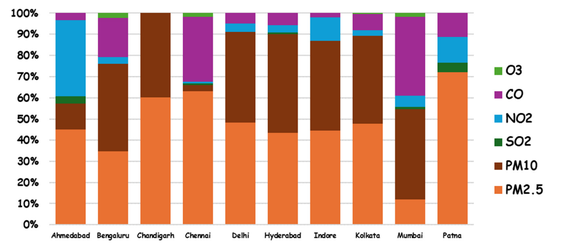
% days PM_{10} as conditional pollutant

	J	F	M	A	M	J	J	A	S	O	N	D
in 2015					24%	11%	13%	24%	22%	17%	16%	18%
in 2016	16%	25%	36%	31%	24%	27%	19%	23%	25%	23%	17%	24%
in 2017	20%	29%	34%	36%	39%	33%	34%	35%	30%	30%	24%	26%
in 2018	26%	42%	47%	58%	53%	54%	52%	49%	55%	49%	34%	32%
in 2019	32%	41%	54%	61%	63%	61%	55%	52%	55%	42%	33%	30%
in 2020	34%	41%	48%	46%	50%	47%	46%	46%	53%	44%	32%	35%
in 2021	31%	46%	57%	58%	52%	53%	48%	53%	48%	46%	30%	31%
in 2022	36%	46%	54%	59%	60%	56%	48%	49%	50%	46%	37%	34%
in 2023	33%	49%	50%	59%	57%	61%	52%	66%	56%	54%	35%	36%

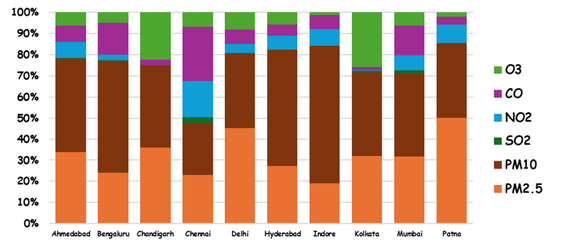
% days gases as conditional pollutant

	J	F	M	A	M	J	J	A	S	O	N	D
in 2015					29%	32%	40%	21%	27%	19%	16%	15%
in 2016	10%	11%	13%	16%	29%	30%	38%	37%	40%	27%	17%	15%
in 2017	15%	21%	21%	21%	26%	34%	35%	37%	37%	25%	20%	15%
in 2018	12%	6%	6%	7%	10%	14%	27%	28%	19%	8%	6%	3%
in 2019	3%	5%	4%	5%	6%	12%	24%	31%	27%	14%	6%	7%
in 2020	9%	11%	27%	34%	34%	39%	40%	43%	27%	16%	14%	10%
in 2021	10%	9%	13%	17%	30%	30%	37%	32%	41%	22%	14%	7%
in 2022	9%	11%	10%	15%	19%	25%	39%	37%	34%	23%	10%	9%
in 2023	8%	10%	18%	21%	26%	27%	37%	23%	31%	15%	11%	10%

Conditional pollutant shares in 2019



Conditional pollutant shares in 2023



- Instances of PM_{10} as conditional pollutant doubled since 2019 – inception of the National Clean Air Programme (NCAP) which designated PM_{10} as the target pollutant.
- There is no significant change in the total occurrence of the gases (SO_2, NO_2, CO, and ozone) as conditional pollutants.

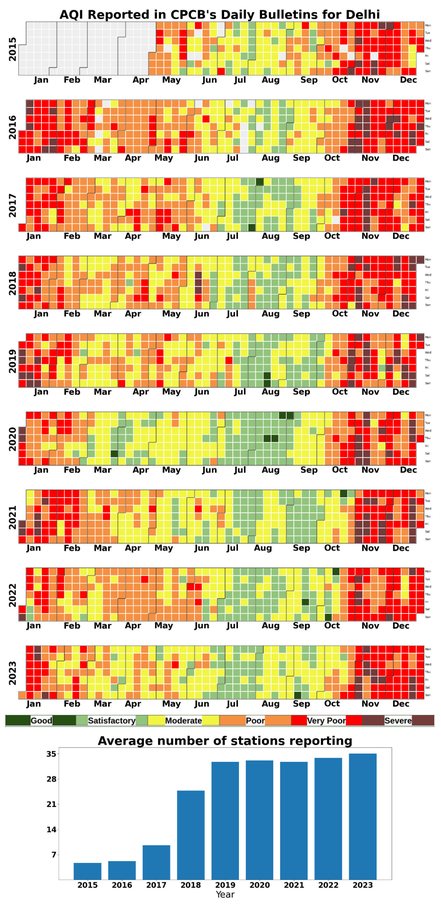
% days across India reporting AQI bins

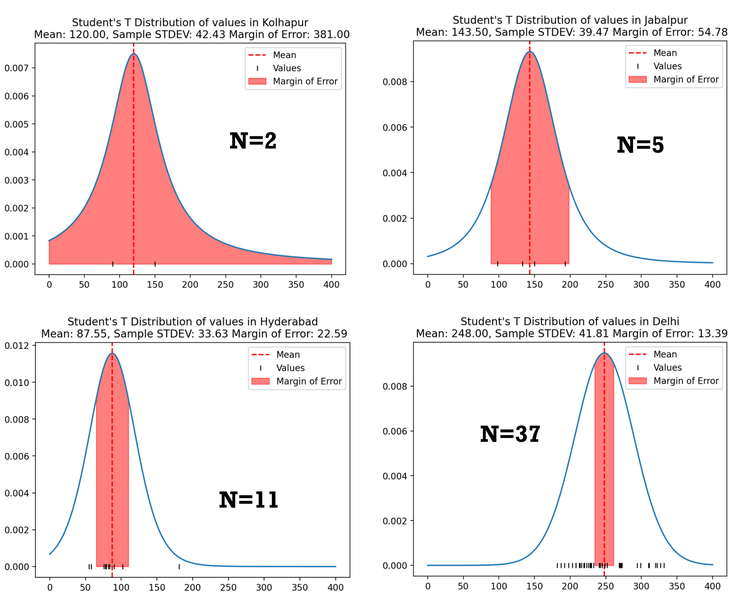
	Good	Satisfactory	Moderate	Poor	Very Poor	Severe
2015	8%	33%	31%	13%	11%	3.0%
2016	11%	27%	35%	14%	9.3%	3.9%
2017	8%	33%	34%	14%	8.7%	2.4%
2018	8%	31%	38%	14%	7.3%	1.5%
2019	11%	33%	36%	13%	5.3%	1.2%
2020	20%	38%	29%	10%	3.6%	0.7%
2021	19%	35%	29%	12%	4.8%	0.6%
2022	17%	34%	31%	12%	4.1%	0.5%
2023	17%	37%	32%	10%	3.2%	0.3%

Average AQI over all stations and all days in a month

Avg. AQI	J	F	M	A	M	J	J	A	S	O	N	D
in 2015					147	114	87	85	110	178	239	242
in 2016	252	190	149	162	139	118	84	72	82	152	225	234
in 2017	208	188	148	147	144	111	85	82	99	164	215	204
in 2018	209	177	159	141	143	126	77	79	87	157	202	211
in 2019	203	155	134	143	149	122	86	68	70	139	186	183
in 2020	157	145	98	85	93	77	61	53	78	147	179	180
in 2021	173	157	142	126	91	86	69	67	57	109	185	179
in 2022	155	138	144	141	122	106	61	65	70	111	164	174
in 2023	172	145	115	114	103	88	65	77	71	114	167	153

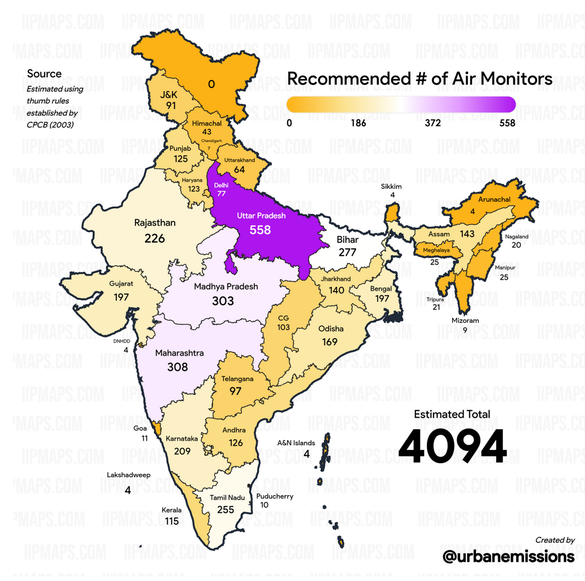
Overall drop in AQI from 2015 to 2023, while some of it is due to reductions in emission intensities in the big cities, a portion of it is also due to an increase in the representativeness of the network by expanding outside the metropolitan and Tier-1 cities. The sharp 30-40% drop in the overall AQI in 2020 from March to June is due to the COVID19 lockdown restrictions.

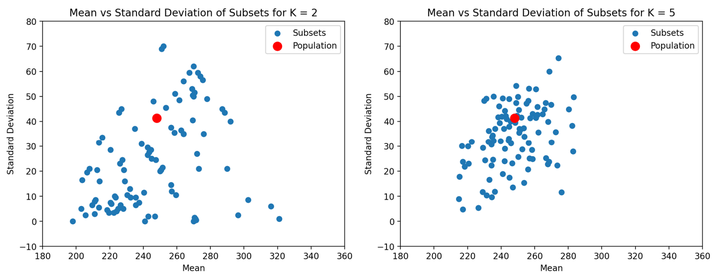




One or two stations is not a good sample size to represent a city's air quality

Even if the assumption of "randomness" in the placement of the monitors is considered, there is an issue of wide confidence intervals. CI of the mean air quality built using the student's t-distribution function will be wide for small sample sizes. For instance, if a city only has 2 monitors, the margin of error would be 12.7 times the standard error of the mean (SEM for a 95% CI) and for 37 it is 2.0.





As an experiment, as we randomly choose different sample sizes (2, 5, and 30), we get different means and variances, and as the sample size increases, they close the gap to the mean and variance of the population (Delhi, total number of samples = 37). This example demonstrates the need for representation from residential, transport, industrial, commercial and background locations and the likely variation in the interpretations when data from some of these stations is not available.

Recommendations

- **Increase in regulatory stations**
- **Promotion of hybrid networks with low-cost sensors**
- **Integration with bottom-up emissions and pollution modeling for more spatial and temporal representation.**

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)