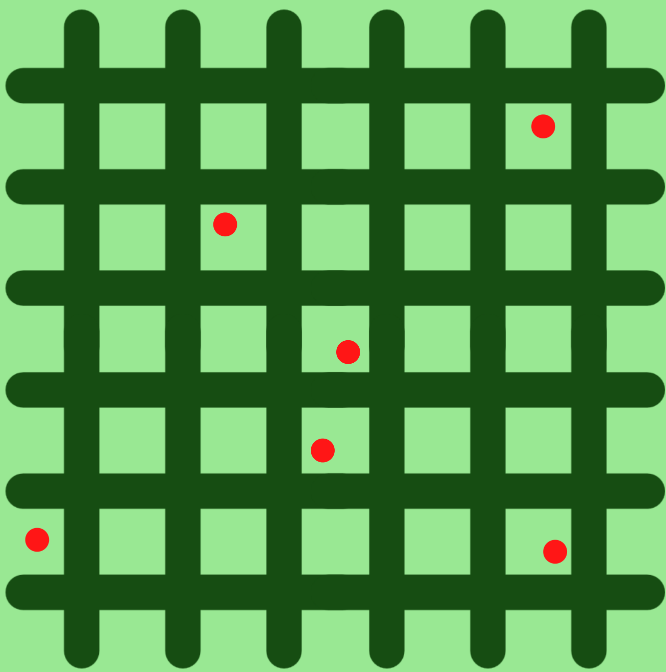
MONITORING AMBIENT AIR QUALITY IN INDIAN CITY AIRSHEDS



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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

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What is this report?

An understanding of sources contributing to a city's air pollution problem is crucial for building an effective clean air action plan. All the non-attainment cities under the National Clean Air Programme (NCAP) are planning or conducting a source apportionment study (annex 1). Irrespective of the approaches and equipment selected to conduct these studies, the initiation process requires an understanding of the pollution loads, mix of sources, and geography of the city to decide how much to monitor for better spatial representation and how many times to monitor for better temporal representation.

In this report, we defined

1. The size of NCAP city airsheds
2. The recommended number of ambient air quality monitoring sites in an airshed
3. The operational sampling frequency to support receptor-based source apportionment studies

These resources are necessary for strengthening the monitoring needs of an airshed to track pollution levels, to conduct receptor-model-based source apportionment studies, and to support long-term air quality management plans.

Total no. of NCAP cities = 122
Total no. of airsheds = 94
Total no. of cities covered by these 94 airsheds = 154
Total population in these 94 airsheds = 290.5 million
Share of national population in the airsheds = 22%
Share of national land area covered by the airsheds = 4.5%
Average share of urban population in the airsheds = 56%
Total no. of PM monitoring stations recommended in the airsheds = 1700

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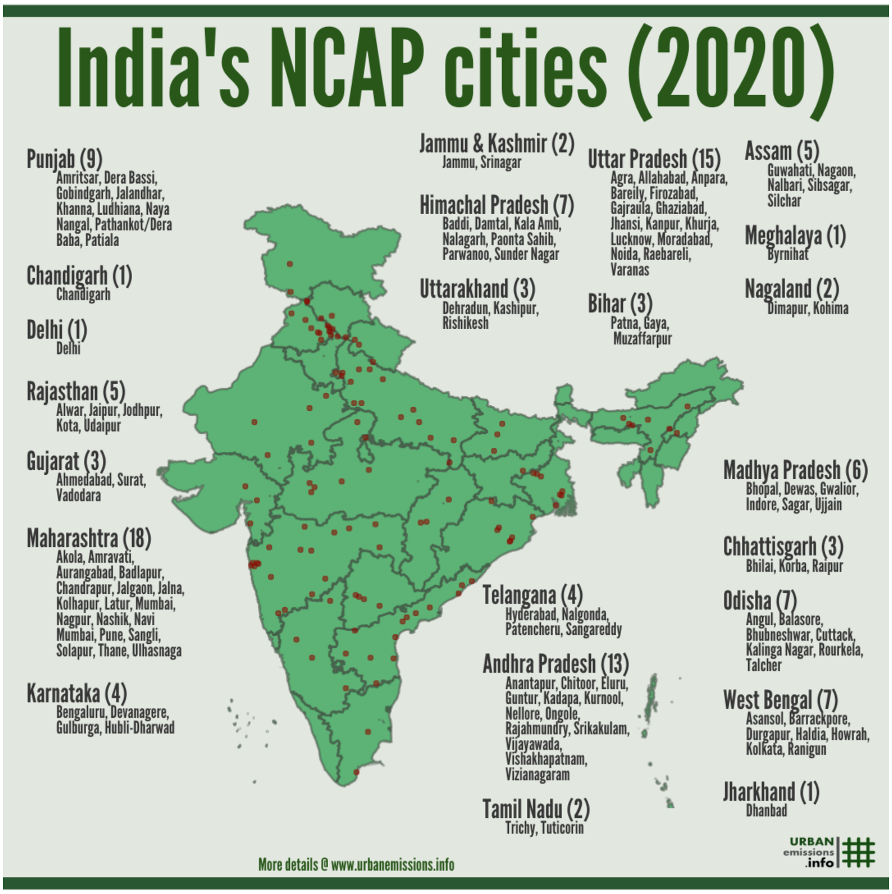
1.0 Introduction

Urban air pollution in India is ranked among the worst in the world and there is a significant health burden. In 2017 alone, exposure to air pollution was estimated to cause 1.24 million deaths (Balakrishnan et al., 2019). In 2019, India's Ministry of Environment Forests and Climate Change (MoEFCC) announced the National Clean Air Programme (NCAP) to build the institutional capacity of the pollution control boards by expanding the monitoring network, upgrading the guidelines for emissions and pollution monitoring, enabling the use of new sensor technology, and establishing an information cell to collate and coordinate data flows to support long-term air quality management and development of clean air action plans.



Under NCAP, 122 non-attainment cities (i.e. cities that did not meet the Indian National Ambient Air Quality Standards in 2017) were asked to prepare action plans to reduce their ambient $PM_{2.5}$ pollution levels by 20-30% by 2024, compared to the pollution levels recorded in 2017 (NCAP, 2019). The list represents 23 of the 36 states and union territories in India.

Prerequisite for prioritizing air pollution mitigation options is the information on emission and pollution loads by sector, also called "*source apportionment*", followed by cost-effectiveness of the options. As of December 2020, MoEFCC has approved 102 clean air plans, although most of them contain limited information on the emission loads and source contributions (Ganguly et al., 2020). Of the approved plans, 50 have at least one study with such information (CPCB, 2011; Gargava and Rajagopalan, 2016; Guttikunda et al., 2019; UEinfo, 2019) and only 25 have incorporated this information in the plans. Cities with no information are expected to conduct pollution load and source apportionment assessment studies.

The term "source apportionment" refers to estimation of various source contributions in a measured sample or modelled pollution levels. This is arrived at via receptor (top-down) modelling approach which involves sampling, chemical analysis, and statistical modelling to match source fingerprints or via emissions (bottom-up) modelling approach which involves modelling of emissions, meteorology, and chemical transport. Both methods require substantial institutional, technical, personnel, and financial support to plan, implement, and sustain the studies. A comparative assessment of the process and needs is presented in the external Supplementary Material.

Between the two approaches, receptor modelling is preferred, as it involves direct measurement of pollution and chemical analysis of the samples in a certified laboratory.

Between the two approaches, emissions-based modelling can provide a resource-rich baseline on emissions and pollution trends and jump-start the other approach. And this approach is less tedious to update frequently (annex 3).

Between 2000 and 2018, more than 500 studies were published on source apportionment using top-down and bottom-up approaches, using a variety of sampling, chemical analysis, surveys, and modelling techniques, with 60% of them covering major cities such as Agra, Chennai, Delhi, Kanpur, Kolkata, Mumbai, and Raipur. In most cases, these cities host an established academic institution and a trained team to conduct such studies, making it convenient to regularly update. Delhi remains the most studied city for both receptor- and emissions-based approaches. Irrespective of the approach and technique, the sources of concern in Indian cities are consistent across the studies, with some variation in the level of contributions.

With administrative support from CPCB and the state pollution control boards, regional academic and research institutions are conducting source apportionment studies under NCAP. Nine cities (Patna, Gaya, Muzaffarpur, Delhi, Mumbai, Pune, Jaipur, Agra, and Dehradun) have completed one round (TERI, 2018; BSPCB, 2019; Nagar et al., 2020; Soni et al., 2020), 46 cities have initiated studies, and the rest are under proposal or planning stages. A detailed list of these proposed and planned studies is in annex 1.

While the receptor modelling methodology has improved over the years, for example from offline sampling and analysis (CPCB, 2011; Pervez et al., 2016) to online instrumentation (Gani et al., 2019; Tobler et al., 2020), shortcomings in the large-scale applications are persistent. These limitations also stem from lack of monitoring stations, trained personnel and instrumentation for chemical analysis, and laboratory facilities, all of which can result in poor spatial and temporal resolution of measurements, mischaracterization of composition, and possibility of contamination of filters.

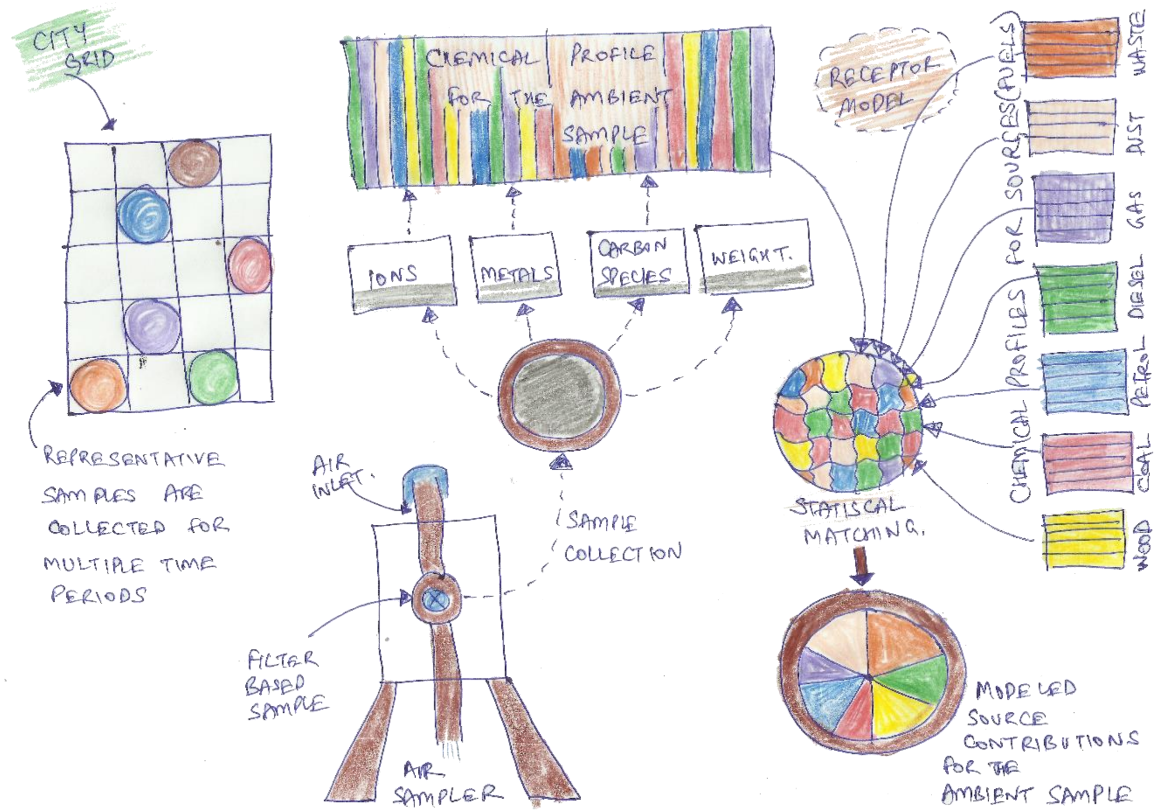


Figure 1: Schematics of receptor-based (top-down) approach to estimate source contributions

These studies require efforts at all the levels – institutional, technical, personnel, and financial; and often compromises (annex 2) are made to fasten the results, thus losing on spatial, temporal, and technical representation of the results. In this report, we focus on "***how to improve the representativeness of the study***".

In the following chapters, we present details on (a) airshed sizes (b) number of sampling sites per airshed and (c) sampling frequency, to strengthen the monitoring needs and improve the overall spatial and temporal representativeness of the study for a city. The resources evaluated to support the planning process are geography, census, geospatial information, meteorology, and guidelines established by CPCB.

2.0 City Backgrounds & Airsheds

In India, due to proximity of several cities feeding each other commercially and economically, it is impractical to draw a practical boundary for analysing urban air pollution. Any discussion on urban air quality using the city administrative boundary will limit the sources to road transport, rail transport, waste management, road dust, greening, and domestic cooking. Often, large and medium scale industrial sources such as coal-fired power plants and brick kilns are located outside city boundaries and fall outside enforcement responsibilities of the city administration. For example, although Delhi's daily power consumption varies between 3000 MW on average to 6000 MW during the peak hours. The total generation capacity in Delhi is under 700 MW. The rest comes from thermal power plants located within a radius of 100 km. This zone also hosts more than 1000 coal and biomass fired brick kilns, with none under Delhi's administration (Guttikunda and Calori, 2013). The situation is similar for a cluster of cities on the Indo-Gangetic Plain such as Amritsar, Chandigarh, Hisar, Agra, Kanpur, Lucknow, Varanasi, Dhanbad, and Kolkata and in Central India such as Nagpur, Bhopal, and Raipur.

For an effective urban air quality management plan, an understanding of the sources inside and outside the city, potential hot spots (industrial, transport, landfills, and residential), and physical characteristics of the airshed is necessary.

What is an airshed? How to define a city airshed?

For determining a city's airshed size, a general thumb rule is that the area should include all the diffused and point sources in the immediately vicinity, that are likely to influence the city's air quality. We used urban-rural classifications, landuse information, and an understanding of the known emission sources in the immediate vicinity of a city's administrative boundary in assigning the airshed sizes. In addition to the administrative boundary of the main city and the satellite cities, in some cases, some manual scanning of sources not documented regularly (such as brick kilns and quarries) and future city expansion plans, can also help in determining the overall airshed size. Human settlements layer is used to estimate the urban and rural shares of area and population in the city's airshed. A database of resources necessary for this exercise are presented in Annex 4.

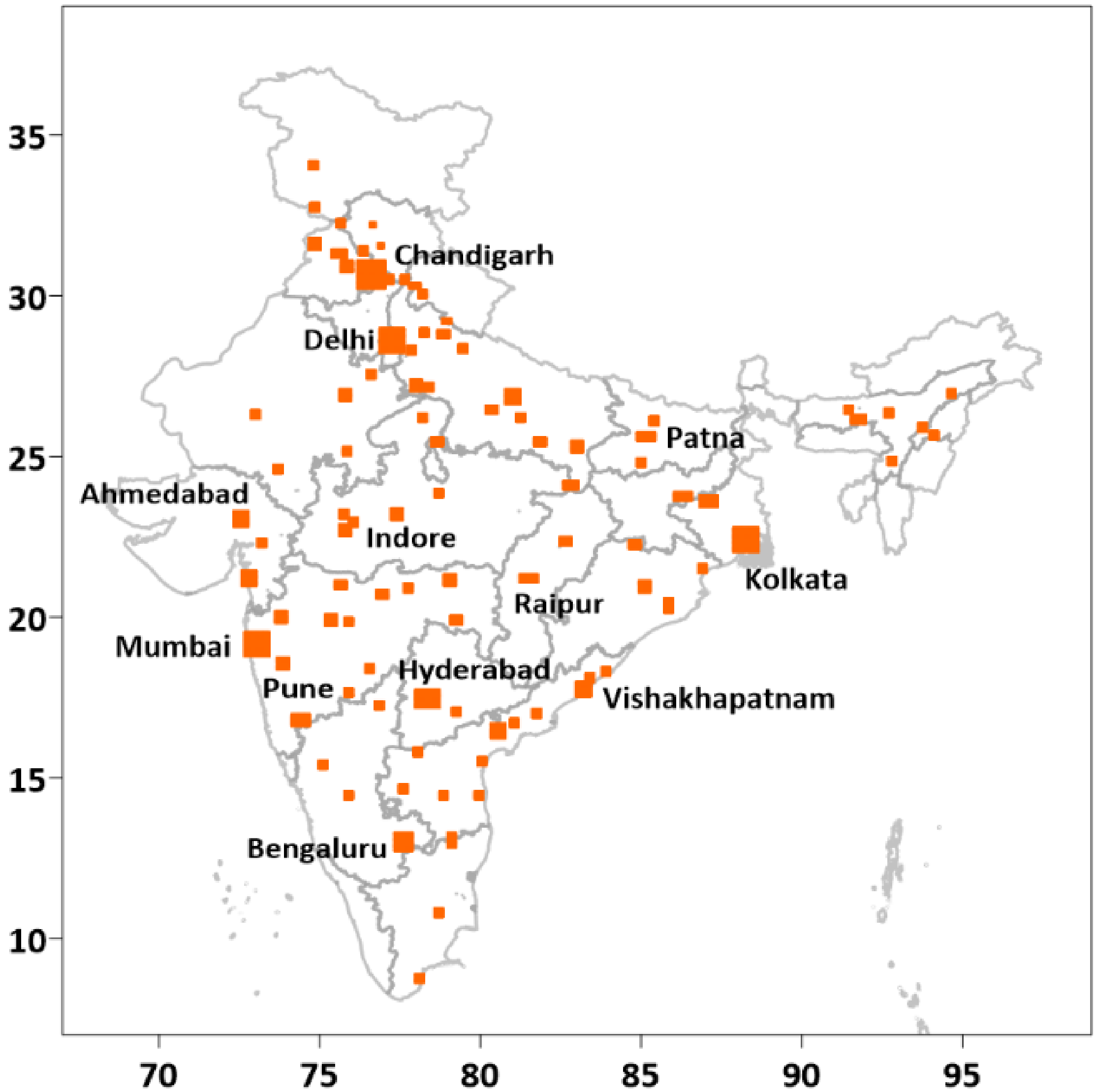


Figure 2: Proposed 94 airsheds covering all 122 NCAP non-attainment cities and an additional 32 cities. A GIS formatted composite of these airsheds with all the grid information is included in the external Supplementary Material

We clubbed the 122 into 94 airsheds, summarized in **Table 1**. The smallest airshed is 20 x 20 grids in the mountain state of Himachal Pradesh with little in the way of outside contributions and the largest airshed is 90 x 90 grids in Chandigarh with 10 Tier-2 and Tier-3 cities in the immediate vicinity (**Figure 2**). All the grids have uniform size of 0.01° (~1.1 km). A GIS formatted composite of these airsheds with all the grid information is included in the external Supplementary Material.

Table 1: Characteristics of airsheds designated for NCAP non-attainment cities. B = cities included in the airshed from the NCAP list; C = cities included in the airshed and not on the NCAP list; D = airshed size in grids of equal size (0.01°); E = total airshed population; F = fraction of grids designated as urban using built-up area information (Pesaresi et al., 2015); G = fraction of population in the urban grids

	State	Airshed	Other NCAP city (B)	Other Non-NCAP city (C)	Airshed size (grids) (D)	Total pop (E)	Urban grids (F)	Urban pop (G)
1	Andhra Pradesh	Anantapur			30 x 30	0.7	8%	63%
2		Chitoor		Vellore	30 x 50	1.4	8%	54%
3		Eluru		Hanuman Junction	30 x 30	0.8	9%	48%
4		Kadapa			30 x 30	0.7	9%	71%
5		Kurnool			30 x 30	0.8	9%	65%
6		Nellore			30 x 30	0.9	8%	60%
7		Ongole			30 x 30	0.5	6%	53%
8		Rajamundry			30 x 30	1.4	28%	66%
9		Srikakulam			30 x 30	0.7	6%	31%
10		Vijayawada	Guntur	Tenali	50 x 50	3.6	17%	70%
11		Vishakhapatnam			50 x 50	3.2	12%	73%
12		Vizianagaram			30 x 30	1.0	16%	55%
13	Assam	Guwahati	Byrnahati	Dispur	50 x 30	2.2	5%	52%
14		Nagaon			30 x 30	1.4	1%	7%
15		Nalbari			30 x 30	1.2	0%	0%
16		Sibsagar			30 x 30	0.6	0%	3%
17		Silchar			30 x 30	1.3	2%	12%
18	Bihar	Gaya			30 x 30	1.6	5%	28%
19		Muzaffarpur			30 x 30	2.7	3%	13%
20		Patna			60 x 30	5.8	7%	49%
21	Chandigarh	Chandigarh	Patiala, Dera Bassi, Khanna, Gobindgarh, Baddi, Nalagarh, Parwanoo	Ambala, Panchkula, Rupnagar, Kalka	90 x 90	7.9	6%	47%
22	Chhattisgarh	Korba			40 x 30	1.2	15%	57%
23		Raipur	Bhillai	Durg	60 x 30	3.5	26%	81%
24	Delhi	Delhi	Noida, Ghaziabad	Greater Noida, Gurugram, Rohtak, Faridabad	80 x 80	28.9	26%	81%
25	Gujarat	Ahmedabad		Gandhi Nagar	50 x 50	9.2	15%	74%
26		Surat		Hazira	50 x 50	5.9	13%	68%
27		Vodadara			30 x 30	2.7	24%	85%
28	Himachal Pradesh	Kalaamb			30 x 30	0.5	3%	27%
29		Paonta Sahib			30 x 30	0.4	11%	42%
30		Sunder Nagar			20 x 20	0.4	5%	19%
31	Jammu & Kashmir	Jammu			30 x 30	2.1	18%	51%
32		Srinagar			30 x 30	2.4	22%	64%
33	Jharkhand	Dhanbad		Bokaro, Jaropokhar	60 x 30	3.2	39%	66%
34	Karnataka	Bengaluru			60 x 60	12.7	19%	79%
35		Devanagere			30 x 30	0.8	6%	59%

	State	Airshed	Other NCAP city (B)	Other Non-NCAP city (C)	Airshed size (grids) (D)	Total pop (E)	Urban grids (F)	Urban pop (G)
36		Gulburga			30 x 30	1.0	8%	67%
37		Hubli Dharwad			30 x 30	1.2	6%	62%
38	Madhya Pradesh	Bhopal			40 x 40	2.8	13%	84%
39		Dewas			30 x 30	0.7	13%	60%
40		Gwalior			30 x 30	1.5	11%	65%
41		Indore		Mhow, Pitampura	40 x 40	3.3	23%	84%
42		Sagar			30 x 30	0.6	4%	43%
43		Ujjain			30 x 30	0.8	10%	61%
44	Maharashtra	Akola			40 x 30	1.0	9%	62%
45		Amravati			30 x 30	1.0	10%	70%
46		Aurangabad			40 x 40	2.2	10%	69%
47		Chandrapur			40 x 30	1.0	14%	59%
48		Jalgaon		Bhusawal	40 x 30	1.3	10%	62%
49		Jalna			30 x 30	0.6	4%	41%
50		Kolhapur	Sangli		60 x 40	4.2	12%	48%
51		Latur			30 x 30	0.8	8%	53%
52		Mumbai	Navi Mumbai, Thane, Ulhas Nagar, Badlapur	Kalyan, Karjat	80 x 80	27.2	17%	86%
53		Nagpur			40 x 40	3.9	20%	86%
54		Nashik			40 x 40	2.9	10%	64%
55		Pune		Pimpri-Chinchwad, Hinjewadi	40 x 40	7.5	23%	77%
56		Solapur			30 x 30	1.3	9%	80%
57	Meghalaya	Dimapur			30 x 30	0.6	1%	16%
58		Kohima			30 x 30	0.2	3%	57%
59	Odisha	Angul	Talcher		40 x 40	0.9	11%	20%
60		Balasore			30 x 30	1.0	8%	29%
61		Bhubaneswar	Cuttack, Kalinga Nagar		30 x 50	4.0	12%	58%
62		Rourkela			40 x 30	1.2	13%	70%
63	Punjab	Amritsar		Tarn Taran	40 x 40	2.4	9%	63%
64		Jalandhar		Phagwara	50 x 30	2.2	16%	65%
65		Ludhiana		Philaur	40 x 40	3.0	18%	75%
66		Naya Nangal		Una	30 x 30	0.5	5%	29%
67		Pathankot	Damtal		30 x 30	0.8	24%	60%
68	Rajasthan	Alwar			30 x 30	0.9	8%	47%
69		Jaipur			40 x 40	5.1	21%	85%
70		Jodhpur			30 x 30	1.7	24%	86%
71		Kota			30 x 30	1.5	16%	87%
72		Udaipur			30 x 30	1.1	18%	66%
73	Tamilnadu	Trichy			30 x 30	1.7	6%	53%
74		Tuticorin			30 x 30	0.8	14%	51%
75	Telangana	Hyderabad	Patancheru, Sangareddy		80 x 60	10.5	18%	83%
76		Nalgonda			30 x 30	0.4	6%	42%
77	Uttar Pradesh	Agra			40 x 40	4.2	9%	53%
78		Allahabad			40 x 30	3.1	7%	37%
79		Anpara		Singrauli	50 x 30	0.8	19%	67%
80		Bareily			30 x 30	2.3	10%	40%

	State	Airshed	Other NCAP city (B)	Other Non-NCAP city (C)	Airshed size (grids) (D)	Total pop (E)	Urban grids (F)	Urban pop (G)
81		Firozabad			30 x 30	1.4	4%	34%
82		Gajraula			30 x 30	1.0	2%	12%
83		Jhansi			40 x 30	1.0	8%	44%
84		Kanpur			40 x 30	5.7	19%	74%
85		Khurja		Bulandshahr	30 x 30	1.5	3%	18%
86		Lucknow		Barabanki	50 x 50	5.7	9%	58%
87		Moradabad		Rampur	40 x 30	2.4	7%	44%
88		Raebareli			30 x 30	1.2	2%	15%
89		Varanasi			40 x 40	4.4	10%	37%
90	Uttarakhand	Dehradun			40 x 20	1.2	12%	70%
91		Kashipur			30 x 20	0.8	20%	40%
92		Rishikesh		Haridwar	30 x 30	1.0	12%	64%
93	West Bengal	Asansol	Durgapur, Ranigunj		60 x 40	4.0	45%	72%
94		Kolkata	Barrackpore, Haldia, Howrah		80 x 80	27.3	14%	56%

Some airsheds include more than one city, some from the NCAP non-attainment list (Column B) and some others (Column C). Together, these 122 cities were grouped into 94 airsheds representing 154 cities and a total population of 290.6 million (Column E). The table also includes information on total airshed population and urban shares of the built-up area (Column F) and population (Column G). 66 airsheds contain only one city; 16 airsheds contain two cities, nine airsheds contain three cities and four airsheds - Chandigarh, Delhi, Mumbai, and Kolkata airsheds - contain 11, 7, 7, and 4 cities respectively. Delhi, Mumbai, and Kolkata airsheds host more than 25 million inhabitants.

Assam's Nagaon, Nilbari, Sibsagar, and Silchar airsheds displayed least number of grids with built-up area and designated urban population under 12%. Overall, average share of urban population in the 94 airsheds is 56% with 11 cities above 80%. The population of 290.6 million in the 94 airsheds represents 22% of the national total covering 4.5% of the national land area. The designated urban population of 189.9 million inhabits 0.6% of the national land area at the rate of 9000 persons/km^2. Ahmedabad, Kanpur, Kolkata Mumbai, Patna, and Trichy have an urban population density of more than 15,000 person/km^2.

The largest airshed is Chandigarh covering 11 additional cities – 7 from the NCAP list (Patiala, Dera Bassi, Gobindgarh, and Khanna from Punjab and Baddi, Nalagarh and Parwanoo from Himachal Pradesh). During the winter months, a majority share of 50% of $PM_{2.5}$ pollution, on an annual basis, can be attributed to sources outside the boundary (Guttikunda et al., 2019). Due to proximity, Chandigarh's airshed size was expanded to include these cities and we can assume that these cities also experience similar contribution trends. Other notable cities in the airshed are Ambala, Panchkula, Rupnagar, and Kalka.

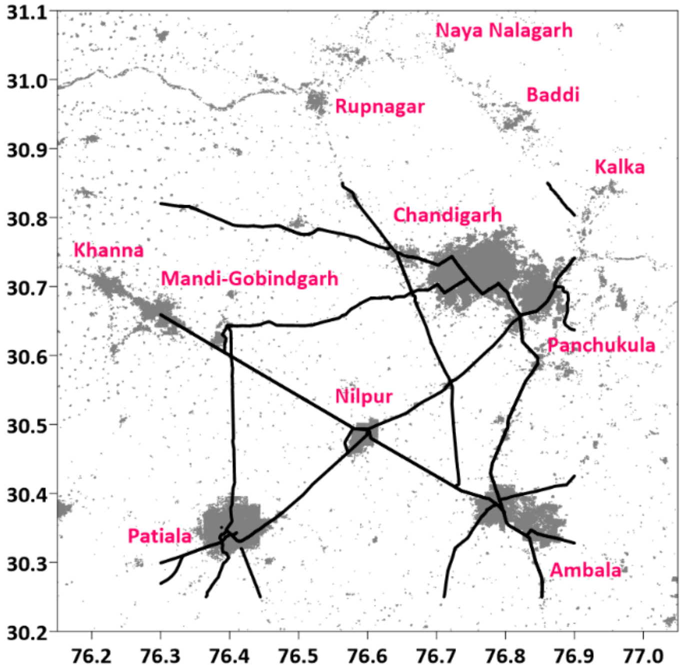


Figure 3: Proposed Chandigarh airshed and other NCAP and non-NCAP cities in the airshed. The shaded area represents satellite retrieval of the urban built-up layer from the global human settlements program for the year 2014

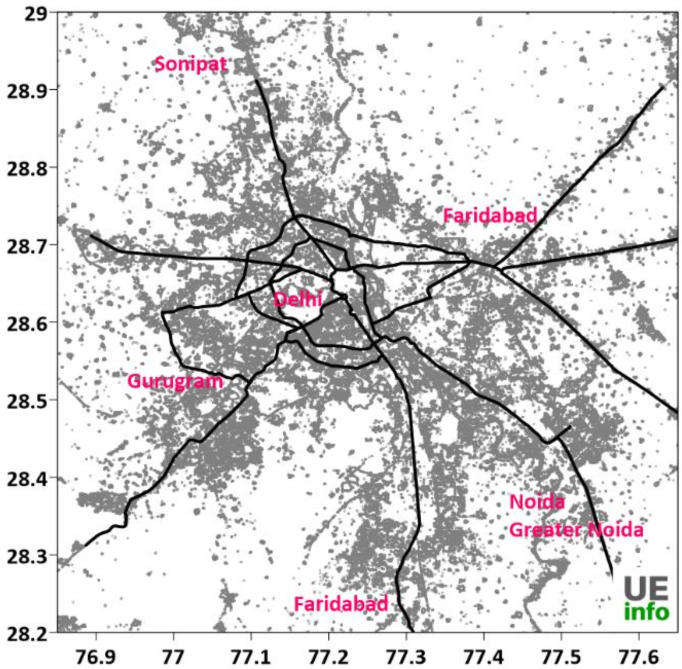


Figure 4: Proposed Delhi airshed and other NCAP and non-NCAP cities in the airshed. The shaded area represents satellite retrieval of the urban built-up layer from the global human settlements program for the year 2014

Delhi's air quality is the most studied in India and also receives a lot of media attention (CPCB, 1997; Bell et al., 2004; Guttikunda and Calori, 2013; Kumar et al., 2017; Patel, 2019). Two NCAP cities from Uttar Pradesh – Ghaziabad and Noida are in this airshed. Other commercially and industrially active satellite cities are Faridabad, Gurugram, and Rohtak in the state of Haryana and some smaller cities in Rajasthan and Uttar Pradesh, collectively referred as the National Capital Region (NCR) of Delhi.

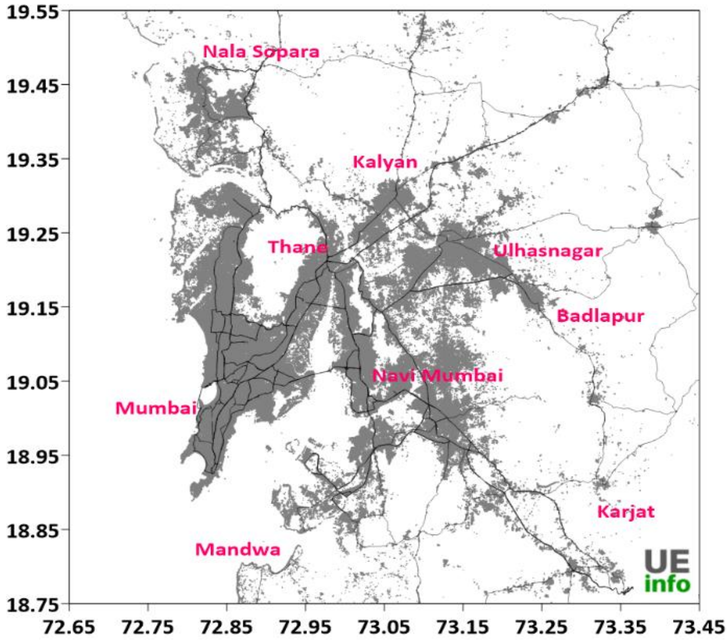


Figure 5: Proposed Mumbai airshed and other NCAP and non-NCAP cities in the airshed. The shaded area represents satellite retrieval of the urban built-up layer from the global human settlements program for the year 2014

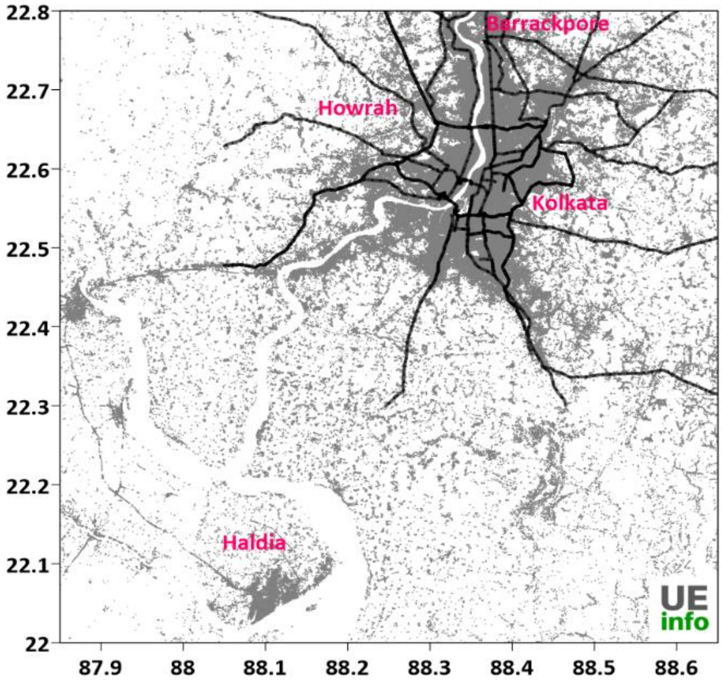


Figure 6: Proposed Kolkata airshed and other NCAP and non-NCAP cities in the airshed. The shaded area represents satellite retrieval of the urban built-up layer from the global human settlements program for the year 2014

Mumbai plays a central role in India's economic and commercial portfolio and along with Delhi, is one of the most studied cities in India. The Indian Institute of Technology in Mumbai, anchored CPCB's six-city study and developed a library of source chemical profiles for Indian cities (CPCB, 2011; Patil et al., 2013; Gargava and Rajagopalan, 2016; Police et al., 2018). The Greater Mumbai's airshed includes Thane, Navi Mumbai, Badlapur, and Ulhas Nagar from the NCAP list and Kalyan and Karjat which are industrial hubs outside the main city. Due to constant commercial and personnel movement between these areas, it is difficult to delineate these cities. The 18 non-attainment cities in Maharashtra were clubbed into 13 airsheds covering a total of 23 cities (all within the state).

Kolkata’s airshed contains its twin city Howarh as well as its neighbouring cities Barrackpore which hosts a coal fired thermal power plant and Haldia which hosts an oil refinery in the South. This airshed includes 700 coal and biomass fired fixed-chimney brick kilns. Unlike Mumbai and Delhi with 86% each, only 56% of the airshed population is accounted in the urban grids, which means a large fraction of the airshed population is in the rural areas with limited access to urban amenities such as waste management and consistent clean cooking fuel access.

Airshed maps for every city with all the support information are included at the end of the chapters. A GIS formatted composite of these airsheds with all the grid information is included in the external Supplementary Material.

3.0 Required # of Monitoring Sites

The goal of ambient air quality monitoring is to represent the trends spatially and temporally, and as accurately as possible. This also applies for source apportionment studies. It is important to differentiate between the need for ambient monitoring on a day to day basis, to study diurnal and seasonal variations in the pollution levels and to understand the changes due to implementation of control measures or their lack off and the need to sample pollution at various times and locations to understand the potential sources contributing to the problem and how best to address these sources. While both these objectives need monitoring and good representation, the former requires continuous operations while the later can be conducted as and when significant changes are observed in the emissions mix or every 3-5 years to support the policy discussions. In this chapter, we present "***what is a representative size of monitoring network***" for both the cases.

A thumb rule for representativeness of a continuous monitoring station is 2 km radius. This could be lesser inside the cities with multiple obstructions like tall buildings and trees or could be more outside the cities which is commonly referred to as "background".

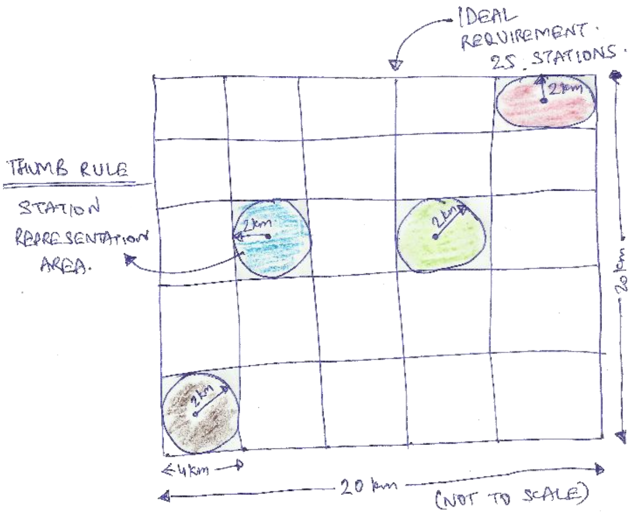


Figure 7: Representation of the thumb rule to estimate ideal number of required ambient monitoring stations in a city

Placing a monitor every 9 km^2 is financially and technically prohibitive for any city or country (Brauer et al., 2019). So, we used the databases in **Table 2** and the guidelines established by CPCB (CPCB, 2003) to estimate the minimum number of monitoring sites recommended for an airshed. These guidelines are summarized in **Table 3** for estimating recommended number of monitoring stations for total suspended particulate matter (SPM), SO_2, NO_2, and CO (and other oxidants). New ambient air quality standards were introduced in November 2009, with no change in the guidelines to address the need for more $PM_{2.5}$ and PM_{10} measurements in the cities. To account for growing commercial density of urban activities, a correction factor was introduced to account for urban population density in the form of urban-area/urban-population shares in the airshed.

Table 2: Source and use case of databases for receptor modelling

Field	Database	Receptor modelling component
Meteorology	Weather Research and Forecasting (WRF) model with global inputs from (NCEP, 2018) was used to build all the necessary 3-dimensional meteorological fields, such as wind speeds, wind directions, temperature, relative humidity, pressure, precipitation, mixing layer heights, and surface threshold velocities (and others), at 0.1° spatial resolution and 1-hour temporal resolution for the year 2018.	Number of sampling seasons
Population	Census-India database at the district level (Census-India, 2011) and gridded population from Gridded Population of the World version 4 (GRUMP, 2019) and Landscan of Oakridge National Laboratory (Rose et al., 2019) available at 30-sec spatial resolution was used to create 0.01° resolution population database for the city airsheds. The population database was also projected to 2050, using state level birth rates and death rates (by age group).	Number of sampling sites
Global Human settlement (GHS)	GHS layer of landsat satellite imagery was used to designate the city airshed grids and the gridded population as urban and rural (Pesaresi et al., 2015).	Number of sampling sites

Table 3: Recommended number of ambient air quality monitoring stations based on the (CPCB, 2003) protocols

Pollutant	Population in the airshed	Number of stations
Suspended particulate matter (SPM)	< 100,000 100,000 to 1,000,000 1,000,000 to 5,000,000 > 5,000,000	4 4 + 0.6 per 100,000 population 7.5 + 0.25 per 100,000 population 12 + 0.16 per 100,000 population
Sulfur dioxide (SO_2)	< 100,000 100,000 to 1,000,000 1,000,000 to 10,000,000 > 10,000,000	3 2.5 + 0.5 per 100,000 population 6 + 0.15 per 100,000 population 20
Nitrogen dioxide (NO_2)	< 100,000 100,000 to 1,000,000 > 1,000,000	4 4 + 0.6 per 100,000 population 10
Carbon monoxide (CO) and Oxidants	< 100,000 100,000 to 5,000,000 > 5,000,000	1 1 + 0.15 per 100,000 population 6 + 0.05 per 100,000 population

Using the guidelines in **Table 3**, we estimated that India requires at least 4000 continuous monitoring stations – 2800 in the urban areas and 1200 in the rural areas, to truly represent the air quality trends (see external Supplementary Material). As of August 2020, there are 230 continuous air monitoring stations operational in 21 states. Most of the cities operate only one station, which is not ideal to represent spatial and temporal trends. In addition to the continuous stations, 750 manual stations are operational to collect 24-hour average pollution levels for at least 104 days in a year. Using the same guidelines, we estimated the number of sampling sites necessary for continuous ambient monitoring and to conduct an ideal source apportionment study in the proposed 94 airsheds.

Table 4: Number of continuous monitoring stations recommended for the tracking PM, SO2, NO2, and Others respectively and to conduct PM2.5 source apportionment studies in the select airsheds; B = cities included in the airshed from the NCAP list; C = cities included in the airshed and not on the NCAP list; D = airshed size in grids of equal size (0.01°)

	State	Airshed	Other NCAP cities (B)	Other non-NCAP cities (C)	Airshed size grids (D)	PM	SO_2	NO_2	Others
1	Andhra Pradesh	Anantapur			30 x 30	10	6	8	2
2		Chitoor		Vellore	30 x 50	14	9	10	4
3		Eluru		Hanuman Junction	30 x 30	11	7	9	3
4		Kadapa			30 x 30	10	6	9	3
5		Kurnool			30 x 30	11	7	9	3
6		Nellore			30 x 30	12	7	10	3
7		Ongole			30 x 30	9	6	8	2
8		Rajamundry			30 x 30	17	9	10	4
9		Srikakulam			30 x 30	11	7	9	3
10		Vijayawada	Guntur	Tenali	50 x 50	22	12	10	7
11		Vishakhapatnam			50 x 50	19	11	10	6
12		Vizianagaram			30 x 30	14	8	10	3
13	Assam	Guwahati	Byrnahati	Dispur	50 x 30	15	10	10	5
14		Nagaon			30 x 30	13	9	10	4
15		Nalbari			30 x 30	11	8	10	3
16		Sibsagar			30 x 30	10	6	8	2
17		Silchar			30 x 30	13	8	10	3
18	Bihar	Gaya			30 x 30	14	9	10	4
19		Muzaffarpur			30 x 30	19	11	10	6
20		Patna			60 x 30	25	15	10	9
21	Chandigarh	Chandigarh	Patiala, Dera Bassi, Khanna, Gobindgarh, Baddi, Nalagarh, Parwanoo	Ambala, Panchkula, Rupnagar, Kalka	90 x 90	29	18	10	10
22	Chhattisgarh	Korba			40 x 30	14	8	10	3
23		Raipur	Bhillai	Durg	60 x 30	22	12	10	7

	State	Airshed	Other NCAP cities (B)	Other non-NCAP cities (C)	Airshed size grids (D)	PM	SO_2	NO_2	Others
24	Delhi	Delhi	Noida, Ghaziabad	Greater Noida, Gurugram, Rohtak, Faridabad	80 x 80	78	20	10	21
25	Gujarat	Ahmedabad		Gandhi Nagar	50 x 50	33	20	10	11
26		Surat		Hazira	50 x 50	27	15	10	9
27		Vodadara			30 x 30	19	10	10	5
28	Himachal Pradesh	Kalaamb			30 x 30	9	6	8	2
29		Paonta Sahib			30 x 30	9	5	7	2
30		Sunder Nagar			20 x 20	9	5	7	2
31	Jammu & Kashmir	Jammu			30 x 30	18	10	10	5
32		Srinagar			30 x 30	19	10	10	5
33	Jharkhand	Dhanbad		Bokaro, Jaropokhar	60 x 30	26	11	10	6
34	Karnataka	Bengaluru			60 x 60	41	20	10	13
35		Devanagere			30 x 30	11	7	9	3
36		Gulburga			30 x 30	12	8	10	3
37		Hubli Dharwad			30 x 30	13	8	10	3
38	Madhya Pradesh	Bhopal			40 x 40	18	11	10	6
39		Dewas			30 x 30	11	7	9	3
40		Gwalior			30 x 30	14	9	10	4
41		Indore		Mhow, Pitampura	40 x 40	21	12	10	7
42		Sagar			30 x 30	9	6	8	2
43		Ujjain			30 x 30	11	7	9	3
44	Maharashtra	Akola			40 x 30	13	8	10	3
45		Amravati			30 x 30	12	8	10	3
46		Aurangabad			40 x 40	16	10	10	5
47		Chandrapur			40 x 30	13	8	10	3
48		Jalgaon		Bhusawal	40 x 30	13	8	10	3
49		Jalna			30 x 30	9	6	8	2
50		Kolhapur	Sangli		60 x 40	24	13	10	8
51		Latur			30 x 30	11	7	9	3
52		Mumbai	Navi Mumbai, Thane, Ulhas Nagar, Badlapur	Kalyan, Karjat	80 x 80	68	20	10	20
53		Nagpur			40 x 40	22	12	10	7
54		Nashik			40 x 40	18	11	10	6
55		Pune		Pimpri-Chinchwad, Hinjewadi	40 x 40	32	18	10	10
56		Solapur			30 x 30	13	8	10	3
57	Meghalaya	Dimapur			30 x 30	9	6	8	2
58		Kohima			30 x 30	7	4	6	2
59	Odisha	Angul	Talcher		40 x 40	15	7	10	3
60		Balasore			30 x 30	13	8	10	3
61		Bhubaneswar	Cuttack, Kalinga Nagar		30 x 50	22	12	10	7
62		Rourkela			40 x 30	13	8	10	3
63	Punjab	Amritsar		Tarn Taran	40 x 40	17	10	10	5
64		Jalandhar		Phagwara	50 x 30	17	10	10	5
65		Ludhiana		Philaur	40 x 40	20	11	10	6

	State	Airshed	Other NCAP cities (B)	Other non-NCAP cities (C)	Airshed size grids (D)	PM	SO_2	NO_2	Others
66		Naya Nangal		Una	30 x 30	9	6	8	2
67		Pathankot	Damtal		30 x 30	13	7	9	3
68	Rajasthan	Alwar			30 x 30	12	7	10	3
69		Jaipur			40 x 40	26	14	10	9
70		Jodhpur			30 x 30	16	9	10	4
71		Kota			30 x 30	14	9	10	4
72		Udaipur			30 x 30	14	8	10	3
73	Tamilnadu	Trichy			30 x 30	14	9	10	4
74		Tuticorin			30 x 30	12	7	9	3
75	Telangana	Hyderabad	Patancheru, Sangareddy		80 x 60	36	20	10	12
76		Nalgonda			30 x 30	9	5	7	2
77	Uttar Pradesh	Agra			40 x 40	22	13	10	8
78		Allahabad			40 x 30	19	11	10	6
79		Anpara		Singrauli	50 x 30	12	7	9	3
80		Bareily			30 x 30	17	10	10	5
81		Firozabad			30 x 30	13	9	10	4
82		Gajraula			30 x 30	12	8	10	3
83		Jhansi			40 x 30	13	8	10	3
84		Kanpur			40 x 30	27	15	10	9
85		Khurja		Bulandshahr	30 x 30	14	9	10	4
86		Lucknow		Barabanki	50 x 50	25	15	10	9
87		Moradabad		Rampur	40 x 30	17	10	10	5
88		Raebareli			30 x 30	13	8	10	3
89		Varanasi			40 x 40	24	13	10	8
90	Uttarakhand	Dehradun			40 x 20	13	8	10	3
91		Kashipur			30 x 20	14	7	9	3
92		Rishikesh		Haridwar	30 x 30	13	8	10	3
93	West Bengal	Asansol	Durgapur, Ranigunj		60 x 40	30	13	10	8
94		Kolkata	Barrackpore, Haldia, Howrah		80 x 80	70	20	10	20

For the 94 airsheds, a total of 1700 sampling sites are recommended to measure and analyse particulate matter. The proposed source apportionment studies (annex 1) are targeting only $PM_{2.5}$. In case of SO_2 and NO_2, the concentrations tend to be higher at the sources and quickly disperse and transform into secondary aerosols as the gases move through the region. In case of CO and other oxidants the variability in the concentrations is more uniform, resulting in the need for lesser number of monitoring stations.

For the 94 airsheds, a total of 925, 904, and 484 stations are recommended for SO_2, NO_2, and CO respectively.

The number of recommended sampling sites varies from seven for Kohima (in Meghalaya) and Damtal (in Himachal Pradesh) to 78 in Delhi, at an average of 18 per airshed. The Tier-1 cities on the NCAP list, Ahmedabad, Bengaluru, Delhi, Hyderabad, Kolkata, Mumbai, and Pune require at least 33, 41, 78, 36, 70, 68, and 32 sampling sites, respectively, which is 2-30 times their current operational monitoring capacity (3, 10, 38, 6, 11, 15, and 1 respectively).

The continuous monitoring station density in India is 0.14 per million persons, the lowest among the big countries - China (1.2), the USA (3.4), Japan (0.5), Brazil (1.8) and most European countries (2–3) (Brauer et al., 2019). The recommended number of stations for the 94 airsheds will bring this ratio up to 5.8 monitors per million persons.

4.0 Sampling Frequency

Preparation of an air quality management plan is a long-term process, which requires knowledge of spatial and temporal trends for the entire year, for multiple years. While continuous monitoring at ideal number of stations is required to know the trends in the pollution levels, to support policy development, physical samples must be collected at all the sampling sites every day, which will be subjected to chemical analysis and further scrutiny. However, like the number of sampling sites, this ideal requirement is also technically and financially prohibitive and the frequency of sampling for source apportionment studies is partly determined by availability of the sampling equipment and seasonality in weather and pollution levels. For example, continuous samplers used for regulatory compliance are operated every day, while others for source apportionment study can collect samples for only 15 days per month (or less) at every site.

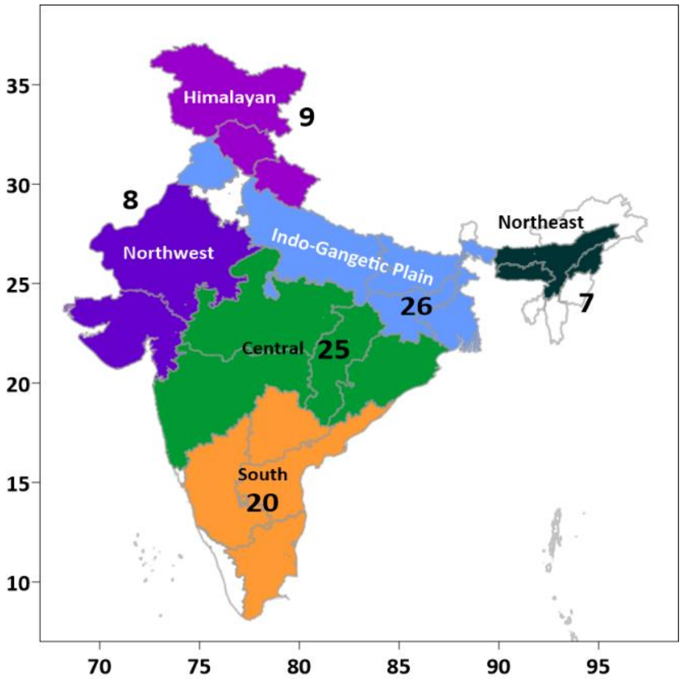


Figure 8: Grouping of NCAP states based on temperate and geographical conditions and number of airsheds in each group. The number indicates the number of designed airsheds (94) in each group

Meteorology plays a significant role in determining the seasons. The variation in weather and pollution levels is stronger in the Northern states as compared to the

Southern peninsular states, which allows for some compromise in the number of days of sampling. For ease, we grouped the airsheds into eight zones (**Table 5** & **Figure 8**) – six zones based on the states temperate conditions (South, Central, Northeast, Indo-Gangetic plain, Northwest, and Himalayan) and two zones based on the airsheds location (coastal and non-coastal). A summary of variations and averages by month for near surface (2m) temperature, near surface (10m) wind speed, precipitation, and mixing heights for 94 airsheds is included in the external Supplementary Material.

Table 5: Grouping of states and airsheds based on meteorological data and proposed minimum number of sampling days in a year to conduct source apportionment studies

Zone	Name	Airshed count	NCAP States or Airsheds	Proposed minimum no. of sampling days
Z1	South	20	States: Tamil Nadu, Telangana, Andhra Pradesh, and Karnataka	116
Z2	Central	25	States: Odisha, Chhattisgarh, Madhya Pradesh, and Maharashtra	115
Z3	Northeast	7	States: Assam, Meghalaya, and Nagaland	86
Z4	Indo-Gangetic Plain	26	States: West Bengal, Bihar, Jharkhand, Uttar Pradesh, Delhi, Chandigarh, and Punjab	122
Z5	Northwest	8	States: Gujarat, Rajasthan	123
Z6	Himalayan	9	States: Uttarakhand, Himachal Pradesh and Jammu & Kashmir	116
Z7	Coastal	10	Airsheds: Tuticorin, Nellore, Ongole, Vishakhapatnam, Vizianagaram, Srikakulam, Balasore, Kolkata, Surat, Mumbai	104
Z8	Non-coastal	84	The rest	118

Two parameters that can be used for optimizing the number of samples for source apportionment are precipitation rate and ventilation rate (mixing layer height * wind speed).

- Under wet conditions, most of the aerosols are entrained in the rain. Typically, June to September are the wet months (precipitation greater than 100 mm/month) and these months require fewer samples to catch the trend.
- Higher ventilation rate (greater than 4000 m^2/sec) means either the wind speeds are high allowing for long-range transport of pollutants, or the mixing height is high allowing for more vertical mixing. In both the cases, the probability of regional contribution and consequently secondary pollution is high, which requires more frequent sampling to catch the trends.
- Lower ventilation rates, which is a proxy for stagnant conditions can mean need for lesser number of samples.

The Supplementary database also includes monthly variation in average near surface temperature, but not used in assessing the need for sampling frequency because temperature is an integral parameter which determines mixing height. It is important to note that the compromise on more sampling during less rainy and higher ventilation periods and less sampling during more rainy and lower ventilation periods, is primarily driven by the fact that the process of source apportionment is technically and financially burdensome and this is one way to reduce it.

The total number of proposed sampling days varies from 86 for the Northeast states (Z3) to 122 for the Indo-Gangetic Plain (IGP) states (Z4) and 123 for Northwest states (Z5).

- Least number of the sampling days for the Northeast is mainly because this region receives more than 100 mm of rain for six months and the least variation in the ventilation rates (under 1500 m^2/sec).
- Most number of sampling days for IGP is an indicator of strong seasonality in the region and the need to carry out more sampling to better represent the trends.
- South India (Z1) is on average hotter than the rest of the country and receives more scattered rains in the second half of the year.
- While the number of sampling days for South and Central India (Z2) are the same, we estimate the need for more sampling in the first half of the year in Z2.
- In general, coastal regions (Z7) have better ventilation rate due to consistent land-sea breeze and more precipitation compared to the inland cities (Z8), thus needing 14 less sampling days. This is an advantage that coastal cities use to reduce their overall pollution load. For example, while the estimated emission load in Chennai and Delhi are similar, the overall $PM_{2.5}$ pollution level in Chennai is half or less of that observed in Delhi (Guttikunda and Calori, 2013; Guttikunda et al., 2014).

The estimated minimum number of sampling days per month by zone and airshed is representative of the meteorological conditions observed in 2018. We did not estimate the same for other years. However, assuming consistent conditions, this number will be applicable for future applications. The estimates in **Table 5** can be used as a guideline for distributing the monthly sampling load, depending on the meteorological conditions. However, if the goal is to analyse a particular source, then more sampling is warranted in that area and for that period. For example, the influence of regional emission sources on urban air quality. This is important for IGP and Northwest, both with strong seasonal sources such as post-harvest agricultural residue fires in October and dust storms in April-May.

5.0 Supporting Activities

The list of planned and proposed studies in **Annex 1** is the largest coalition of studies to understand the source contributions. For several cities, these studies are being conducted for the first time. The only shortcoming of this program is the lack of room to update the information as often as possible, and that is primarily due to technical and financial reasons. Currently, all the studies are designed as a one-time exercise, conducted by a regional academic and research institution, with no provision to repeat and update the air quality changes, say in 3 years and forward. In addition to establishing protocols for conducting receptor-based sampling studies, a national institutional framework is necessary to continue supporting these efforts.

The regulatory framework of the national ambient monitoring programme has limited capacity to represent spatial air quality trends in India. As of May 2020, of the 232 regulatory monitors, 38 are in Delhi and another 30 in Delhi's satellite cities, making it the most represented city and the most studied city in India. Similar networks are necessary in all the cities and across rural India, not only to study the compliance levels, but also to study the regional and meteorological influences on urban air quality. Cost of setting up and operating such a network is high, which can be complemented with the use of well calibrated low-cost sensors at high density (Zheng et al., 2018; Brauer et al., 2019; Robinson et al., 2019).

Since the need for instrumentation, personnel, and finances is higher in the case of receptor modelling studies, the missing gaps can be filled with emission-based studies, which can be conducted at more regular intervals (such as monthly) at lower financial burden. For this to be successful, the emission inventories need regular updates at the city, airshed, and national level and requires an open and constant flow of information from several sources. For example:

(a) in case of road transport emissions, information is required on vehicle sales by type and fuel; vehicle usage characteristics; fuel efficiency characteristics; road network and traffic management; and emission factors for a mix of vehicles to represent the fleet averages. Since, there are significant differences between how vehicles are managed and operated between cities, there is need for as delineated information as possible

(b) in case of heavy industrial emissions, information on real-time emission rates at the operational stacks is missing. While these measurements are conducted as required by the environmental regulations, the information is not open for neither establishing a baseline emissions inventory nor updating the existing ones.

(c) in case of domestic cooking and heating, information on the consumption of various fuels need updates at the sub-district level, as the number of LPG connections are rapidly expanding across the country. While the individual sectors are providing information in various forms, there is a need for an institutional anchor to collate information immediate relevant for air emissions analysis (UEinfo, 2020).

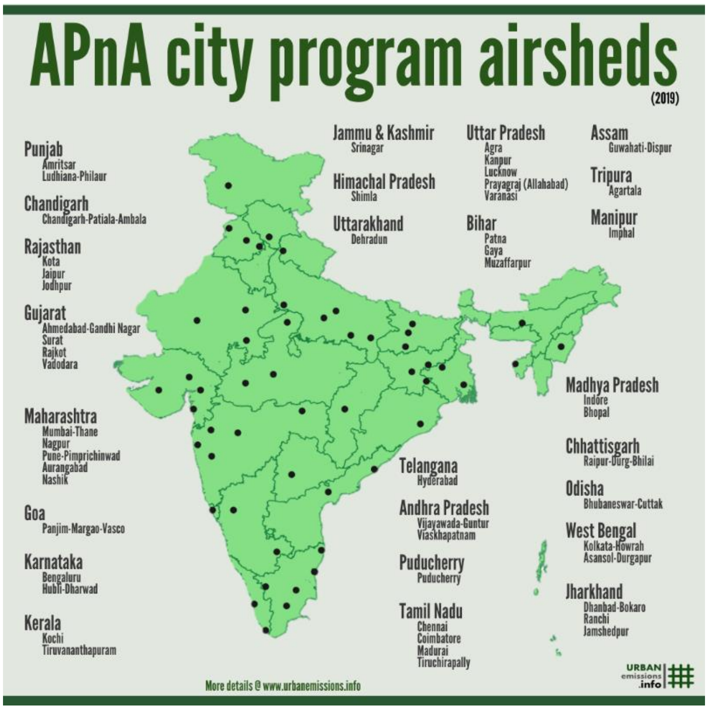


Figure 9: Air Pollution knowledge Assessment (APnA) city program. A summary of the program is included in Annex 3

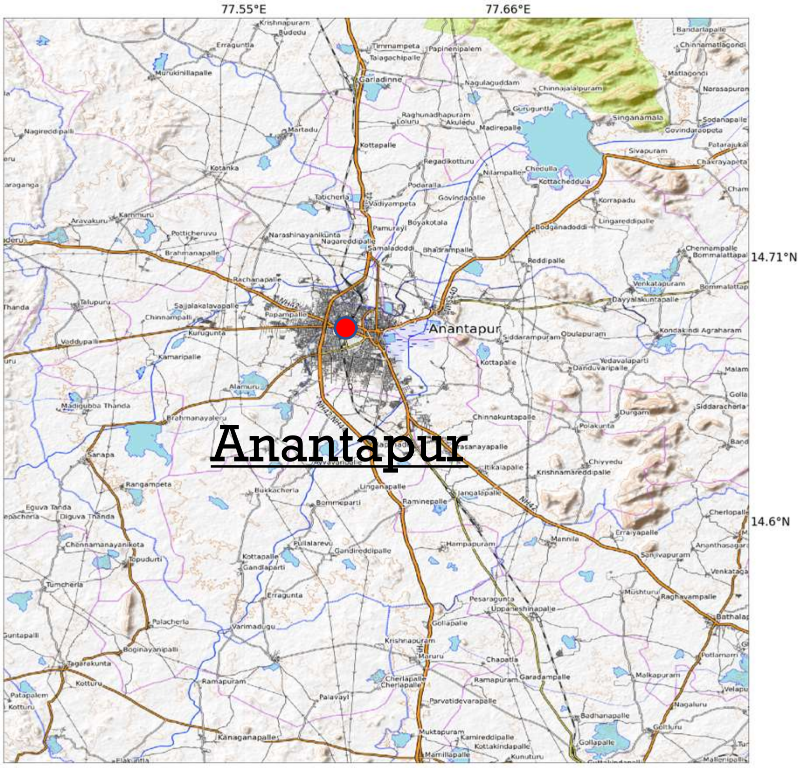
The *air information cell* at CPCB and the *national knowledge network* of academic institutions, both under NCAP are expected to fill this gap.

94 airsheds with information on the grid size, cities included in the airshed (154, including 122 NCAP cities), population statistics, and recommended number of monitoring stations for PM, SO_2, NO_2, and Others

List is arranged in the alphabetical order of the state name

National Clean Air Programme (NCAP) of India

Airshed: Anantapur (AP)



NCAP cities (1)

Non NCAP cities (0)

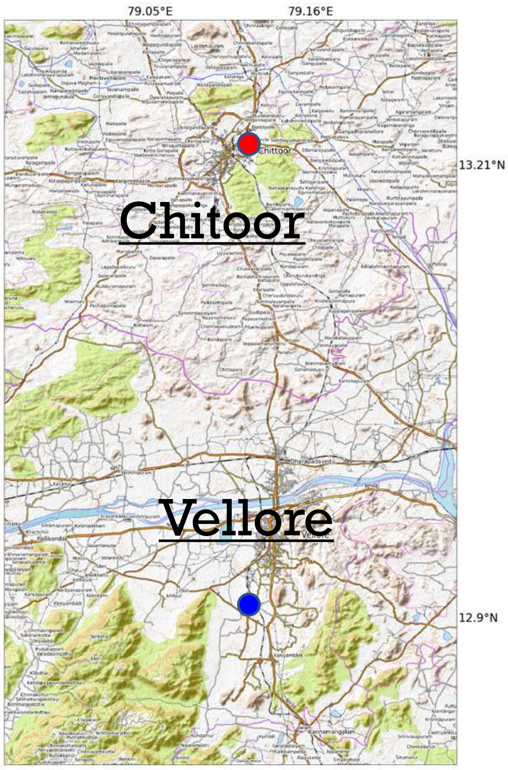
Airshed size	Total population
30x30 ~1-km grids	**0.4** million
Urban pop share	**Urban area share**
60%	**8%**
Maximum pop density	**Average pop density**
22200 persons/km²	**3300** persons/km²

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
9	**5**
Nitrogen Dioxide	**Carbon Monoxide**
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Chitoor (AP)



NCAP cities (1)

Non NCAP cities (1)

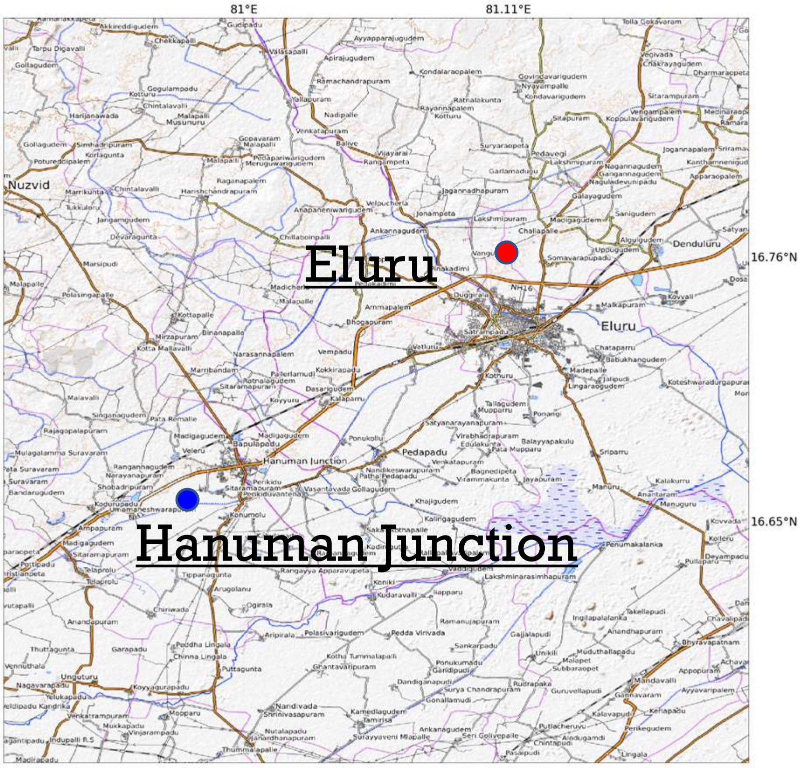
Airshed size **30x50** ~1-km grids	Total population **1.1** million
Urban pop share **62%**	Urban area share **13%**
Maximum pop density **37400** persons/km^2	Average pop density **3200** persons/km^2

Minimum air monitors needed

Particulate matter **14**	Sulphur Dioxide **8**
Nitrogen Dioxide **10**	Carbon Monoxide **3**

National Clean Air Programme (NCAP) of India

Airshed: Eluru (AP)



NCAP cities (1)

Non NCAP cities (1)

Airshed size	Total population
30x30 ~1-km grids	**0.6** million

Urban pop share	Urban area share
48%	**9%**

Maximum pop density	Average pop density
11800 persons/km^2	**2900** persons/km^2

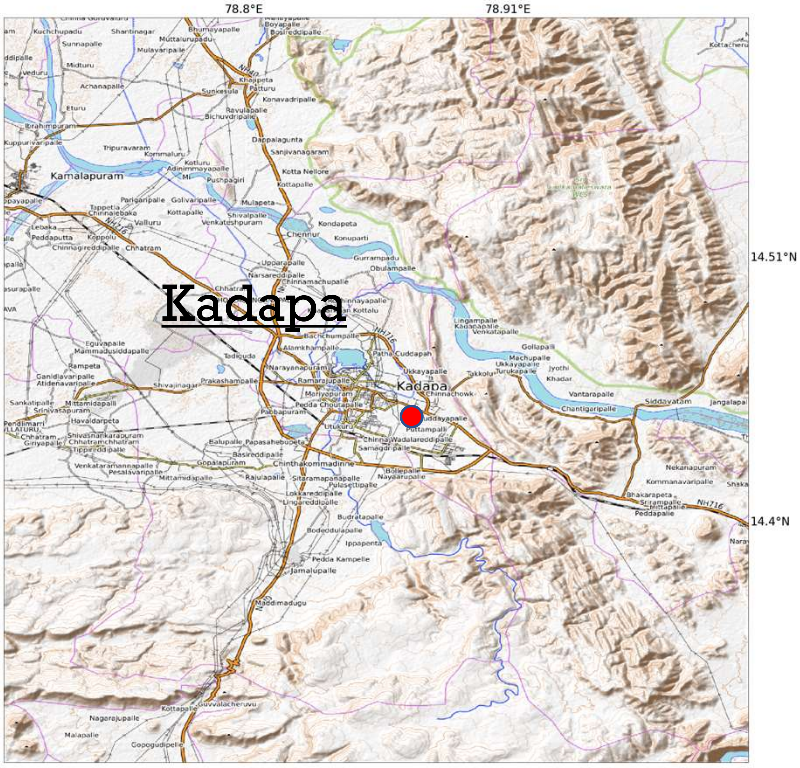
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Kadapa (AP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30	**0.5**
~1-km grids	million

Urban pop share	Urban area share
71%	**9%**

Maximum pop density	Average pop density
17300	**3500**
persons/km^2	persons/km^2

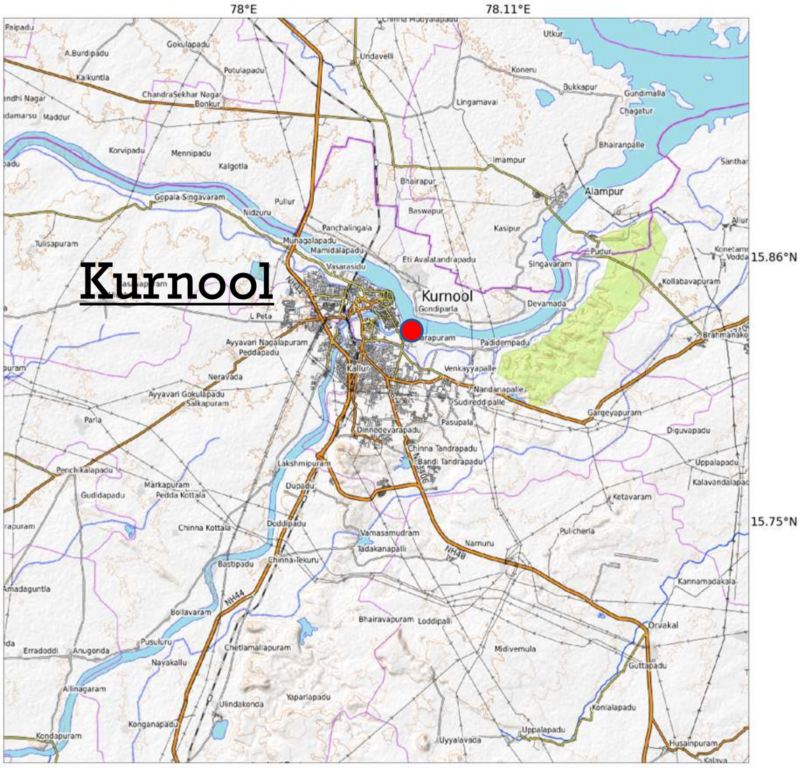
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**5**

Nitrogen Dioxide	Carbon Monoxide
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Kurnool (AP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.6** million

Urban pop share	Urban area share
62%	**9%**

Maximum pop density	Average pop density
22500 persons/km^2	**4000** persons/km^2

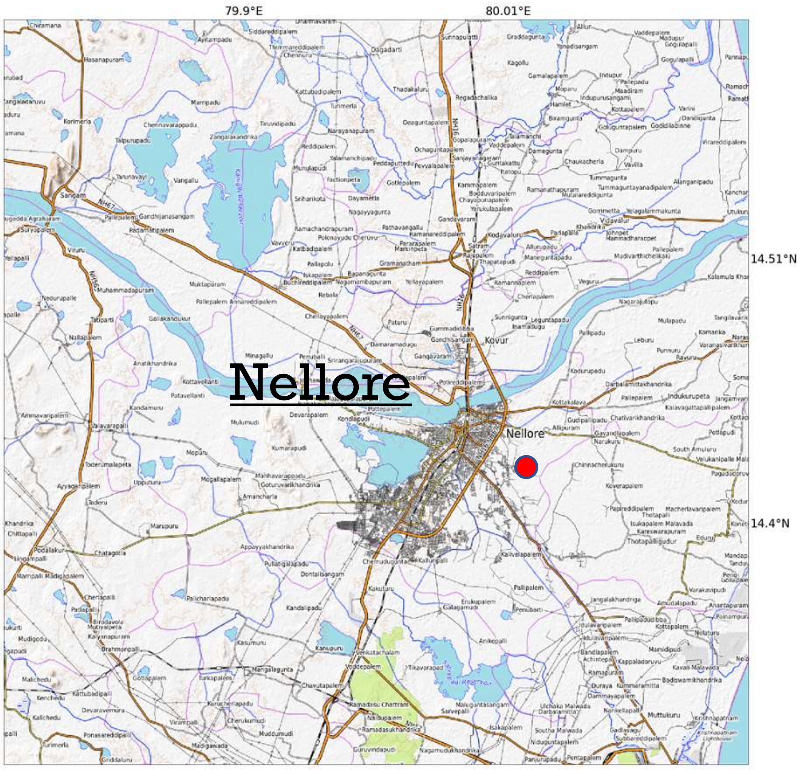
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Nellore (AP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.7** million

Urban pop share	Urban area share
63%	**8%**

Maximum pop density	Average pop density
19700 persons/km^2	**6100** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
13	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India
Airshed: Ongole (AP)

NCAP cities (1)
Non NCAP cities (0)

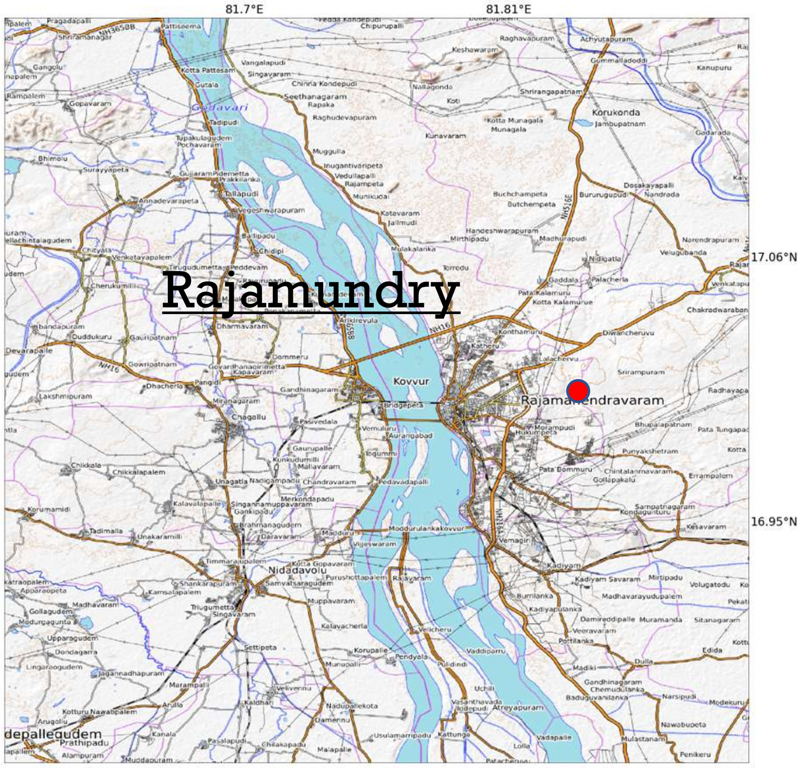
Airshed size **30x30** ~1-km grids	Total population **0.4** million
Urban pop share **58%**	Urban area share **6%**
Maximum pop density **24300** persons/km²	Average pop density **3900** persons/km²

Minimum air monitors needed

Particulate matter **10**	Sulphur Dioxide **5**
Nitrogen Dioxide **7**	Carbon Monoxide **2**

National Clean Air Programme (NCAP) of India

Airshed: Rajamundry (AP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
1.2
million

Urban pop share
82%

Urban area share
43%

Maximum pop density
42700
persons/km^2

Average pop density
2200
persons/km^2

Minimum air monitors needed

Particulate matter
14

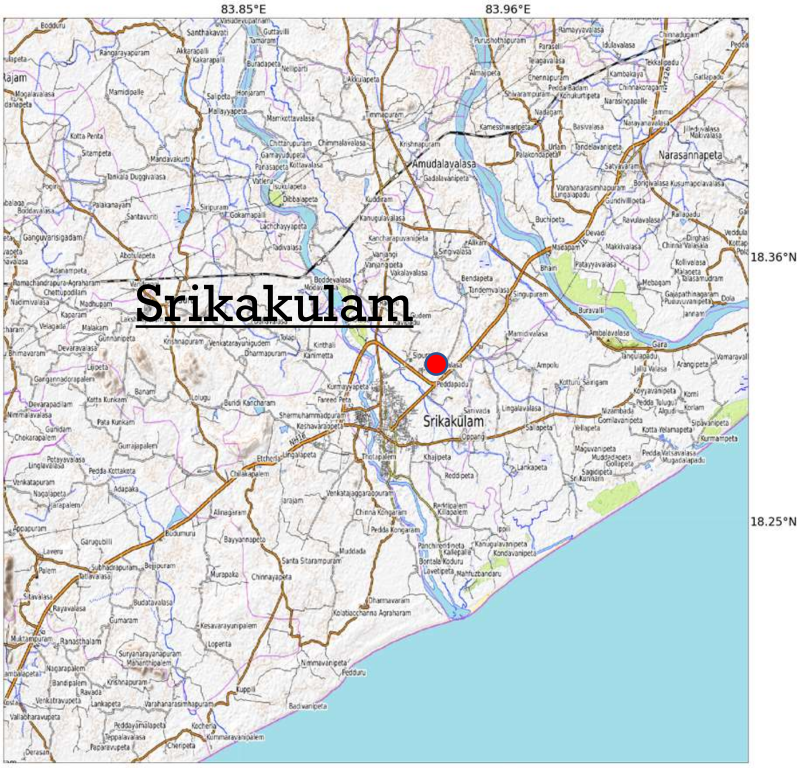
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Srikakulam (AP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.6** million

Urban pop share	Urban area share
35%	**6%**

Maximum pop density	Average pop density
17200 persons/km^2	**3400** persons/km^2

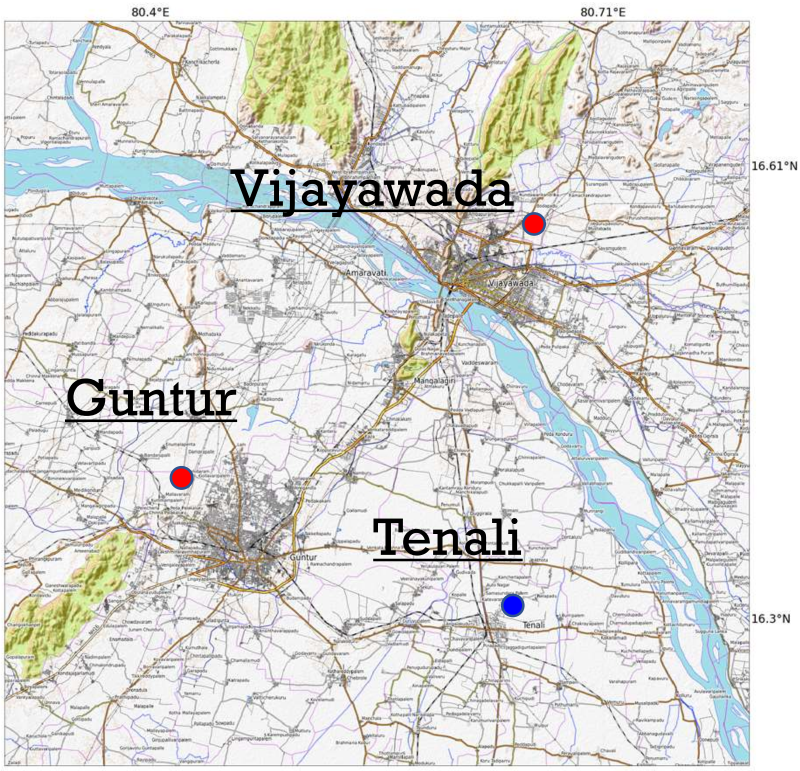
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Vijayawada (AP)



NCAP cities (2)

Non NCAP cities (1)

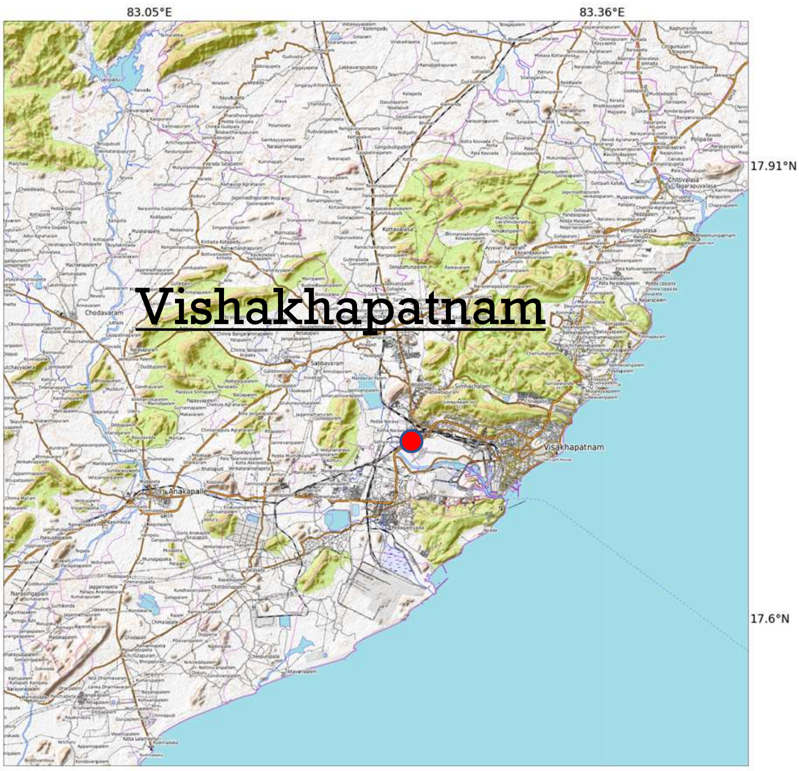
Airshed size **50x50** ~1-km grids	Total population **2.6** million
Urban pop share **72%**	Urban area share **17%**
Maximum pop density **45100** persons/km²	Average pop density **4100** persons/km²

Minimum air monitors needed

Particulate matter **20**	Sulphur Dioxide **10**
Nitrogen Dioxide **10**	Carbon Monoxide **5**

National Clean Air Programme (NCAP) of India

Airshed: Vishakhapatnam (AP)



Airshed size
50x50
~1-km grids

Total population
2.2
million

Urban pop share
69%

Urban area share
12%

Maximum pop density
55500
persons/km^2

Average pop density
4700
persons/km^2

Minimum air monitors needed

Particulate matter
19

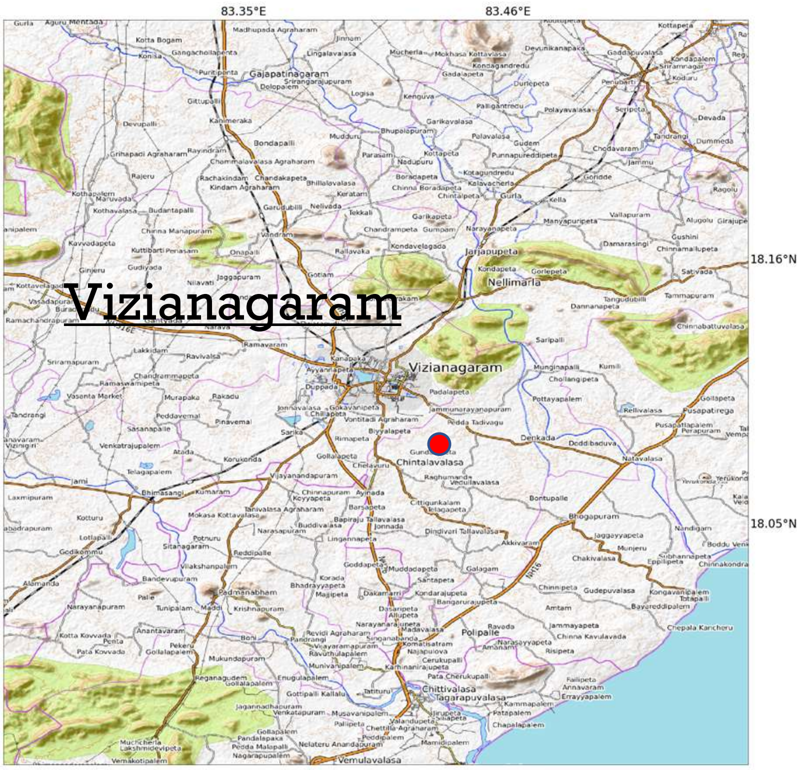
Sulphur Dioxide
10

Nitrogen Dioxide
10

Carbon Monoxide
5

National Clean Air Programme (NCAP) of India

Airshed: Vizianagaram (AP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.8
million

Urban pop share
54%

Urban area share
16%

Maximum pop density
26600
persons/km^2

Average pop density
2700
persons/km^2

Minimum air monitors needed

Particulate matter
11

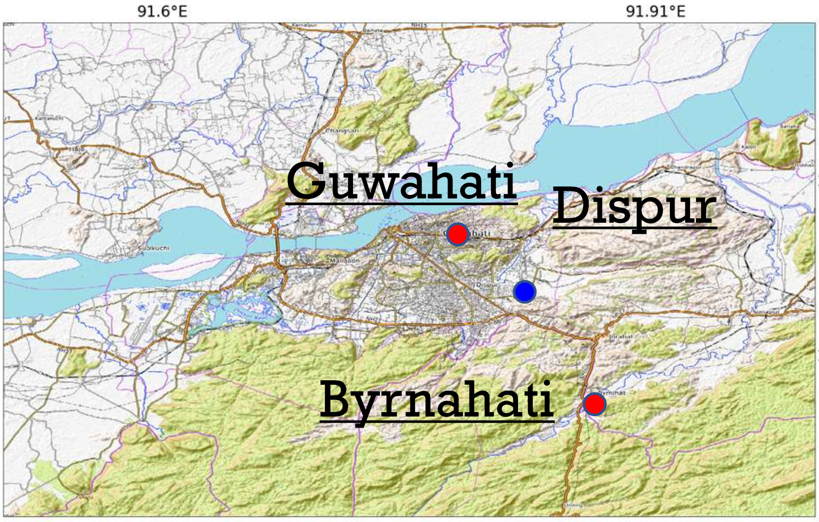
Sulphur Dioxide
7

Nitrogen Dioxide
9

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Guwahati (AS)



NCAP cities (2)
Non NCAP cities (1)

Airshed size	Total population
50x30 ~1-km grids	**1.7** million

Urban pop share	Urban area share
51%	**5%**

Maximum pop density	Average pop density
40600 persons/km^2	**10500** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
21	**9**

Nitrogen Dioxide	Carbon Monoxide
10	**4**

National Clean Air Programme (NCAP) of India

Airshed: Nagaon (AS)

NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
1.2
million

Urban pop share
10%

Urban area share
1%

Maximum pop density
19900
persons/km²

Average pop density
9000
persons/km²

Minimum air monitors needed

Particulate matter
18

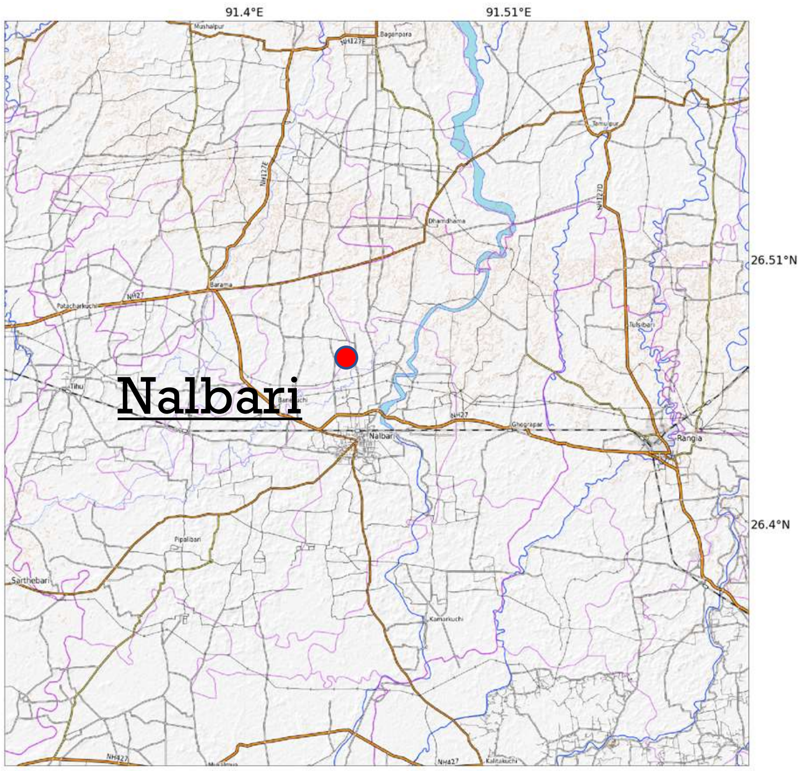
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Nalbari (AS)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30	**1**
~1-km grids	million

Urban pop share	Urban area share
0%	**0%**

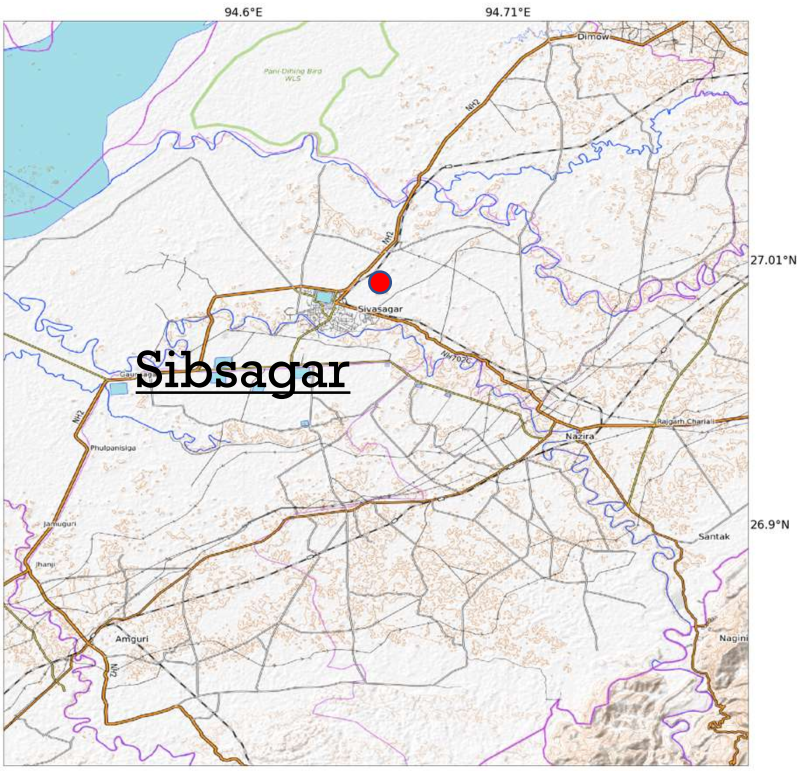
Maximum pop density	Average pop density
15100	**0**
persons/km^2	persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India
Airshed: Sibsagar (AS)



NCAP cities (1)
Non NCAP cities (0)

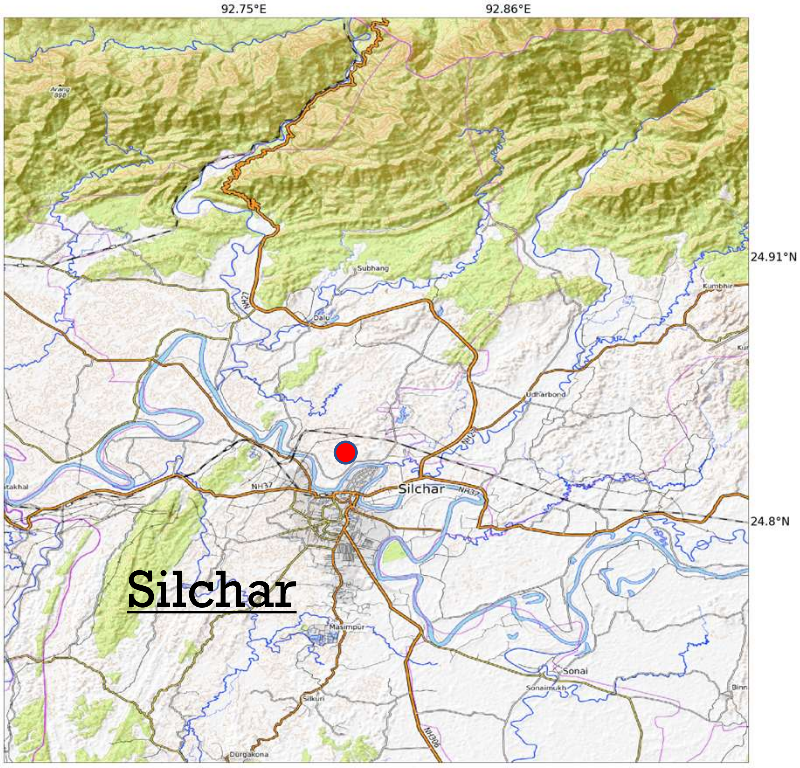
Airshed size	Total population
30x30 ~1-km grids	**0.5** million
Urban pop share **4%**	Urban area share **0%**
Maximum pop density **10800** persons/km^2	Average pop density **4400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**5**
Nitrogen Dioxide	**Carbon Monoxide**
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Silchar (AS)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
1
million

Urban pop share
17%

Urban area share
2%

Maximum pop density
17400
persons/km²

Average pop density
7700
persons/km²

Minimum air monitors needed

Particulate matter
16

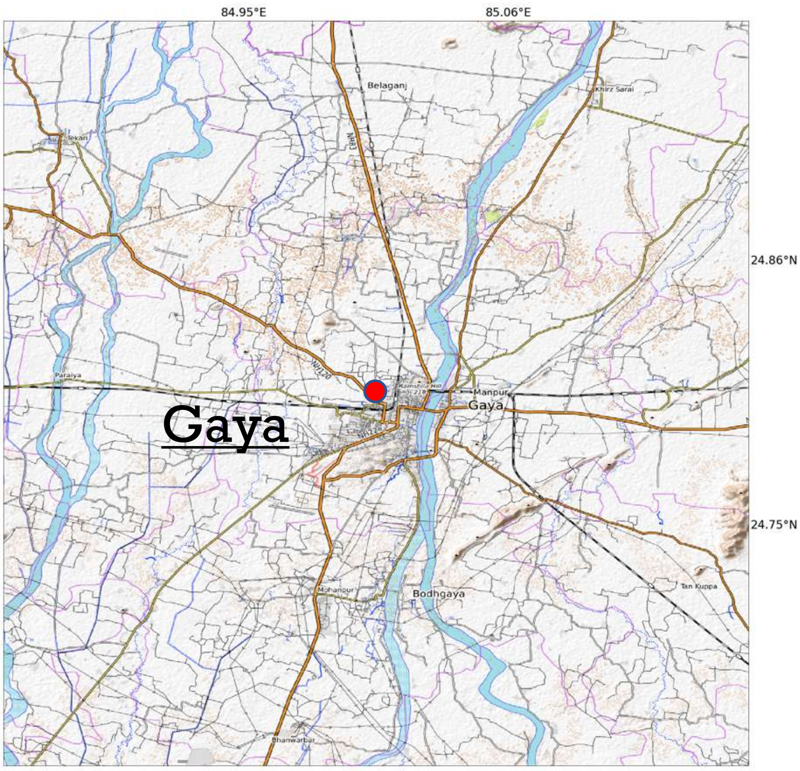
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Gaya (BR)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.2** million

Urban pop share	Urban area share
36%	**7%**

Maximum pop density	Average pop density
27000 persons/km^2	**5800** persons/km^2

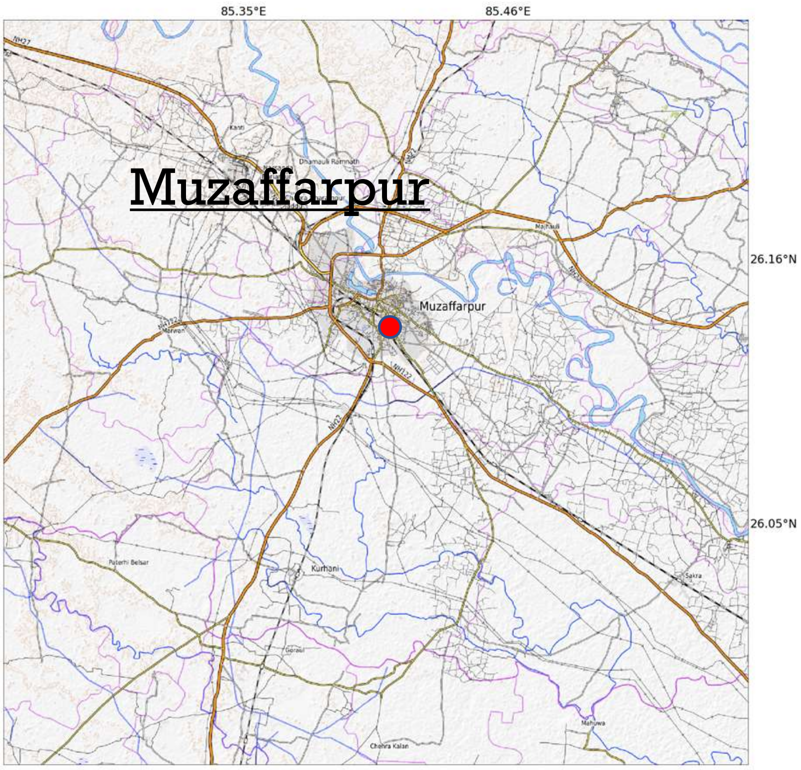
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
16	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Muzaffarpur (BR)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**2** million

Urban pop share	Urban area share
14%	**3%**

Maximum pop density	Average pop density
38900 persons/km^2	**9000** persons/km^2

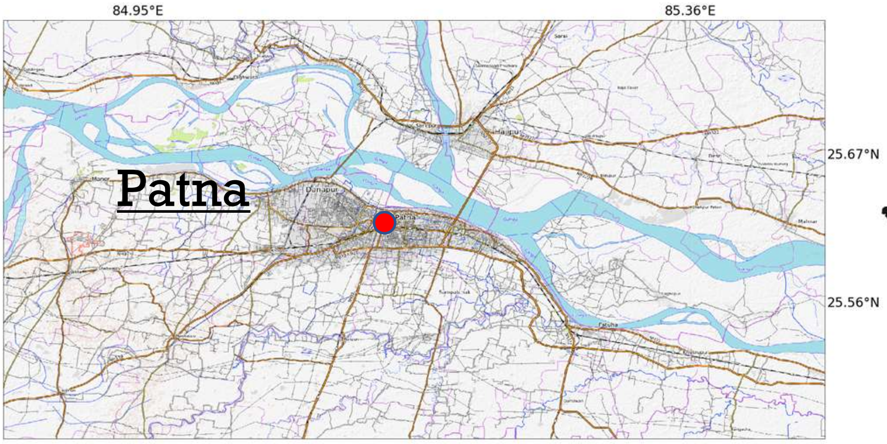
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
21	**10**

Nitrogen Dioxide	Carbon Monoxide
10	**5**

National Clean Air Programme (NCAP) of India

Airshed: Patna (BR)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
60x30 ~1-km grids	**4.4** million
Urban pop share	**Urban area share**
51%	**7%**
Maximum pop density	**Average pop density**
46000 persons/km^2	**16400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
39	**13**
Nitrogen Dioxide	**Carbon Monoxide**
10	**8**

National Clean Air Programme (NCAP) of India
Airshed: Korba (CG)

NCAP cities (1)
Non NCAP cities (0)

Airshed size
40x30
~1-km grids

Total population
1
million

Urban pop share
63%

Urban area share
18%

Maximum pop density
45300
persons/km^2

Average pop density
2500
persons/km^2

Minimum air monitors needed

Particulate matter
13

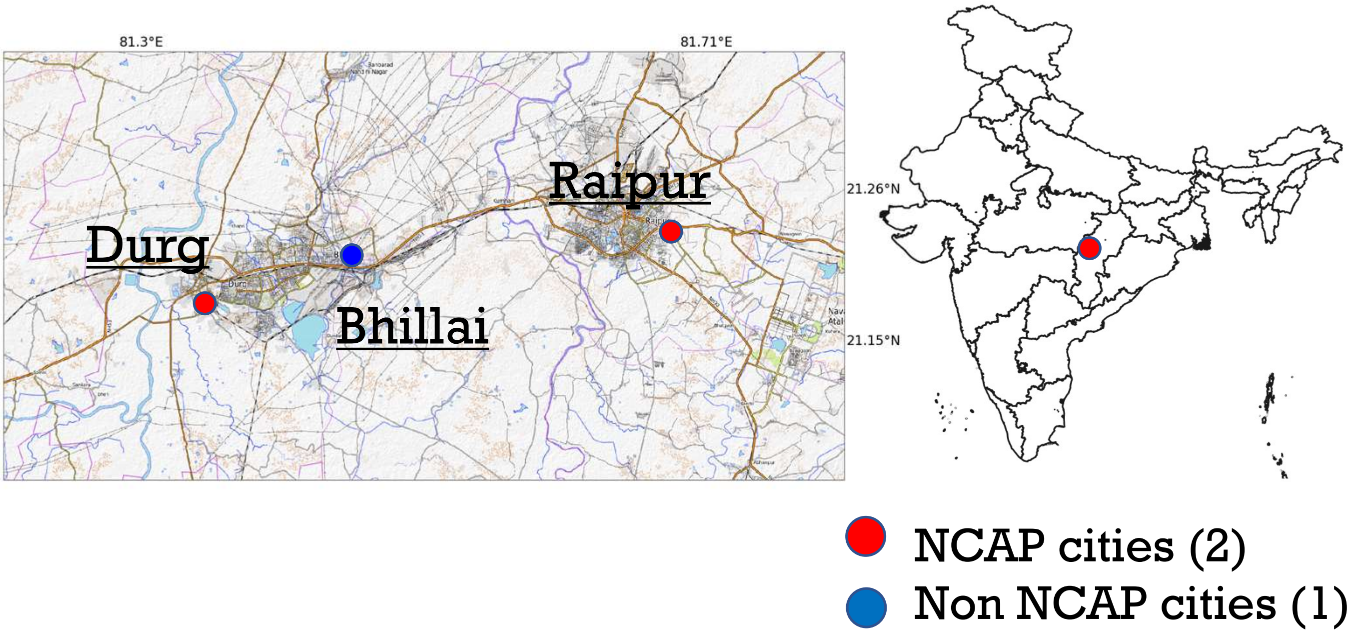
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Raipur (CG)



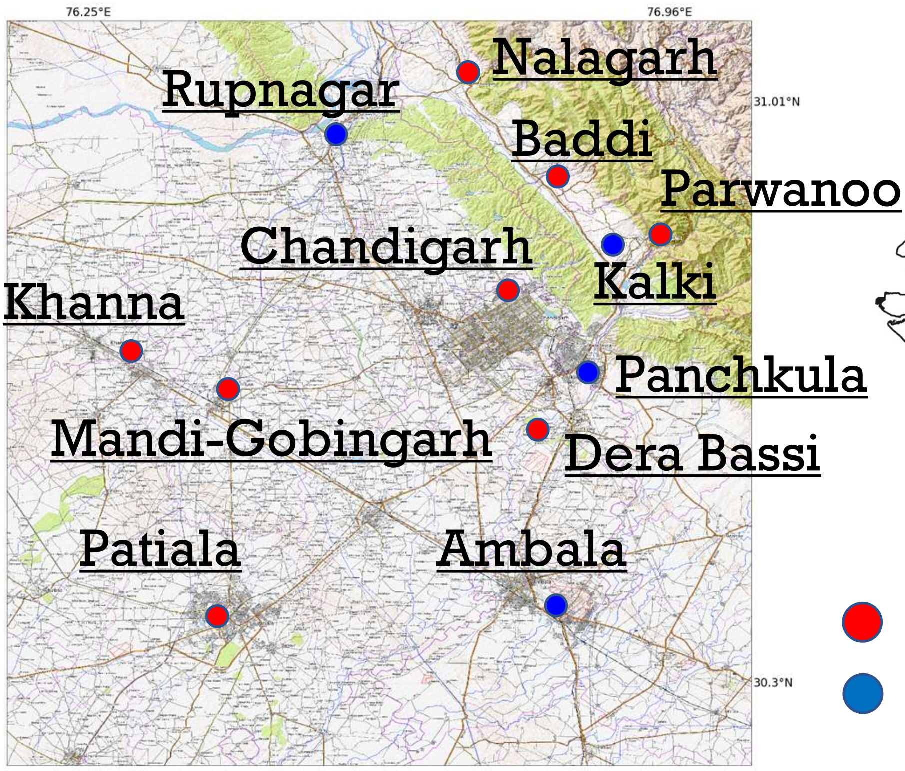
Airshed size	Total population
60x30 ~1-km grids	**2.6** million
Urban pop share **81%**	Urban area share **26%**
Maximum pop density **27300** persons/km^2	Average pop density **4000** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
18	**10**
Nitrogen Dioxide	**Carbon Monoxide**
10	**5**

National Clean Air Programme (NCAP) of India

Airshed: Chandigarh (CH)



NCAP cities (8)

Non NCAP cities (4)

Airshed size
90x90
~1-km grids

Total population
5.7
million

Urban pop share
48%

Urban area share
7%

Maximum pop density
42300
persons/km²

Average pop density
4000
persons/km²

Minimum air monitors needed

Particulate matter
28

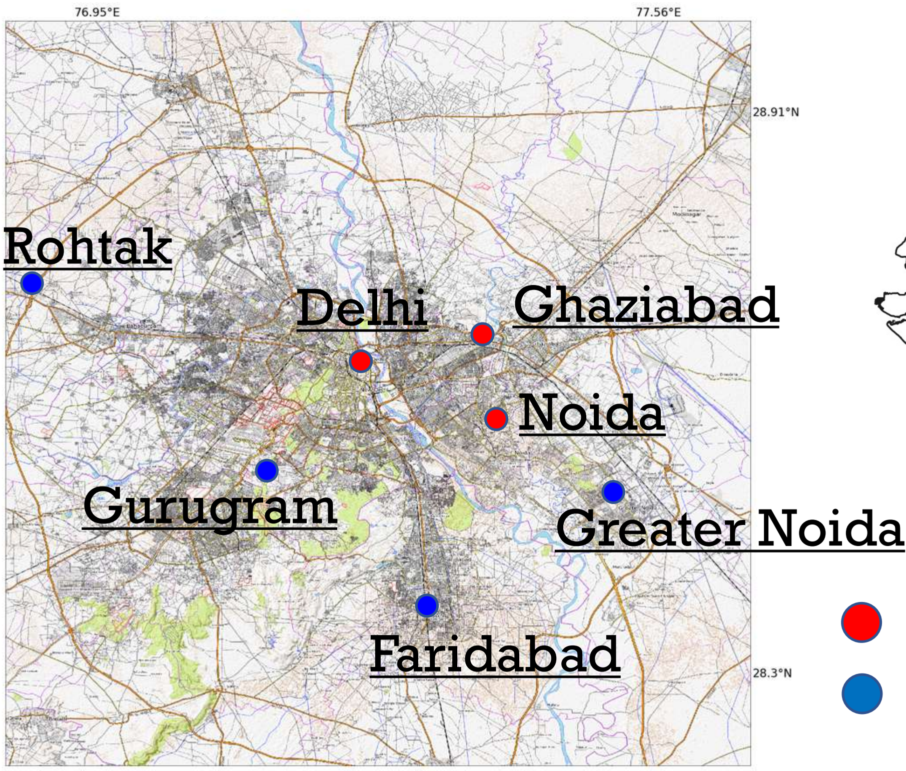
Sulphur Dioxide
15

Nitrogen Dioxide
10

Carbon Monoxide
9

National Clean Air Programme (NCAP) of India

Airshed: Delhi (DL)



NCAP cities (3)

Non NCAP cities (4)

Airshed size
80x80
~1-km grids

Total population
21.5
million

Urban pop share
79%

Urban area share
26%

Maximum pop density
69300
persons/km^2

Average pop density
9300
persons/km^2

Minimum air monitors needed

Particulate matter
75

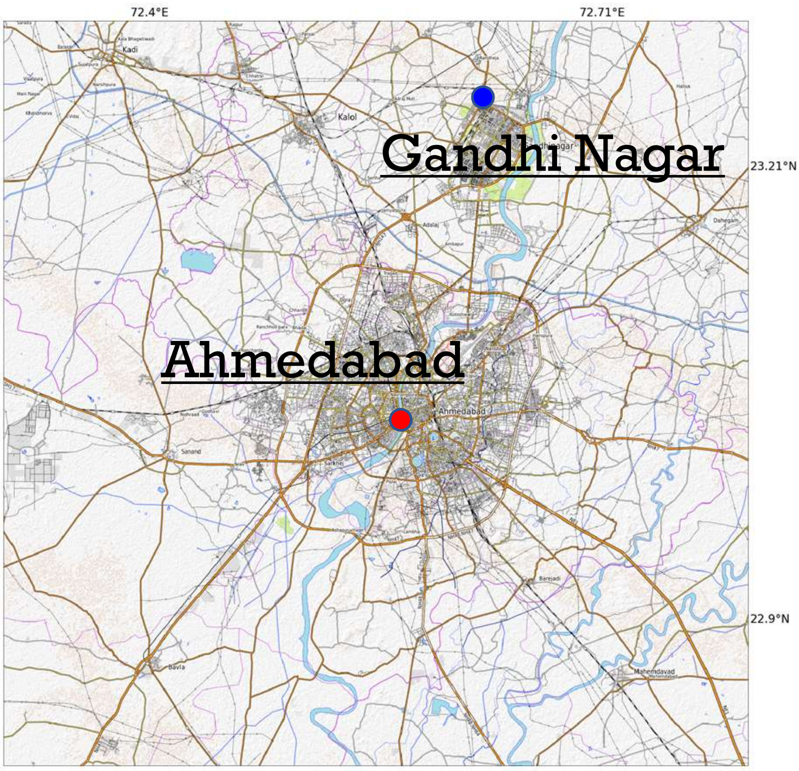
Sulphur Dioxide
20

Nitrogen Dioxide
10

Carbon Monoxide
17

National Clean Air Programme (NCAP) of India

Airshed: Ahmedabad (GJ)



NCAP cities (1)

Non NCAP cities (1)

Airshed size	Total population
50x50 ~1-km grids	**6.6** million

Urban pop share	Urban area share
73%	**15%**

Maximum pop density	Average pop density
62800 persons/km^2	**11200** persons/km^2

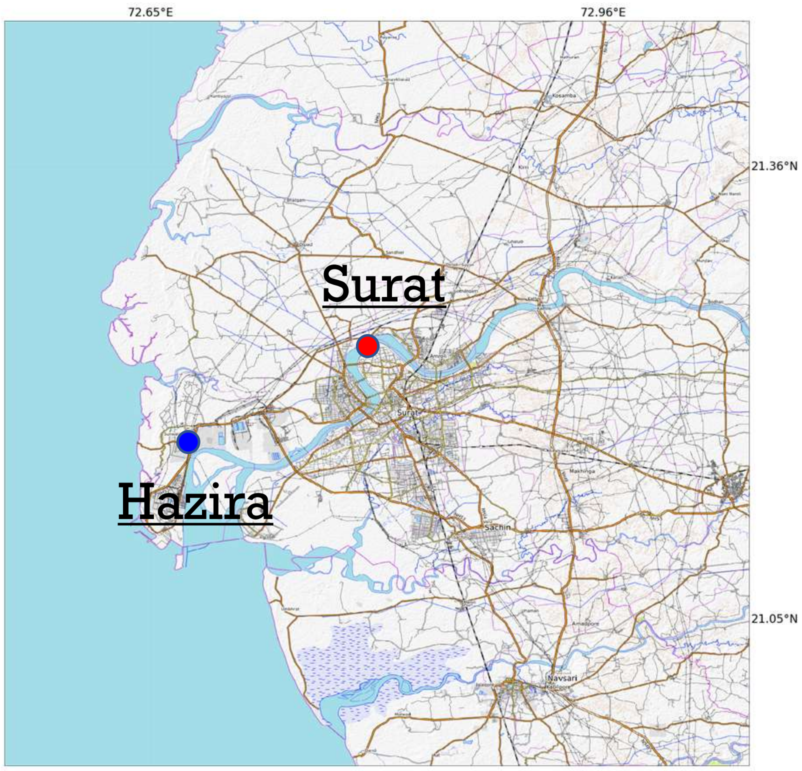
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
40	**16**

Nitrogen Dioxide	Carbon Monoxide
10	**10**

National Clean Air Programme (NCAP) of India

Airshed: Surat (GJ)



NCAP cities (1)
Non NCAP cities (1)

Airshed size
50x50
~1-km grids

Total population
4.3
million

Urban pop share
70%

Urban area share
18%

Maximum pop density
50800
persons/km^2

Average pop density
6100
persons/km^2

Minimum air monitors needed

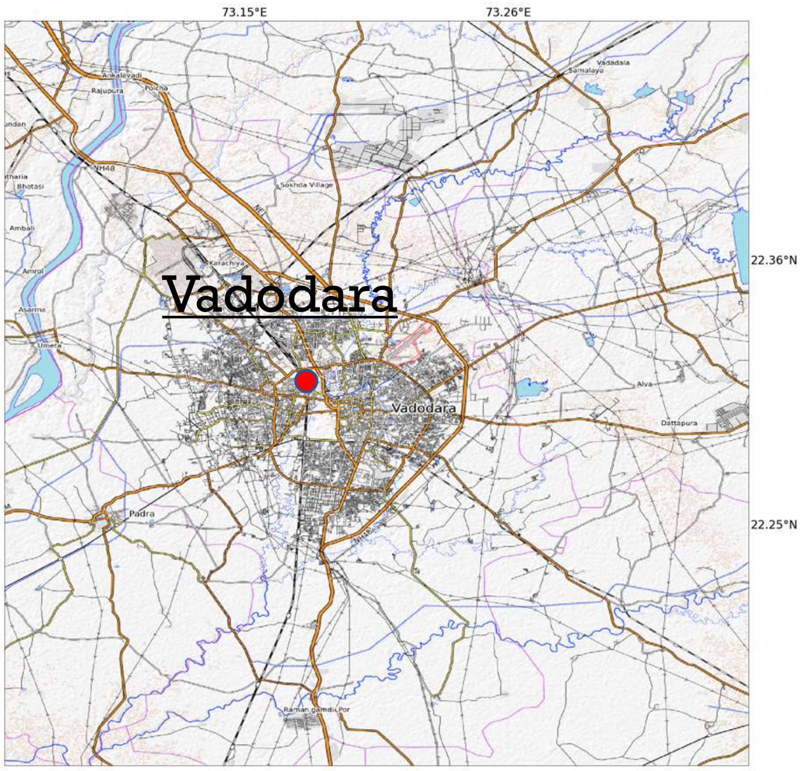
Particulate matter
27

Sulphur Dioxide
13

Nitrogen Dioxide
10

Carbon Monoxide
8

National Clean Air Programme (NCAP) of India
Airshed: Vadodara (GJ)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
2
million

Urban pop share
85%

Urban area share
24%

Maximum pop density
26500
persons/km^2

Average pop density
7200
persons/km^2

Minimum air monitors needed

Particulate matter
20

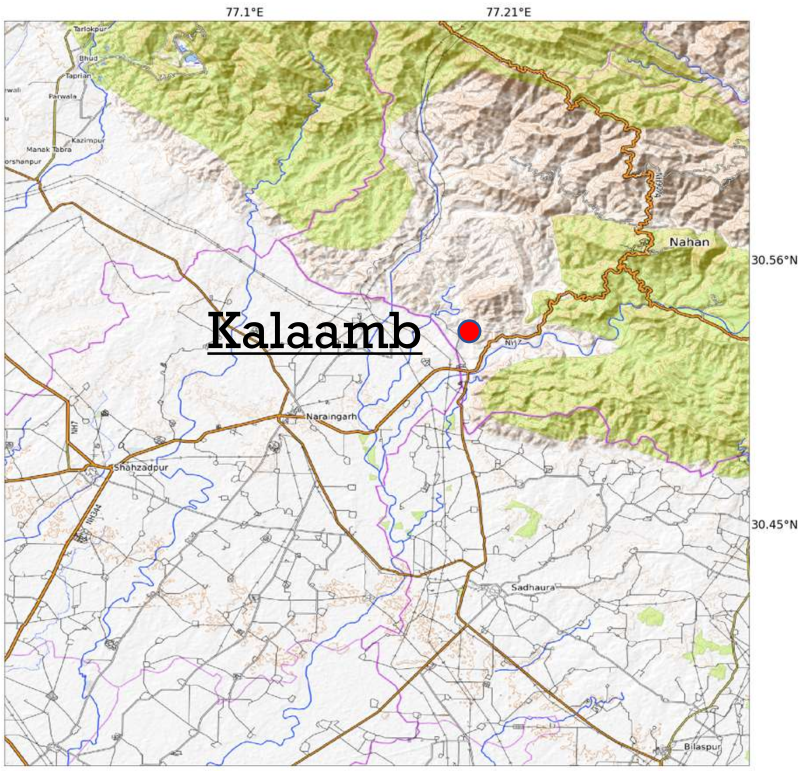
Sulphur Dioxide
10

Nitrogen Dioxide
10

Carbon Monoxide
5

National Clean Air Programme (NCAP) of India

Airshed: Kalaamb (HP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.4** million

Urban pop share	Urban area share
18%	**3%**

Maximum pop density	Average pop density
39600 persons/km^2	**2400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
9	**5**

Nitrogen Dioxide	Carbon Monoxide
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Paonta Sahib (HP)

NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30	**0.3**
~1-km grids	million

Urban pop share	Urban area share
38%	**11%**

Maximum pop density	Average pop density
24400	**800**
persons/km^2	persons/km^2

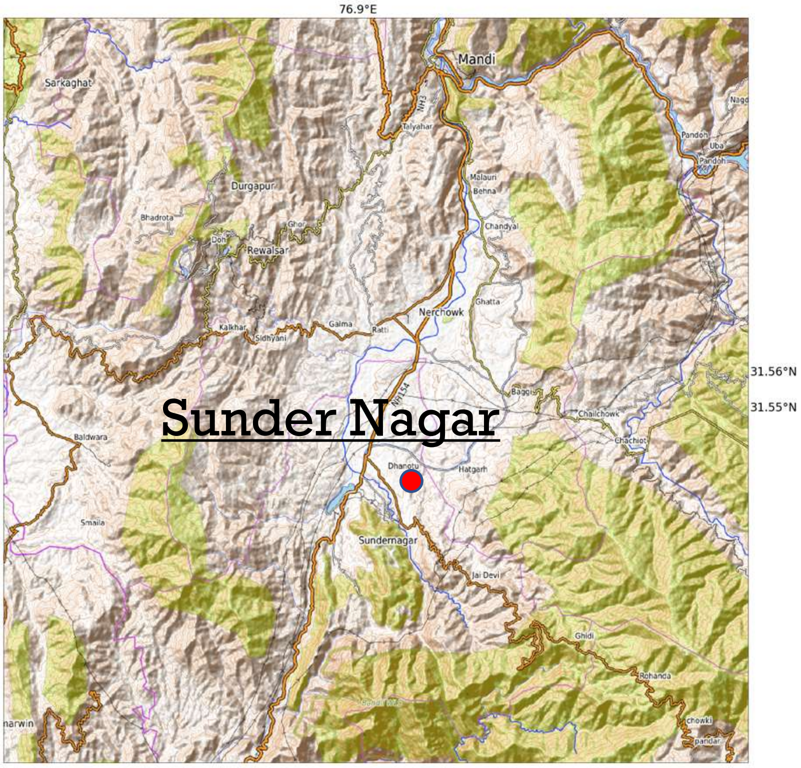
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
7	**4**

Nitrogen Dioxide	Carbon Monoxide
6	**2**

National Clean Air Programme (NCAP) of India

Airshed: Sunder Nagar (HP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
20x20	**0.2**
~1-km grids	million

Urban pop share	Urban area share
23%	**5%**

Maximum pop density	Average pop density
18900	**2300**
persons/km^2	persons/km^2

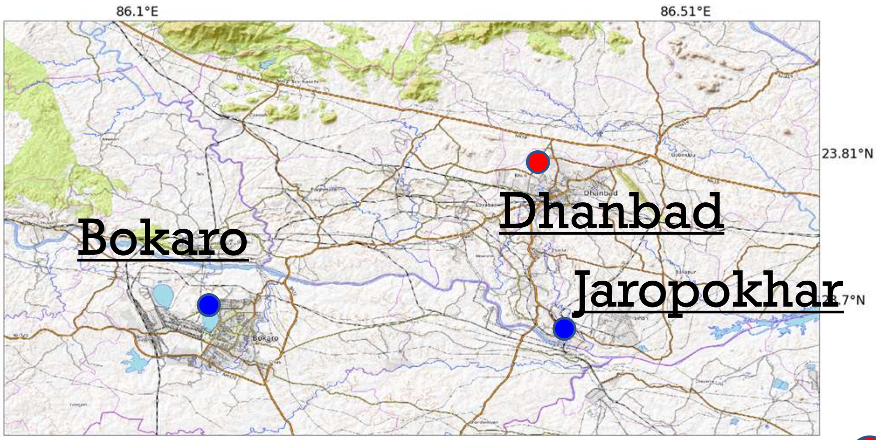
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
8	**4**

Nitrogen Dioxide	Carbon Monoxide
6	**2**

National Clean Air Programme (NCAP) of India

Airshed: Dhanbad (JH)



NCAP cities (1)

Non NCAP cities (2)

Airshed size	Total population
60x30	**2.3**
~1-km grids	million

Urban pop share	Urban area share
65%	**39%**

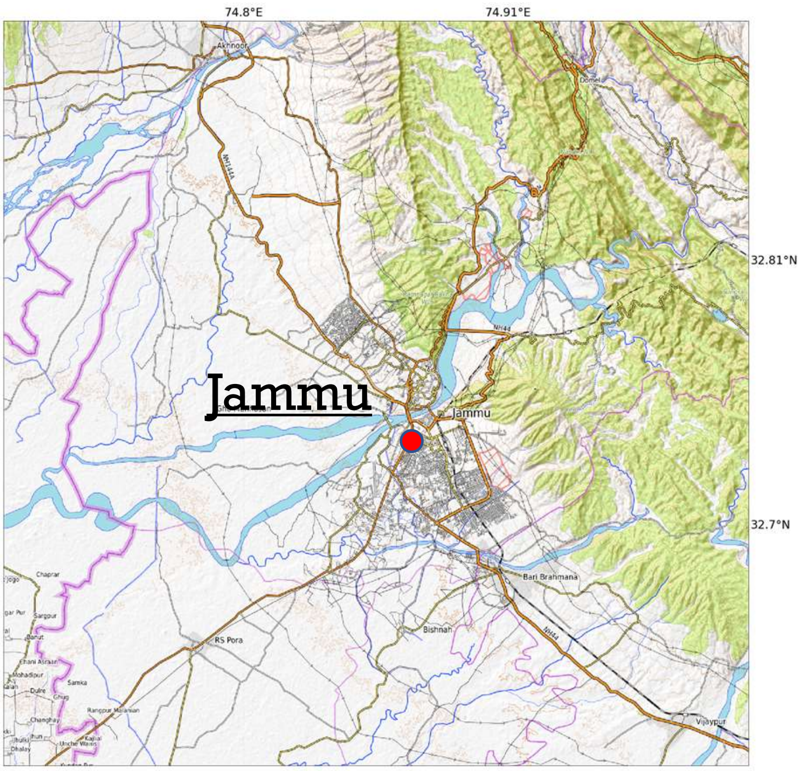
Maximum pop density	Average pop density
32700	**1900**
persons/km^2	persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
17	**10**

Nitrogen Dioxide	Carbon Monoxide
10	**5**

National Clean Air Programme (NCAP) of India
Airshed: Jammu (JK)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
1.4
million

Urban pop share
48%

Urban area share
18%

Maximum pop density
21800
persons/km^2

Average pop density
4000
persons/km^2

Minimum air monitors needed

Particulate matter
16

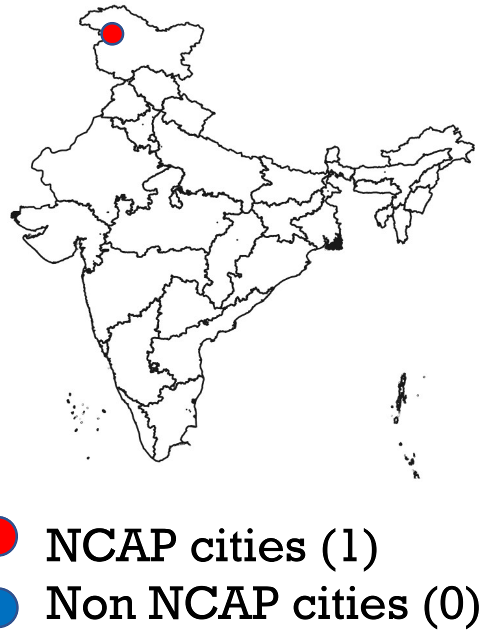
Sulphur Dioxide
9

Nitrogen Dioxide
10

Carbon Monoxide
4

National Clean Air Programme (NCAP) of India

Airshed: Srinagar (JK)



Airshed size
30x30
~1-km grids

Total population
1.7
million

Urban pop share
63%

Urban area share
22%

Maximum pop density
32300
persons/km^2

Average pop density
4600
persons/km^2

Minimum air monitors needed

Particulate matter
16

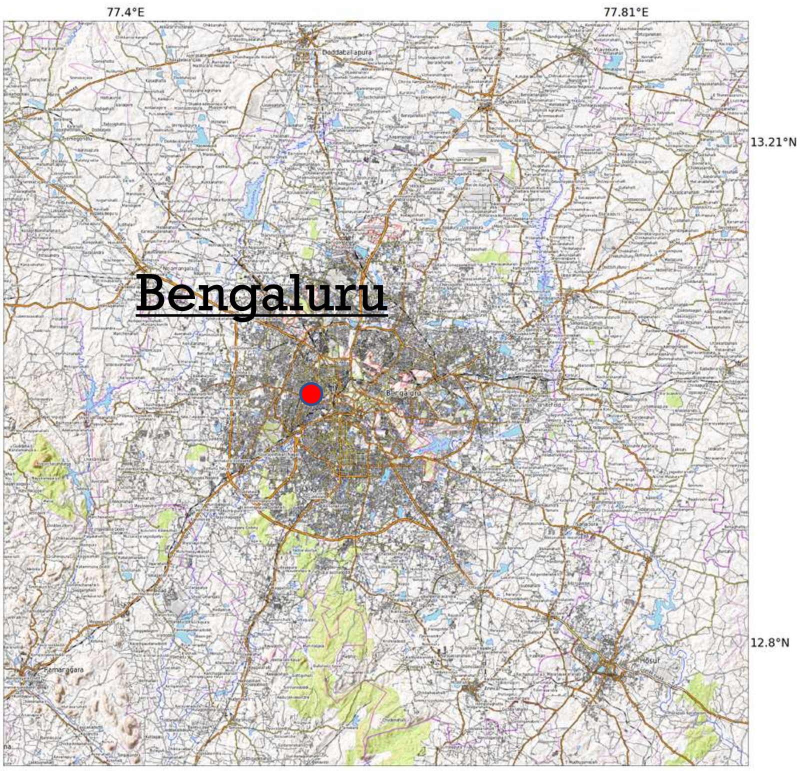
Sulphur Dioxide
9

Nitrogen Dioxide
10

Carbon Monoxide
4

National Clean Air Programme (NCAP) of India

Airshed: Bengaluru (KA)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
60x60
~1-km grids

Total population
9.2
million

Urban pop share
78%

Urban area share
19%

Maximum pop density
73900
persons/km²

Average pop density
9300
persons/km²

Minimum air monitors needed

Particulate matter
43

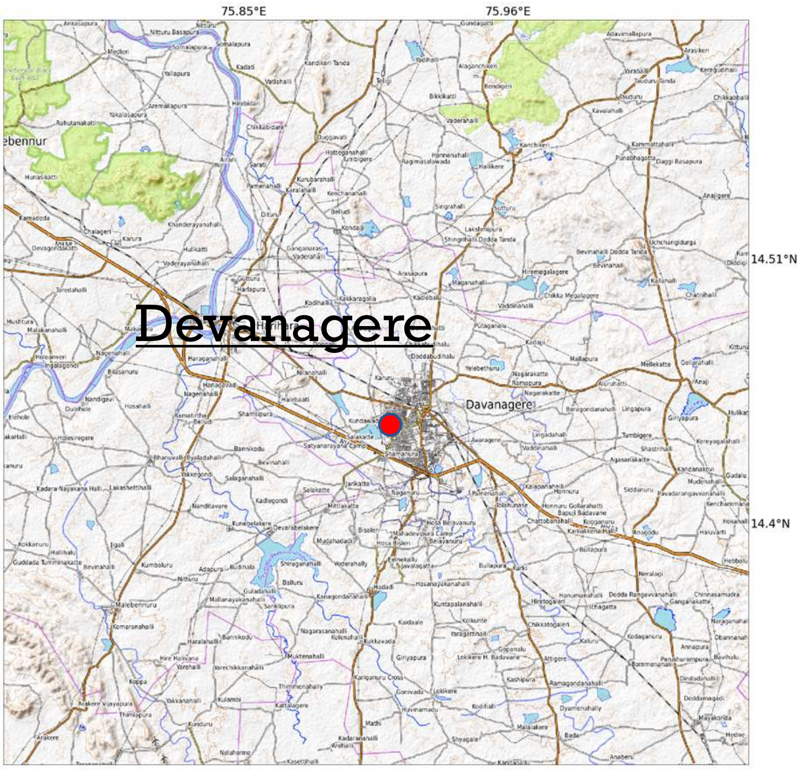
Sulphur Dioxide
20

Nitrogen Dioxide
10

Carbon Monoxide
11

National Clean Air Programme (NCAP) of India

Airshed: Devanagere (KA)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.7** million

Urban pop share	Urban area share
58%	**6%**

Maximum pop density	Average pop density
32700 persons/km^2	**6900** persons/km^2

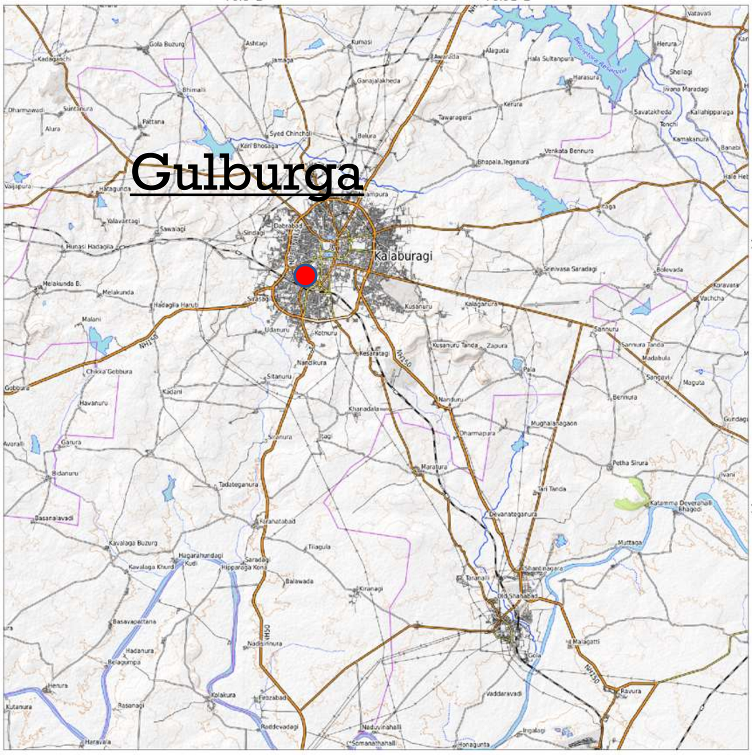
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
14	**6**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Gulburga (KA)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30	**0.7**
~1-km grids	million

Urban pop share	Urban area share
67%	**8%**

Maximum pop density	Average pop density
24100	**6000**
persons/km^2	persons/km^2

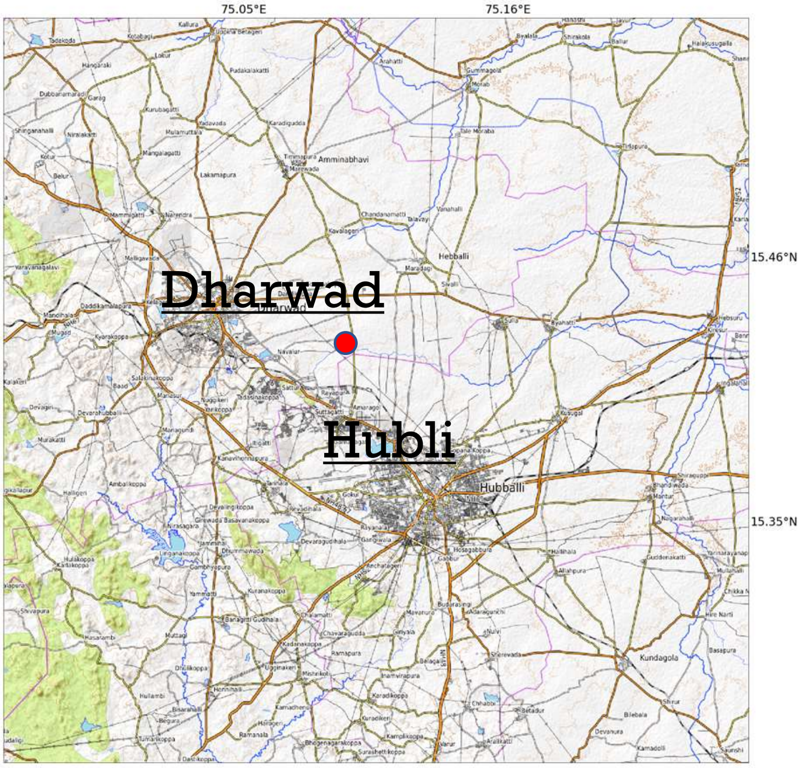
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
13	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Hubli Dharwad (KA)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
1.1
million

Urban pop share
76%

Urban area share
10%

Maximum pop density
39000
persons/km^2

Average pop density
8100
persons/km^2

Minimum air monitors needed

Particulate matter
17

Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Akola (MH)

NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
40x30	**0.8**
~1-km grids	million

Urban pop share	Urban area share
60%	**9%**

Maximum pop density	Average pop density
20700	**3800**
persons/km^2	persons/km^2

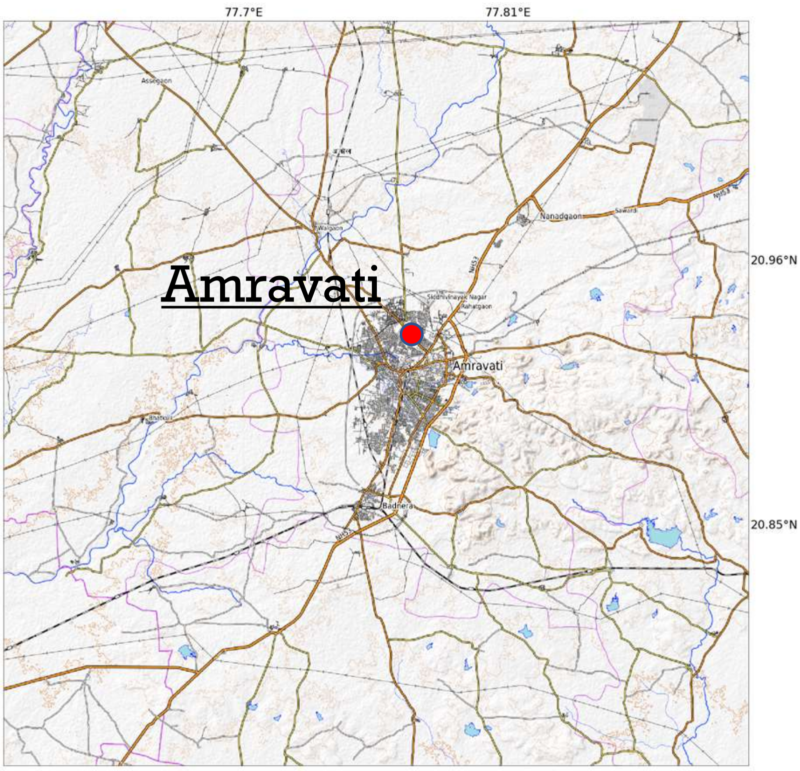
Minimum air monitors needed

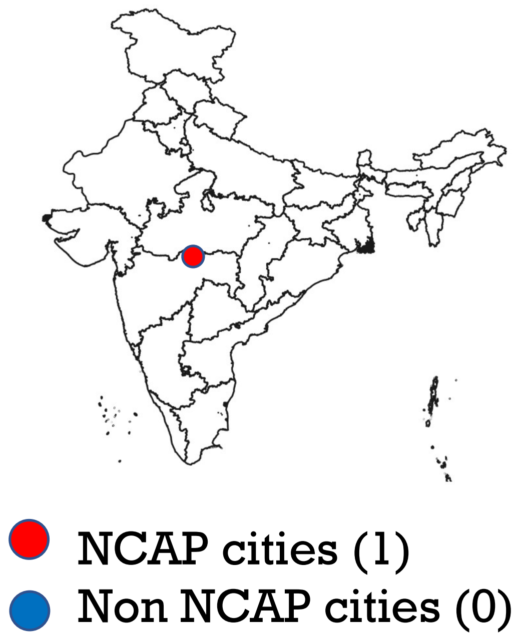
Particulate matter	Sulphur Dioxide
12	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Amravati (MH)





Airshed size	Total population
30x30 ~1-km grids	**0.8** million

Urban pop share	Urban area share
70%	**10%**

Maximum pop density	Average pop density
20600 persons/km^2	**5700** persons/km^2

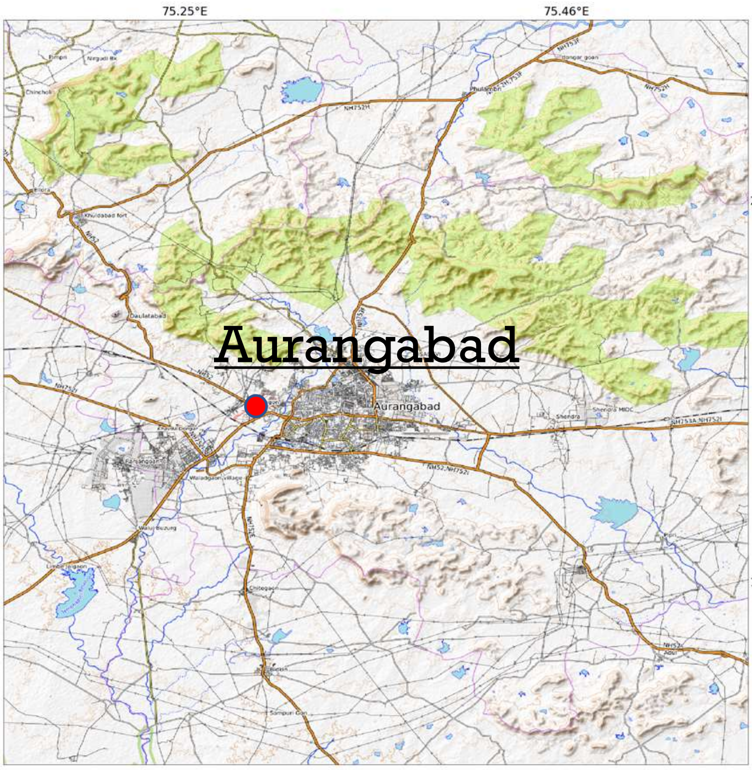
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
13	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Aurangabad (MH)



NCAP cities (1)

Non NCAP cities (0)

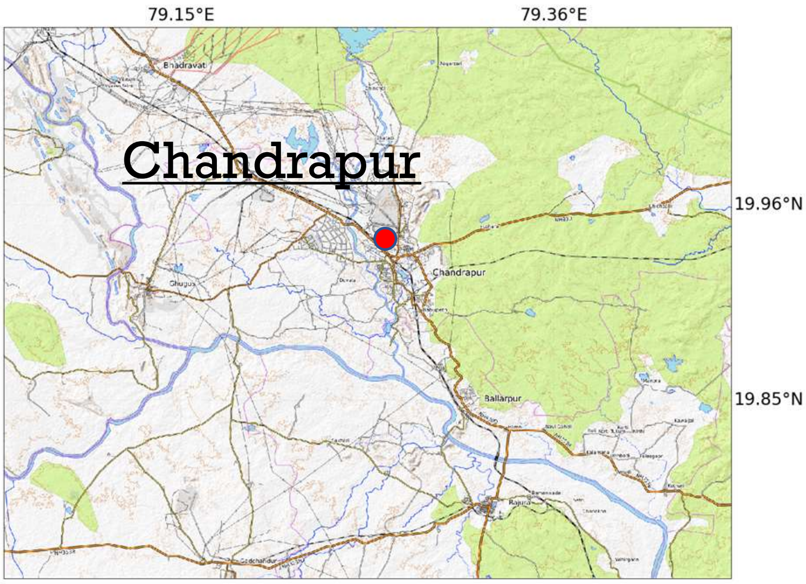
Airshed size	Total population
40x40 ~1-km grids	**1.6** million
Urban pop share 68%	**Urban area share** 10%
Maximum pop density **40900** persons/km^2	Average pop density **5900** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
17	**9**
Nitrogen Dioxide	**Carbon Monoxide**
10	**4**

National Clean Air Programme (NCAP) of India

Airshed: Chandrapur (MH)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
40x30 ~1-km grids	**0.8** million

Urban pop share	Urban area share
62%	**14%**

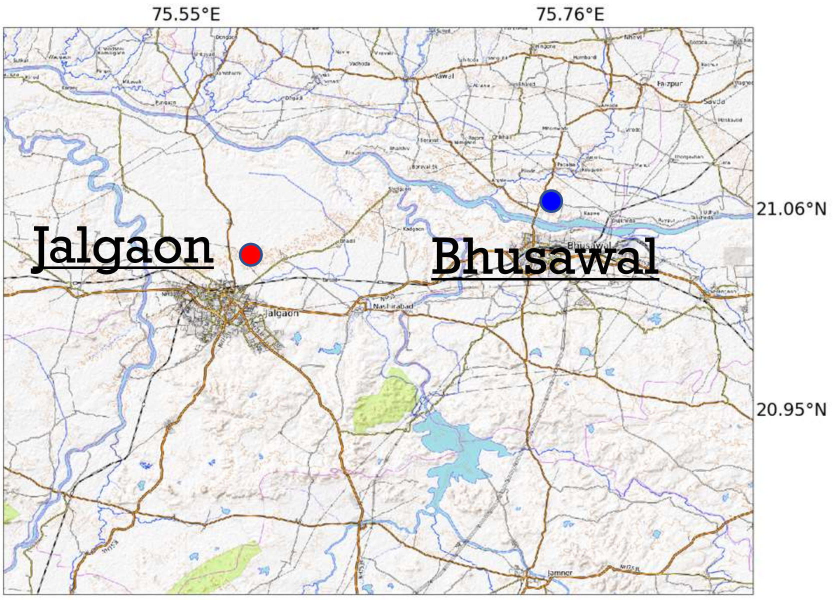
Maximum pop density	Average pop density
22100 persons/km^2	**2700** persons/km^2

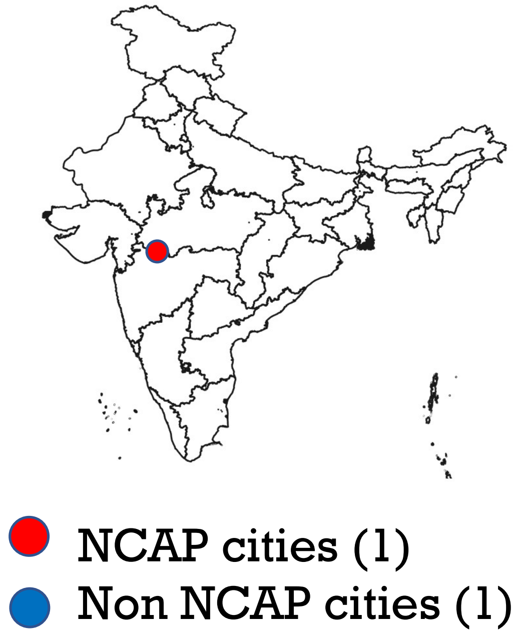
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
12	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India
Airshed: Jalgaon (MH)





Airshed size
40x30
~1-km grids

Total population
1
million

Urban pop share
71%

Urban area share
16%

Maximum pop density
22500
persons/km^2

Average pop density
3300
persons/km^2

Minimum air monitors needed

Particulate matter
13

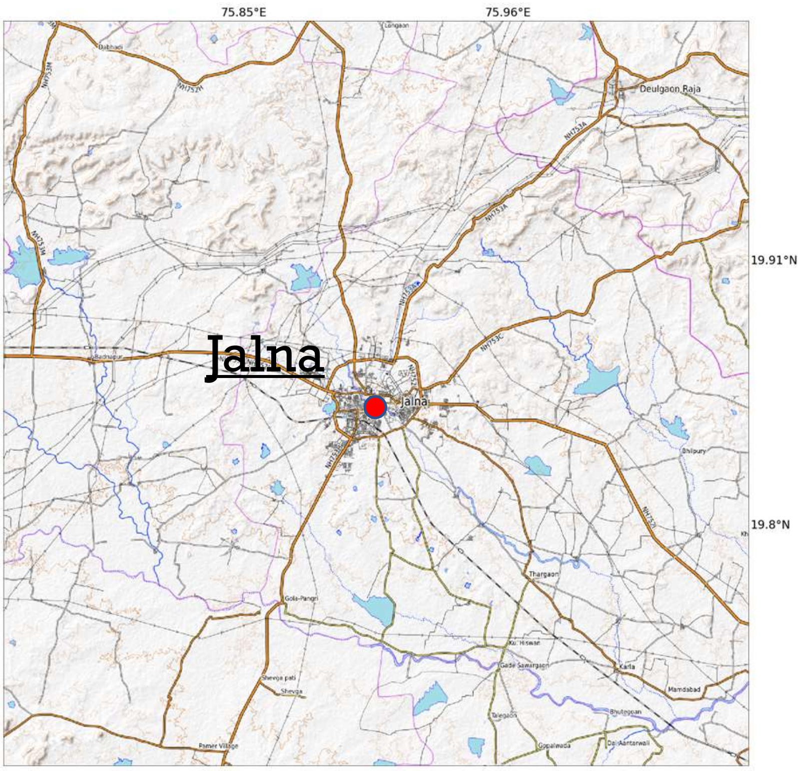
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Jalna (MH)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.5** million

Urban pop share	Urban area share
46%	**4%**

Maximum pop density	Average pop density
20000 persons/km^2	**5400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**5**

Nitrogen Dioxide	Carbon Monoxide
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Kolhapur (MH)

NCAP cities (2)

Non NCAP cities (0)

Airshed size	Total population
60x40 ~1-km grids	**3.3** million

Urban pop share	Urban area share
49%	**12%**

Maximum pop density	Average pop density
38400 persons/km^2	**5100** persons/km^2

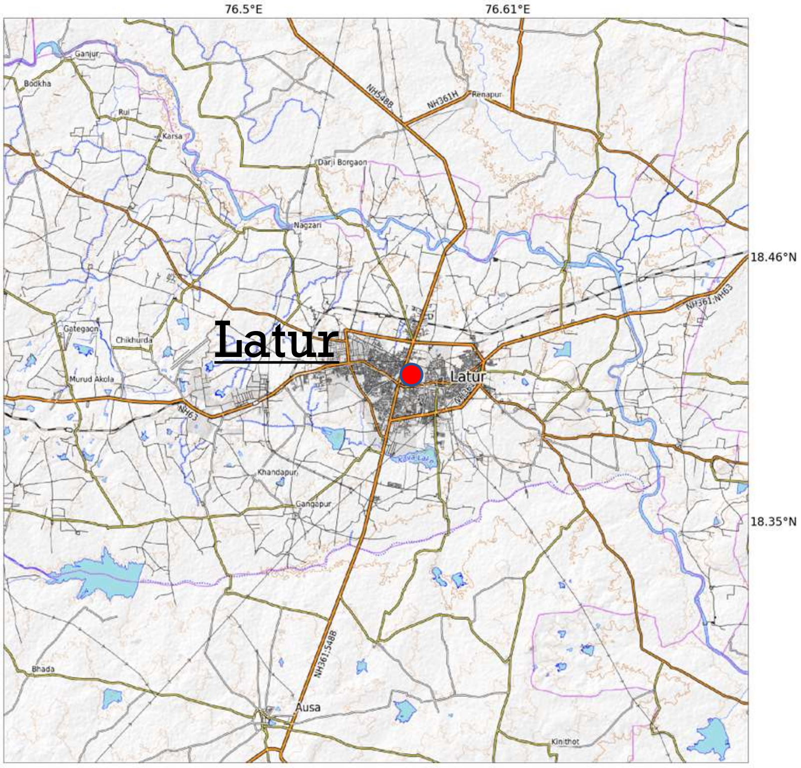
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
22	**11**

Nitrogen Dioxide	Carbon Monoxide
10	**6**

National Clean Air Programme (NCAP) of India

Airshed: Latur (MH)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.6
million

Urban pop share
51%

Urban area share
8%

Maximum pop density
13000
persons/km^2

Average pop density
3700
persons/km^2

Minimum air monitors needed

Particulate matter
11

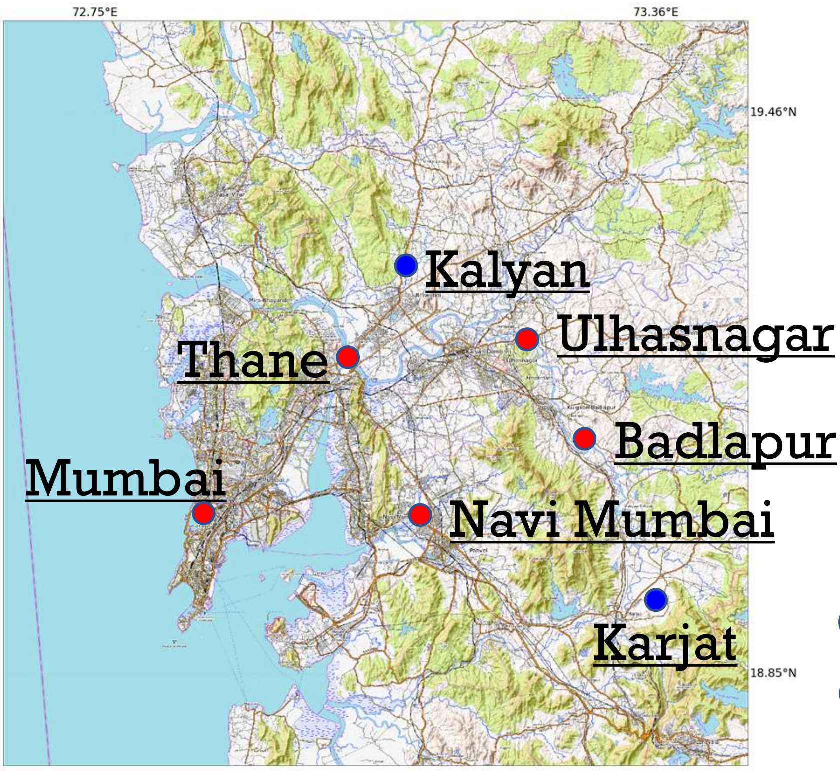
Sulphur Dioxide
6

Nitrogen Dioxide
8

Carbon Monoxide
2

National Clean Air Programme (NCAP) of India

Airshed: Mumbai (MH)



NCAP cities (5)

Non NCAP cities (2)

Airshed size	Total population
80x80 ~1-km grids	**19.2** million

Urban pop share	Urban area share
85%	**17%**

Maximum pop density	Average pop density
87700 persons/km^2	**13300** persons/km^2

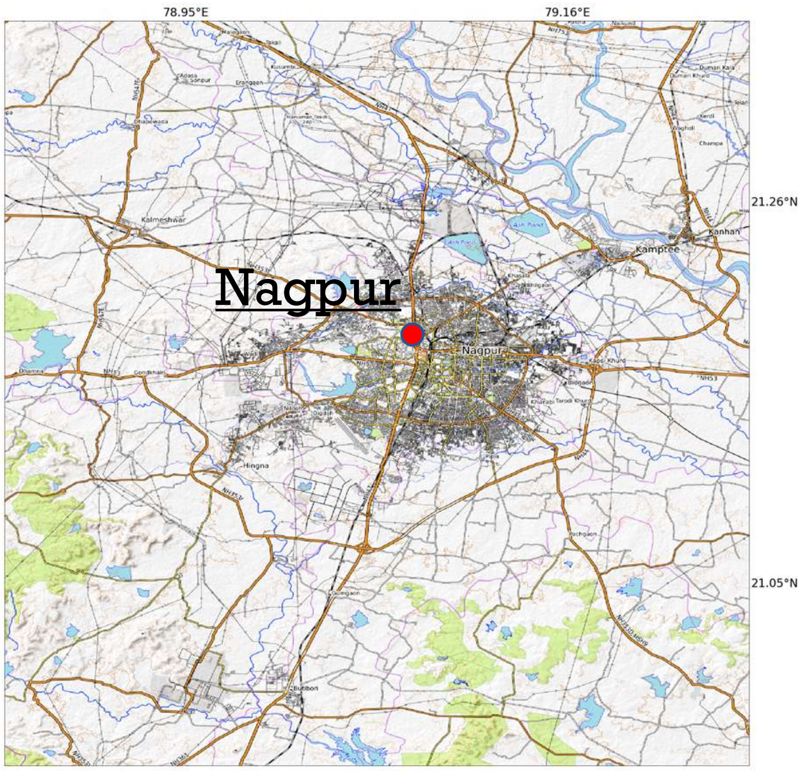
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
79	**20**

Nitrogen Dioxide	Carbon Monoxide
10	**16**

National Clean Air Programme (NCAP) of India

Airshed: Nagpur (MH)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
40x40 ~1-km grids	**2.7** million

Urban pop share	Urban area share
83%	**20%**

Maximum pop density	Average pop density
50900 persons/km^2	**6300** persons/km^2

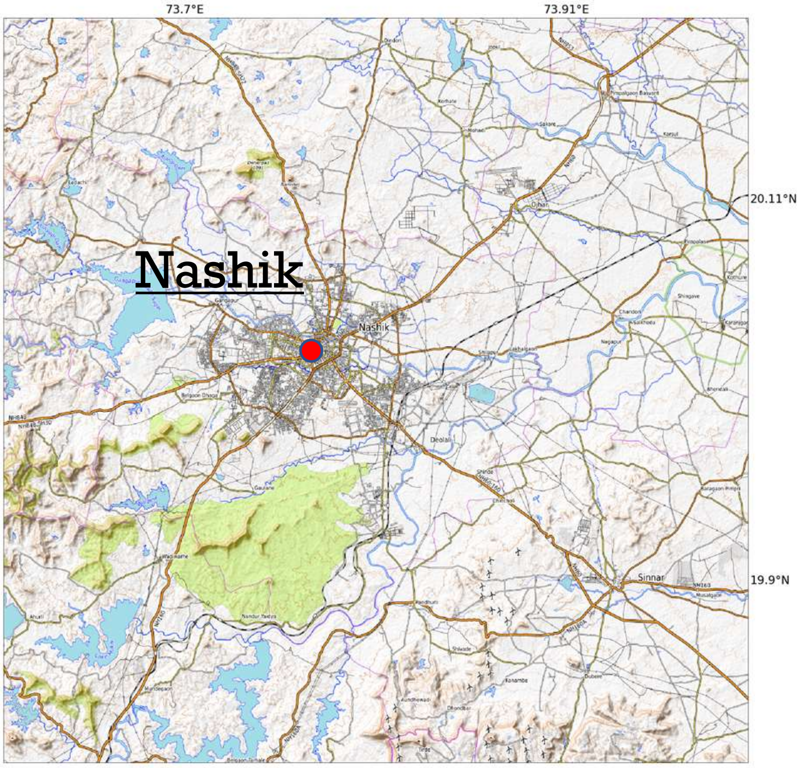
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
22	**10**

Nitrogen Dioxide	Carbon Monoxide
10	**5**

National Clean Air Programme (NCAP) of India

Airshed: Nashik (MH)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
2.2
million

Urban pop share
63%

Urban area share
10%

Maximum pop density
34500
persons/km^2

Average pop density
8200
persons/km^2

Minimum air monitors needed

Particulate matter
21

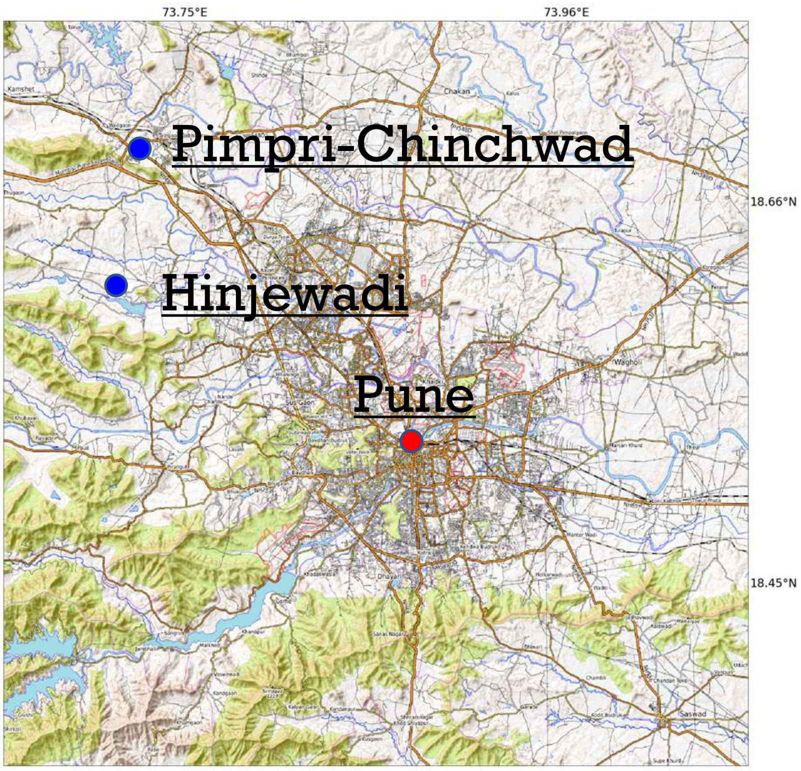
Sulphur Dioxide
10

Nitrogen Dioxide
10

Carbon Monoxide
5

National Clean Air Programme (NCAP) of India

Airshed: Pune (MH)



NCAP cities (1)

Non NCAP cities (2)

Airshed size
40x40
~1-km grids

Total population
5.4
million

Urban pop share
84%

Urban area share
31%

Maximum pop density
75800
persons/km²

Average pop density
8200
persons/km²

Minimum air monitors needed

Particulate matter
33

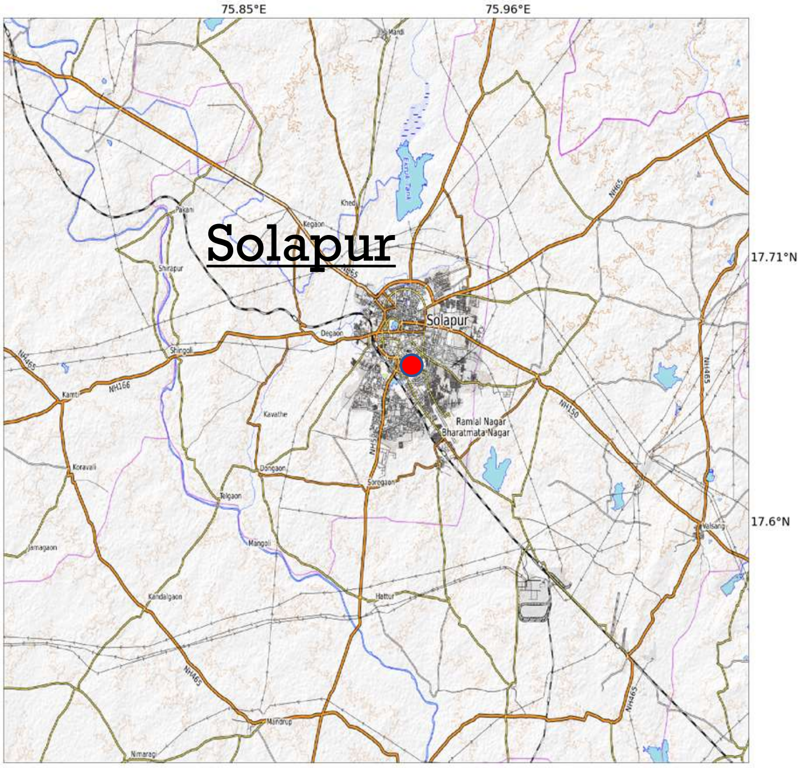
Sulphur Dioxide
15

Nitrogen Dioxide
10

Carbon Monoxide
9

National Clean Air Programme (NCAP) of India

Airshed: Solapur (MH)



NCAP cities (1)

Non NCAP cities (0)

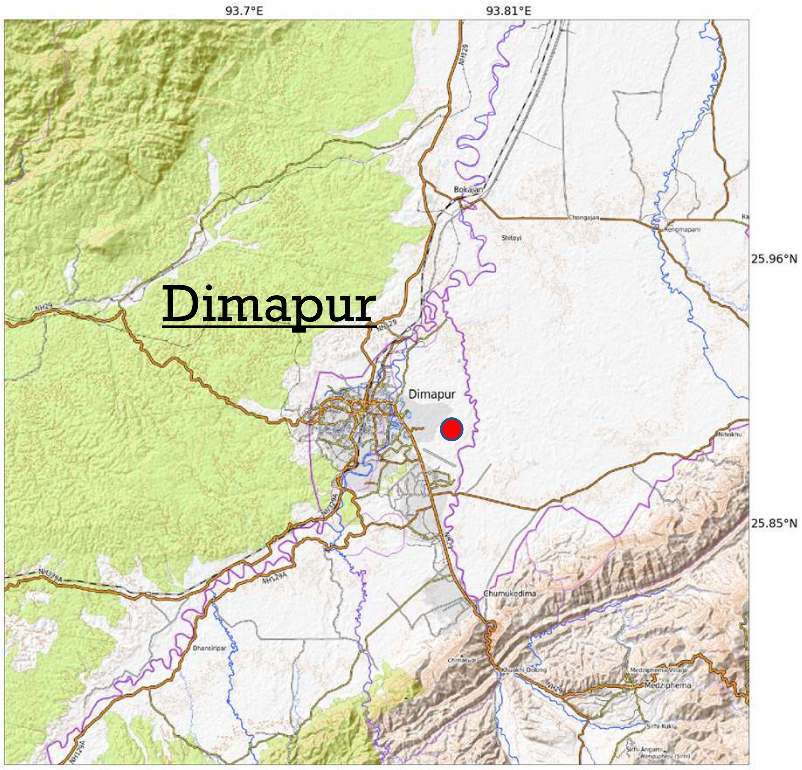
Airshed size	Total population
30x30 ~1-km grids	**0.9** million
Urban pop share **82%**	Urban area share **14%**
Maximum pop density **34300** persons/km^2	Average pop density **5400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
14	**8**
Nitrogen Dioxide	**Carbon Monoxide**
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Dimapur (ML)



NCAP cities (1)
Non NCAP cities (0)

Airshed size **30x30** ~1-km grids	Total population **0.4** million
Urban pop share **20%**	Urban area share **1%**
Maximum pop density **19800** persons/km^2	Average pop density **6100** persons/km^2

Minimum air monitors needed

Particulate matter **11**	Sulphur Dioxide **5**
Nitrogen Dioxide **7**	Carbon Monoxide **2**

National Clean Air Programme (NCAP) of India

Airshed: Kohima (ML)

NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.2** million

Urban pop share	Urban area share
59%	**3%**

Maximum pop density	Average pop density
21200 persons/km^2	**3800** persons/km^2

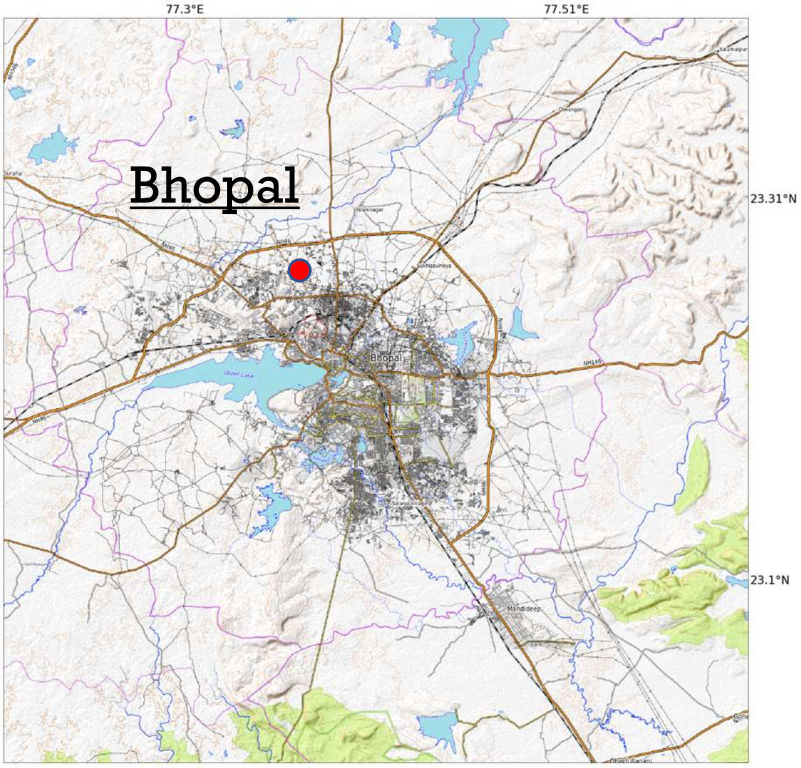
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
8	**4**

Nitrogen Dioxide	Carbon Monoxide
6	**2**

National Clean Air Programme (NCAP) of India

Airshed: Bhopal (MP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
2
million

Urban pop share
83%

Urban area share
13%

Maximum pop density
34200
persons/km^2

Average pop density
6900
persons/km^2

Minimum air monitors needed

Particulate matter
20

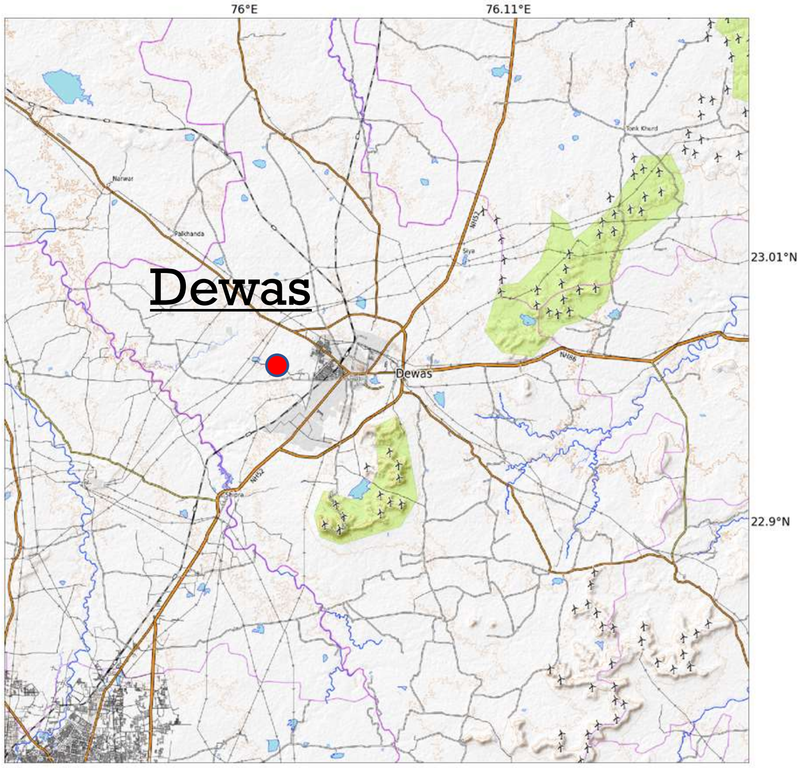
Sulphur Dioxide
9

Nitrogen Dioxide
10

Carbon Monoxide
4

National Clean Air Programme (NCAP) of India

Airshed: Dewas (MP)



- NCAP cities (1)
- Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.6
million

Urban pop share
62%

Urban area share
13%

Maximum pop density
21500
persons/km^2

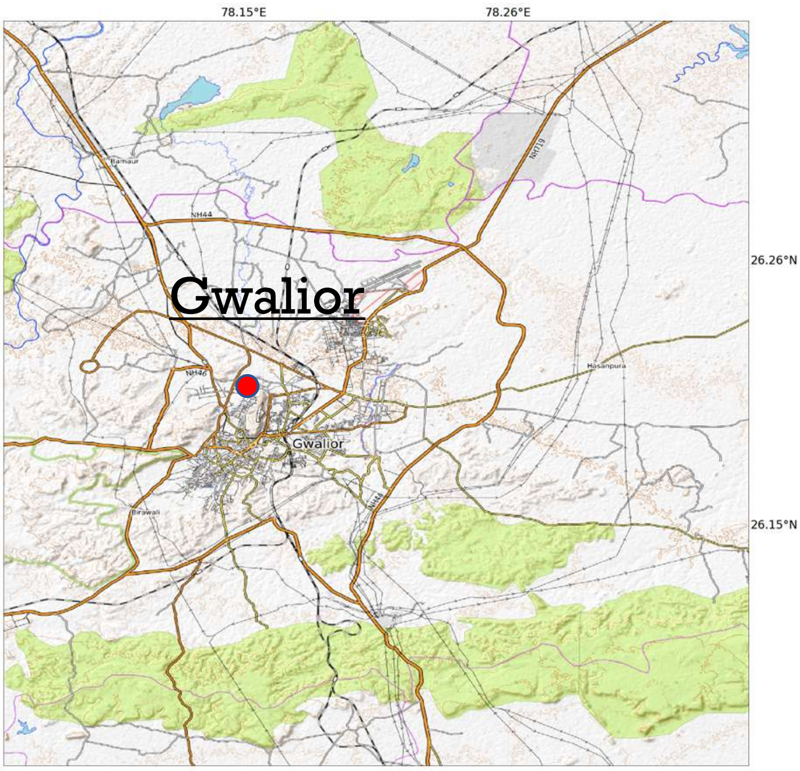
Average pop density
2600
persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide	Nitrogen Dioxide	Carbon Monoxide
10	6	8	2

National Clean Air Programme (NCAP) of India

Airshed: Gwalior (MP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.1** million

Urban pop share	Urban area share
68%	**12%**

Maximum pop density	Average pop density
17400 persons/km^2	**6100** persons/km^2

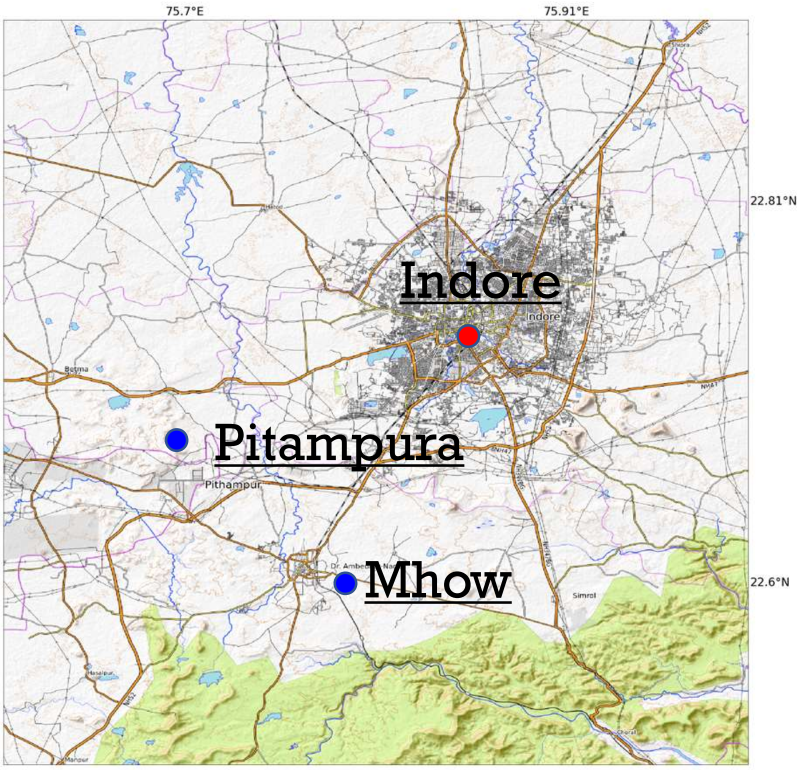
Minimum air monitors needed

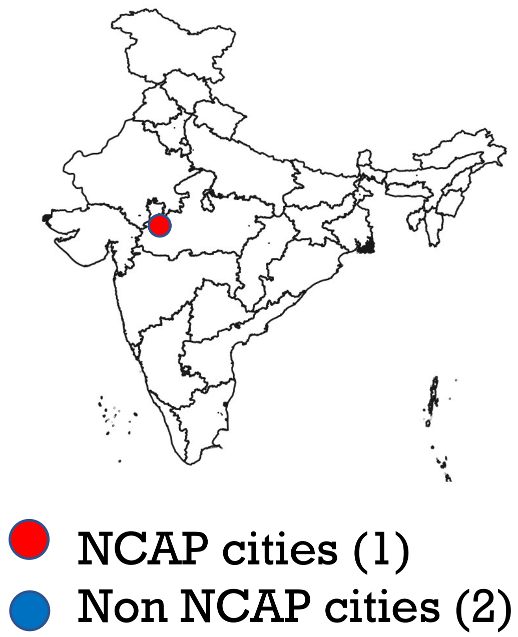
Particulate matter	Sulphur Dioxide
16	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Indore (MP)





Airshed size
40x40
~1-km grids

Total population
2.3
million

Urban pop share
84%

Urban area share
23%

Maximum pop density
34200
persons/km^2

Average pop density
4900
persons/km^2

Minimum air monitors needed

Particulate matter
19

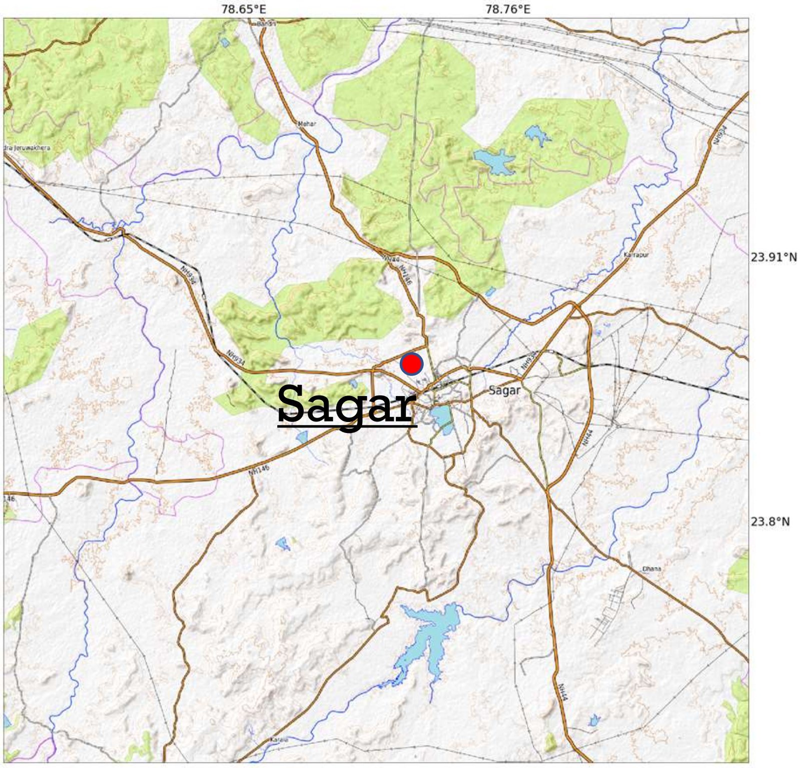
Sulphur Dioxide
10

Nitrogen Dioxide
10

Carbon Monoxide
5

National Clean Air Programme (NCAP) of India

Airshed: Sagar (MP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.5** million

Urban pop share	Urban area share
43%	**4%**

Maximum pop density	Average pop density
12300 persons/km²	**5300** persons/km²

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**5**

Nitrogen Dioxide	Carbon Monoxide
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Ujjain (MP)

NCAP cities (1)

Non NCAP cities (0)

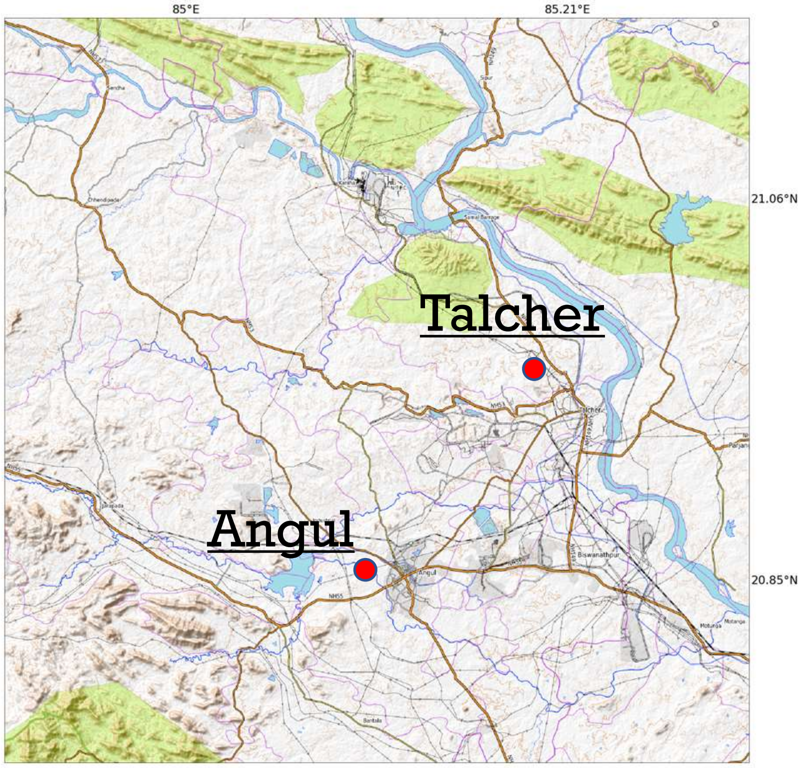
Airshed size	Total population
30x30 ~1-km grids	**0.6** million
Urban pop share **61%**	Urban area share **10%**
Maximum pop density **15400** persons/km^2	Average pop density **3800** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**6**
Nitrogen Dioxide	**Carbon Monoxide**
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Angul (OD)



NCAP cities (2)
Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
0.7
million

Urban pop share
24%

Urban area share
11%

Maximum pop density
14000
persons/km^2

Average pop density
800
persons/km^2

Minimum air monitors needed

Particulate matter
10

Sulphur Dioxide
6

Nitrogen Dioxide
9

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Balasore (OD)

NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.7** million

Urban pop share	Urban area share
27%	**8%**

Maximum pop density	Average pop density
34600 persons/km^2	**2400** persons/km^2

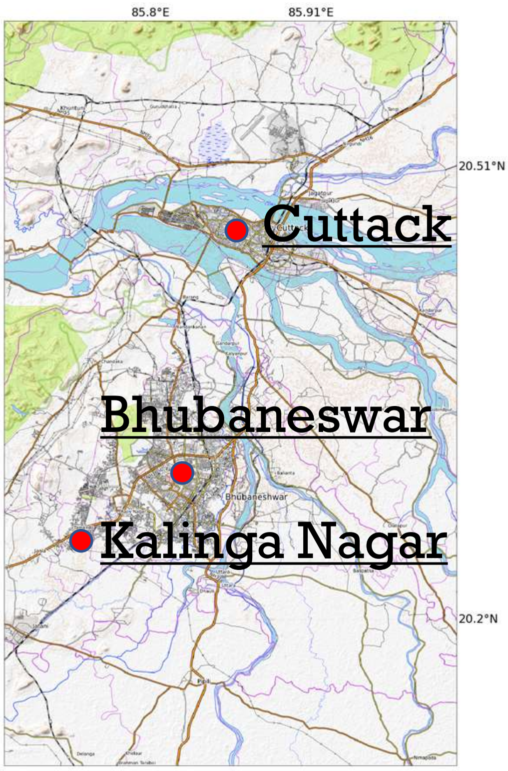
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**6**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Bhubaneswar (OD)



NCAP cities (3)
Non NCAP cities (0)

Airshed size	Total population
30x50	**3**
~1-km grids	million

Urban pop share	Urban area share
58%	**12%**

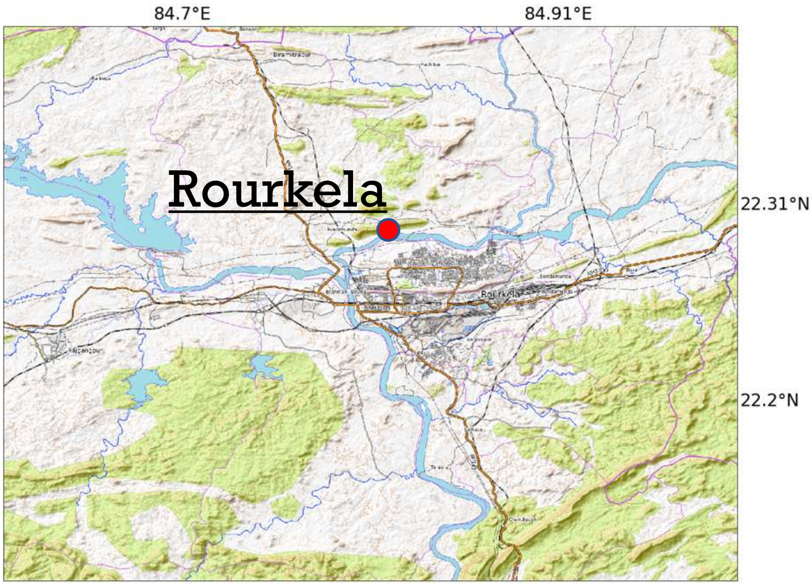
Maximum pop density	Average pop density
48700	**8700**
persons/km^2	persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
24	**11**

Nitrogen Dioxide	Carbon Monoxide
10	**6**

National Clean Air Programme (NCAP) of India
Airshed: Rourkela (OD)



NCAP cities (1)
Non NCAP cities (0)

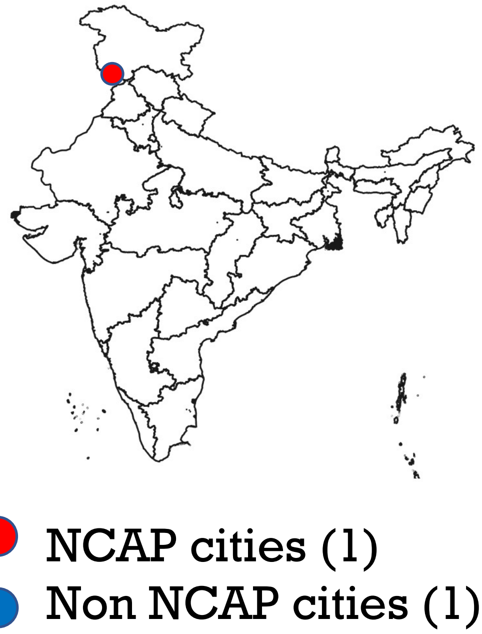
Airshed size	Total population
40x30 ~1-km grids	**0.8** million
Urban pop share 70%	**Urban area share** 16%
Maximum pop density 14200 persons/km^2	**Average pop density** 2700 persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
13	**7**
Nitrogen Dioxide	**Carbon Monoxide**
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Amritsar (PB)



Airshed size
40x40
~1-km grids

Total population
1.7
million

Urban pop share
60%

Urban area share
9%

Maximum pop density
24000
persons/km²

Average pop density
6100
persons/km²

Minimum air monitors needed

Particulate matter
17

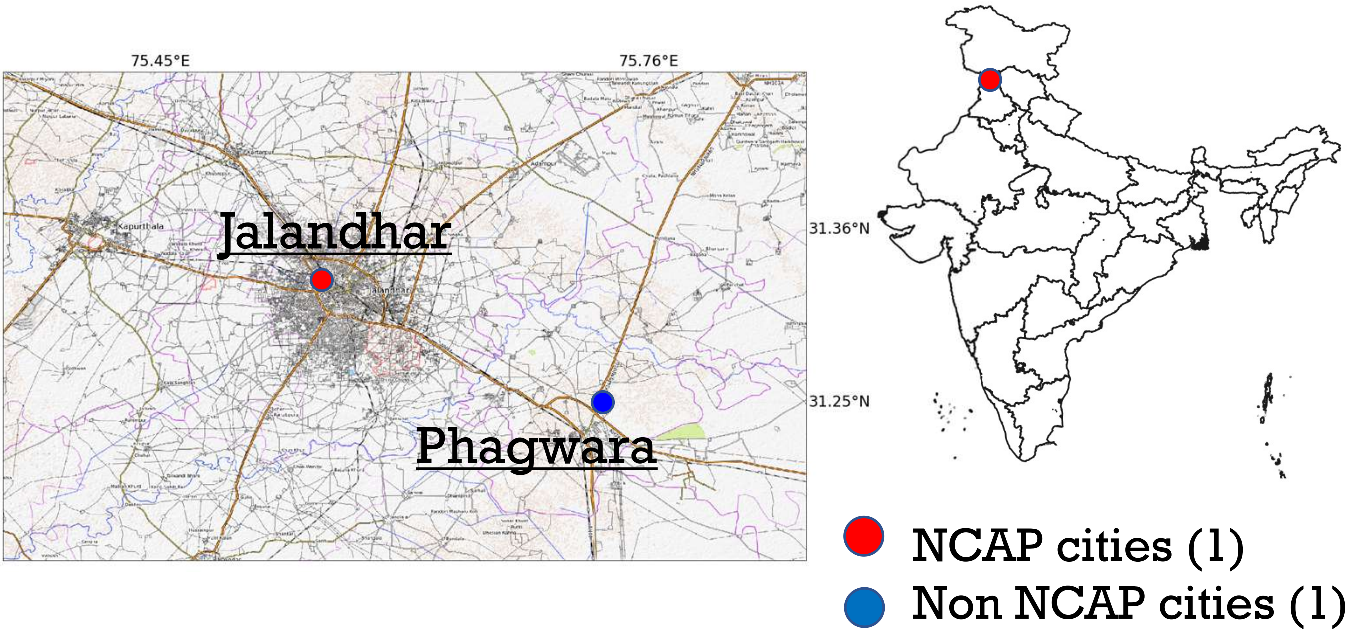
Sulphur Dioxide
9

Nitrogen Dioxide
10

Carbon Monoxide
4

National Clean Air Programme (NCAP) of India

Airshed: Jalandhar (PB)



Airshed size
50x30
~1-km grids

Total population
1.6
million

Urban pop share
64%

Urban area share
16%

Maximum pop density
18600
persons/km^2

Average pop density
3800
persons/km^2

Minimum air monitors needed

Particulate matter
16

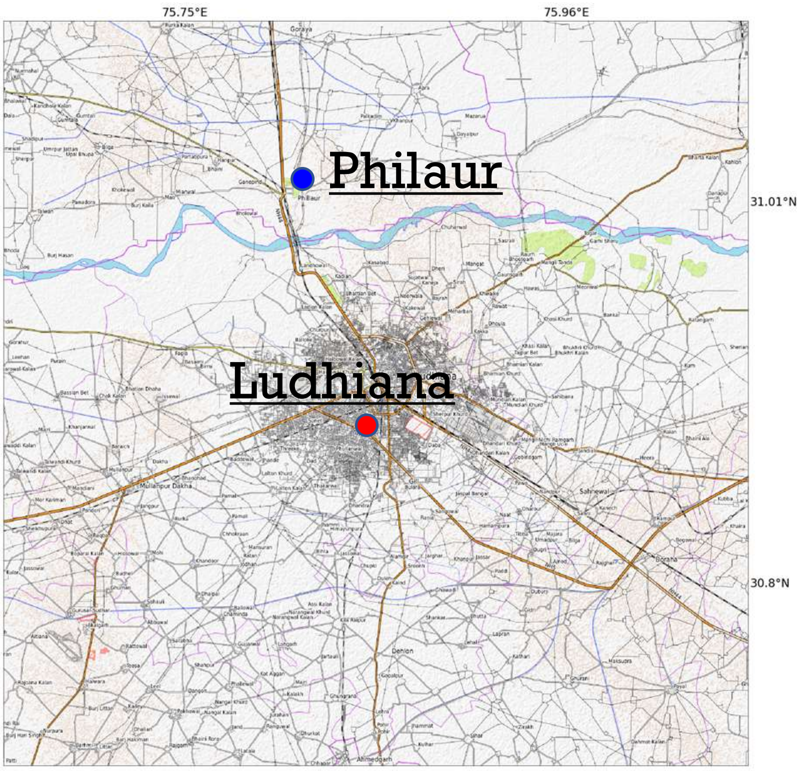
Sulphur Dioxide
9

Nitrogen Dioxide
10

Carbon Monoxide
4

National Clean Air Programme (NCAP) of India

Airshed: Ludhiana (PB)



NCAP cities (1)

Non NCAP cities (1)

Airshed size	Total population
40x40 ~1-km grids	**2.1** million

Urban pop share	Urban area share
73%	**18%**

Maximum pop density	Average pop density
29900 persons/km^2	**4900** persons/km^2

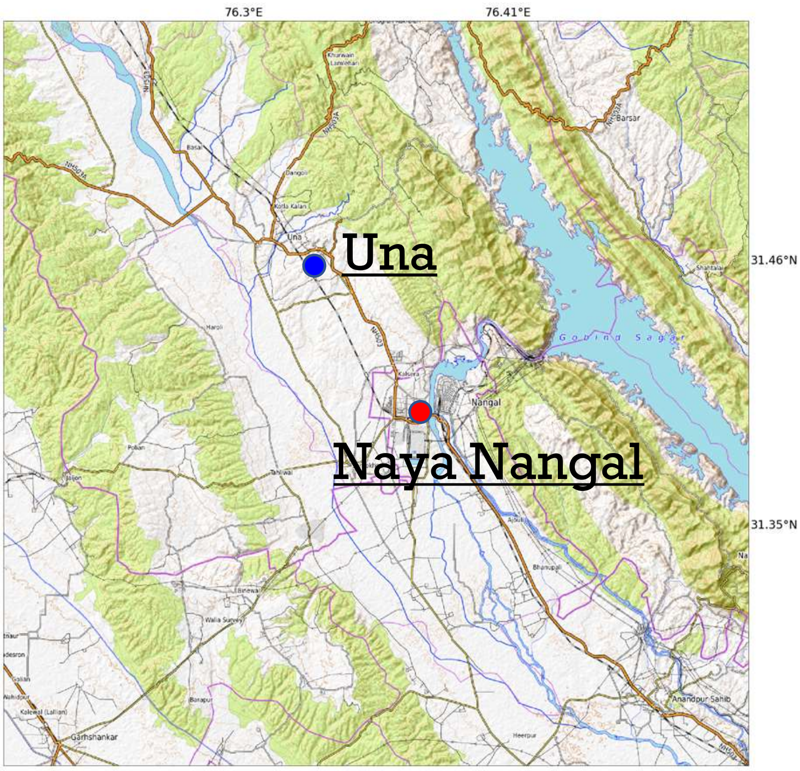
Minimum air monitors needed

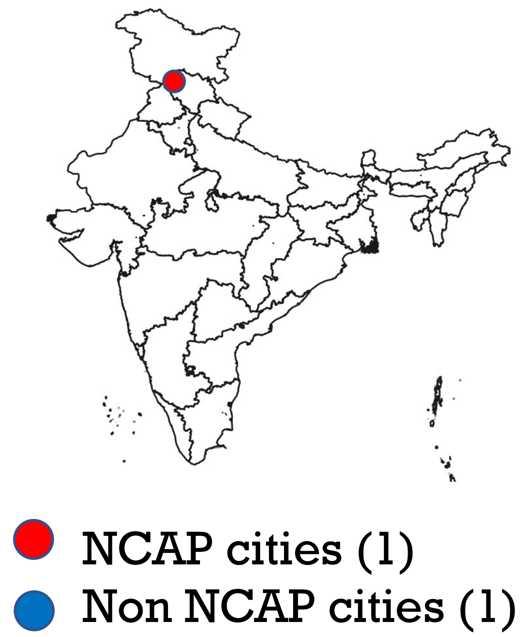
Particulate matter	Sulphur Dioxide
18	**10**

Nitrogen Dioxide	Carbon Monoxide
10	**5**

National Clean Air Programme (NCAP) of India

Airshed: Naya Nangal (PB)





Airshed size	Total population
30x30 ~1-km grids	**0.4** million

Urban pop share	Urban area share
28%	**5%**

Maximum pop density	Average pop density
25300 persons/km^2	**2500** persons/km^2

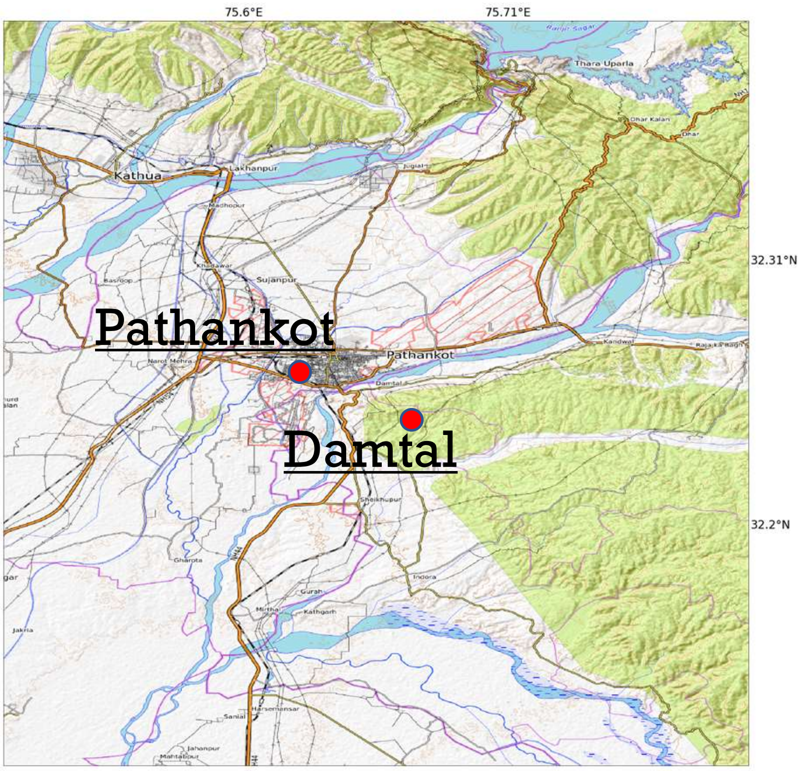
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
9	**5**

Nitrogen Dioxide	Carbon Monoxide
7	**2**

National Clean Air Programme (NCAP) of India

Airshed: Pathankot (PB)



NCAP cities (2)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.6
million

Urban pop share
55%

Urban area share
24%

Maximum pop density
18600
persons/km^2

Average pop density
1300
persons/km^2

Minimum air monitors needed

Particulate matter
10

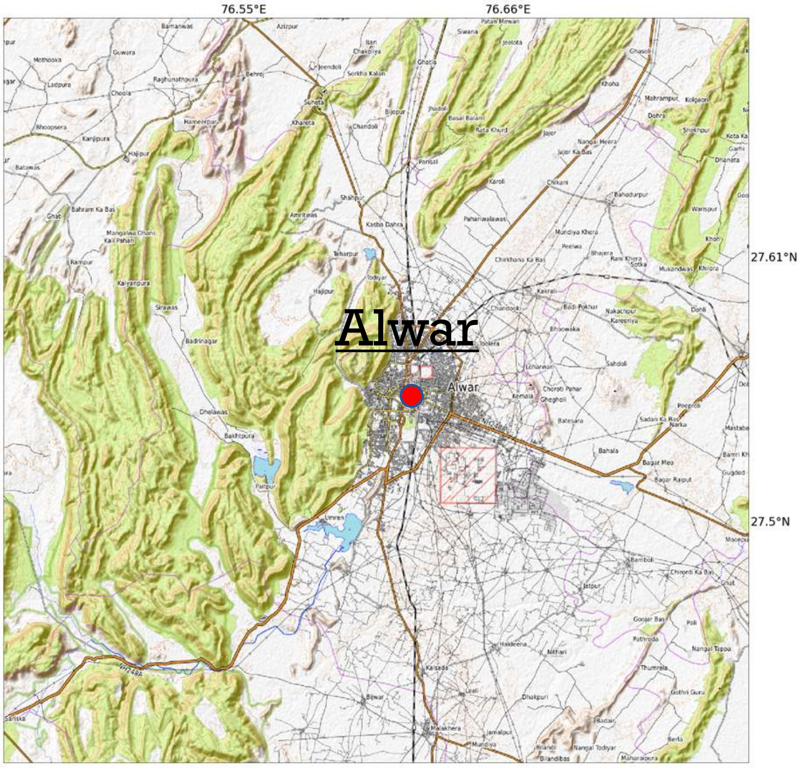
Sulphur Dioxide
6

Nitrogen Dioxide
8

Carbon Monoxide
2

National Clean Air Programme (NCAP) of India

Airshed: Alwar (RJ)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30	**0.7**
~1-km grids	million

Urban pop share	Urban area share
44%	**8%**

Maximum pop density	Average pop density
22600	**3700**
persons/km^2	persons/km^2

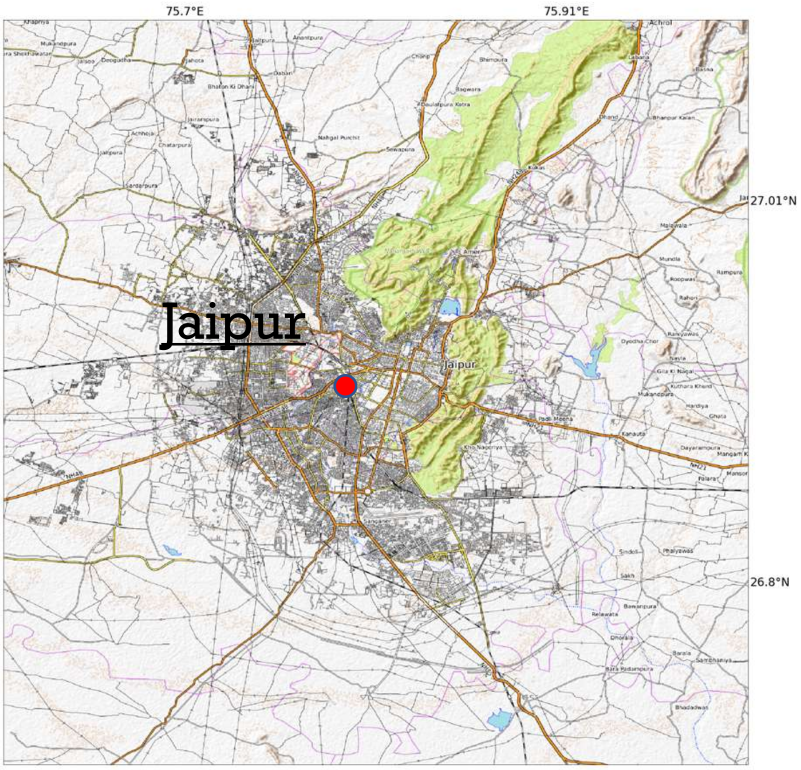
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
11	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Jaipur (RJ)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
3.5
million

Urban pop share
83%

Urban area share
21%

Maximum pop density
52800
persons/km^2

Average pop density
7800
persons/km^2

Minimum air monitors needed

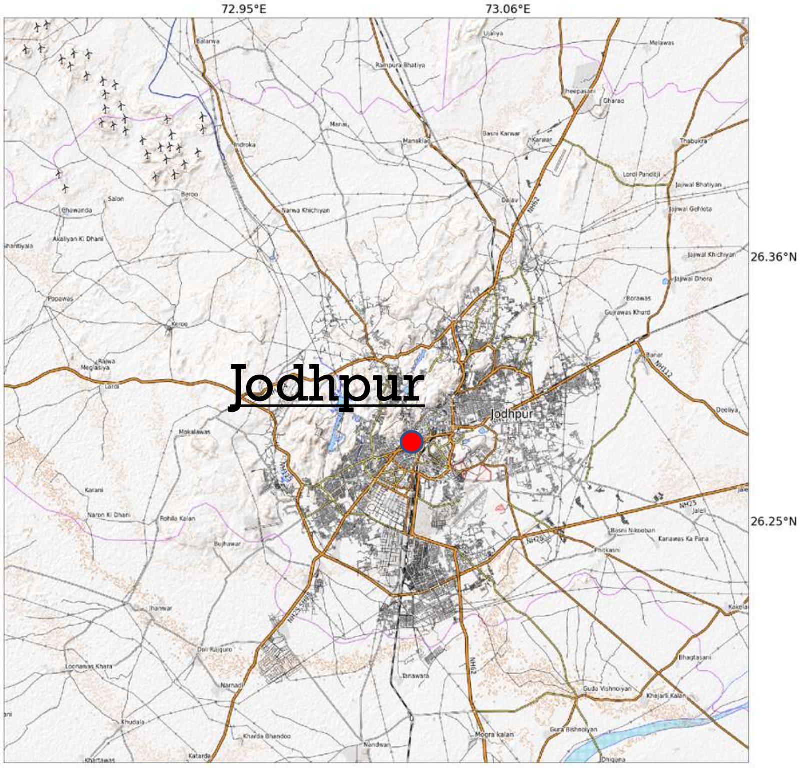
Particulate matter
26

Sulphur Dioxide
12

Nitrogen Dioxide
10

Carbon Monoxide
7

National Clean Air Programme (NCAP) of India
Airshed: Jodhpur (RJ)



Airshed size
30x30
~1-km grids

Total population
1.2
million

Urban pop share
84%

Urban area share
24%

Maximum pop density
22100
persons/km^2

Average pop density
4400
persons/km^2

Minimum air monitors needed

Particulate matter
15

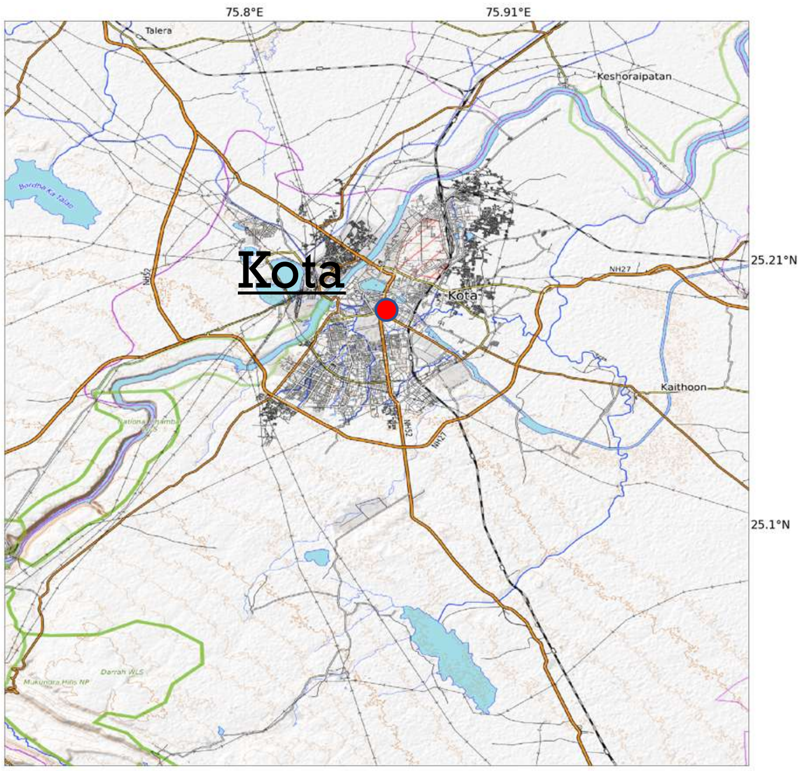
Sulphur Dioxide
8

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Kota (RJ)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.1** million

Urban pop share	Urban area share
89%	**21%**

Maximum pop density	Average pop density
26500 persons/km^2	**4400** persons/km^2

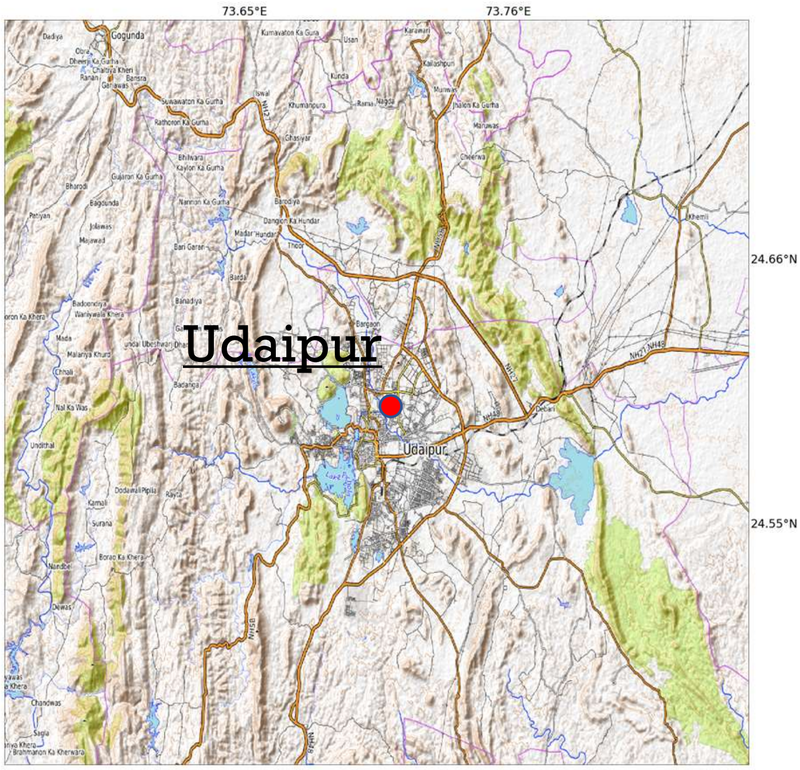
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
15	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Udaipur (RJ)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.8** million

Urban pop share	Urban area share
62%	**18%**

Maximum pop density	Average pop density
15400 persons/km^2	**2700** persons/km^2

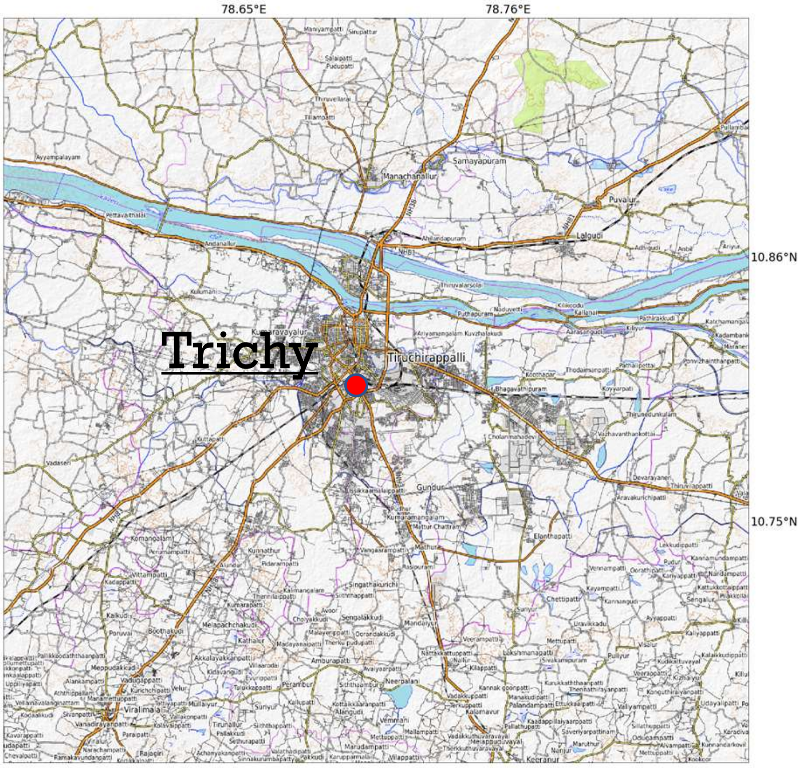
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
12	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Trichy (TN)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.4** million

Urban pop share	Urban area share
56%	**6%**

Maximum pop density	Average pop density
37400 persons/km^2	**13900** persons/km^2

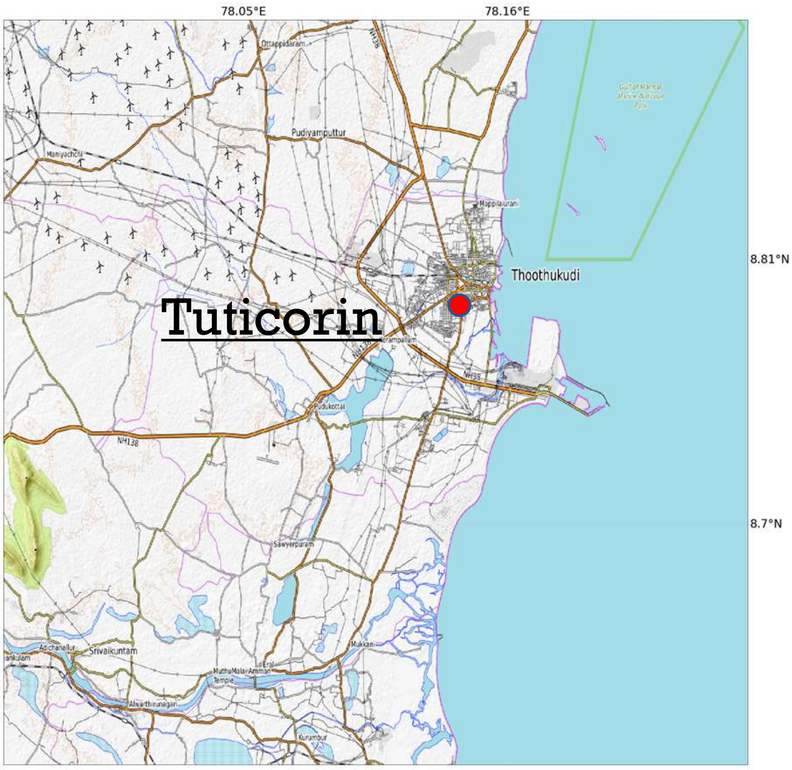
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
21	**9**

Nitrogen Dioxide	Carbon Monoxide
10	**4**

National Clean Air Programme (NCAP) of India

Airshed: Tuticorin (TN)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**0.7** million

Urban pop share	Urban area share
56%	**14%**

Maximum pop density	Average pop density
43000 persons/km^2	**3000** persons/km^2

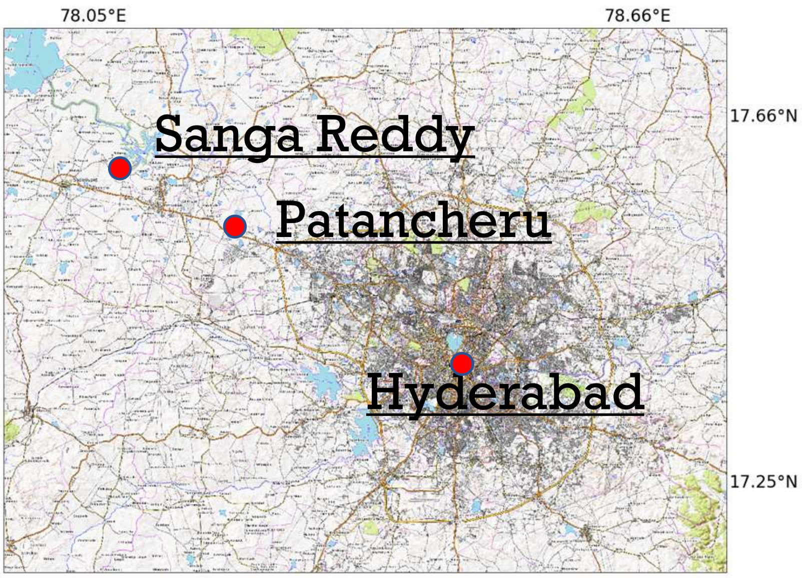
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
12	**7**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Hyderabad (TS)



NCAP cities (3)
Non NCAP cities (0)

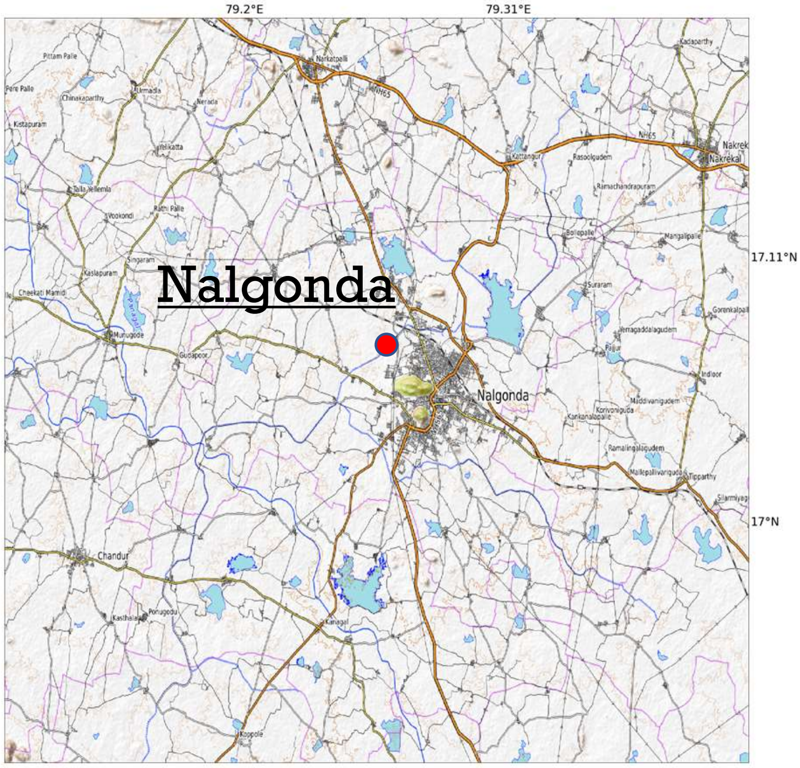
Airshed size	Total population
80x60 ~1-km grids	**7.3** million
Urban pop share **83%**	Urban area share **18%**
Maximum pop density **57900** persons/km^2	Average pop density **6400** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
34	**17**
Nitrogen Dioxide **10**	Carbon Monoxide **10**

National Clean Air Programme (NCAP) of India

Airshed: Nalgonda (TS)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.3
million

Urban pop share
43%

Urban area share
6%

Maximum pop density
13500
persons/km²

Average pop density
2200
persons/km²

Minimum air monitors needed

Particulate matter
8

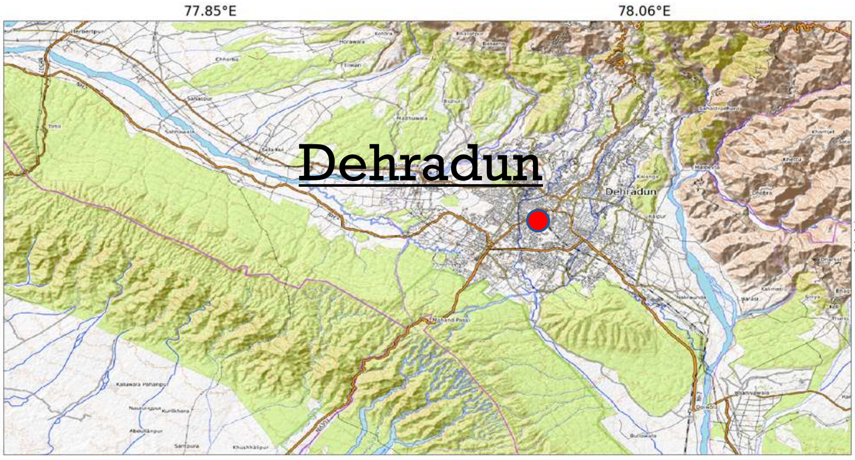
Sulphur Dioxide
5

Nitrogen Dioxide
6

Carbon Monoxide
2

URBAN emissions .info

National Clean Air Programme (NCAP) of India
Airshed: Dehradun (UK)



NCAP cities (1)
Non NCAP cities (0)

Airshed size
40x20
~1-km grids

Total population
0.9
million

Urban pop share
75%

Urban area share
17%

Maximum pop density
32200
persons/km^2

Average pop density
4400
persons/km^2

Minimum air monitors needed

Particulate matter
14

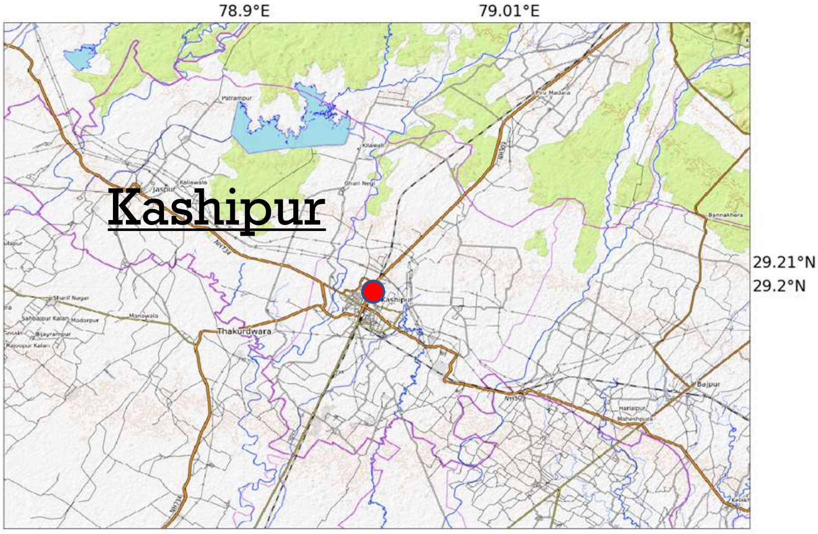
Sulphur Dioxide
7

Nitrogen Dioxide
10

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Kashipur (UK)



Airshed size	Total population
30x20 ~1-km grids	**0.6** million

Urban pop share	Urban area share
43%	**20%**

Maximum pop density	Average pop density
20000 persons/km^2	**1900** persons/km^2

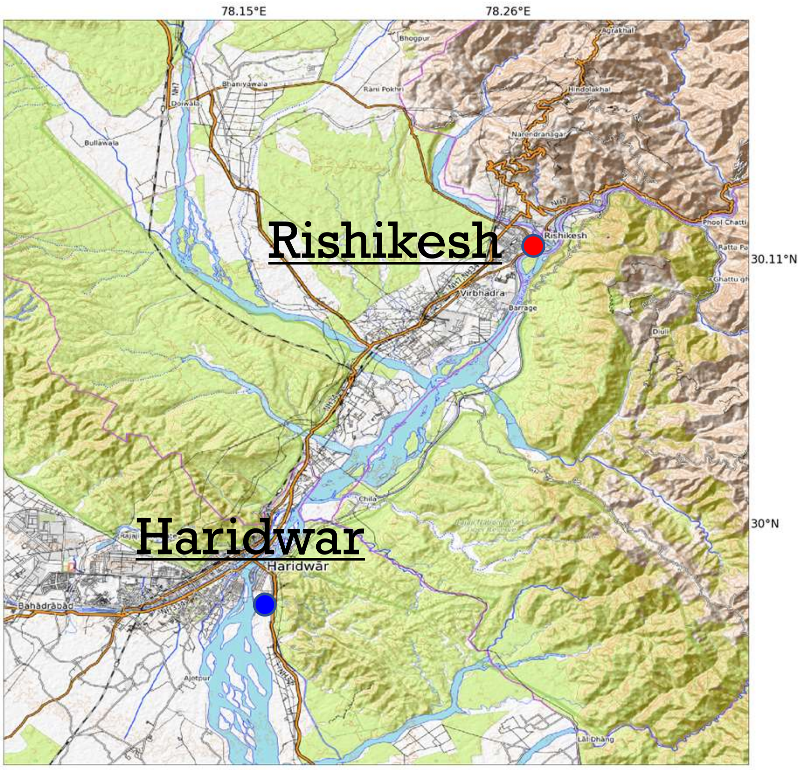
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Rishikesh (UK)



NCAP cities (1)

Non NCAP cities (1)

Airshed size	Total population
30x30 ~1-km grids	**0.7** million

Urban pop share	Urban area share
60%	**12%**

Maximum pop density	Average pop density
34800 persons/km^2	**3300** persons/km^2

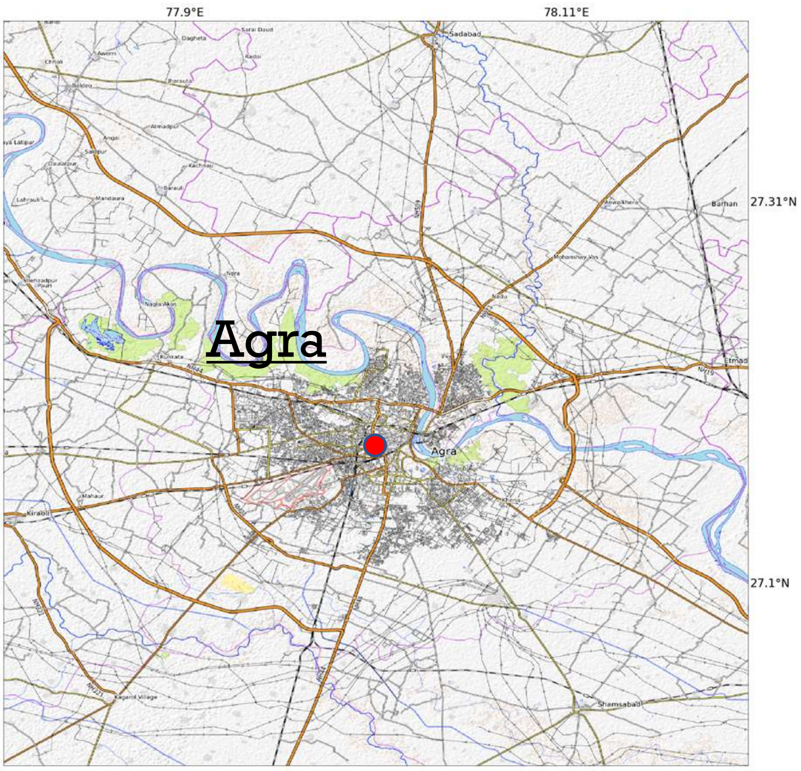
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
12	**6**

Nitrogen Dioxide	Carbon Monoxide
9	**3**

National Clean Air Programme (NCAP) of India

Airshed: Agra (UP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
40x40	**3.2**
~1-km grids	million

Urban pop share	Urban area share
55%	**9%**

Maximum pop density	Average pop density
42400	**10700**
persons/km^2	persons/km^2

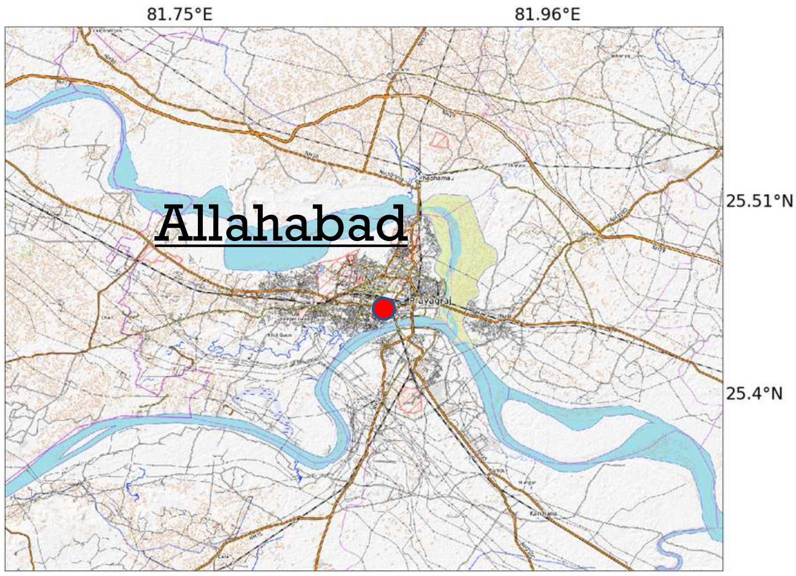
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
27	**11**

Nitrogen Dioxide	Carbon Monoxide
10	**6**

National Clean Air Programme (NCAP) of India

Airshed: Allahabad (UP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
40x30 ~1-km grids	**2.3** million

Urban pop share	Urban area share
36%	**7%**

Maximum pop density	Average pop density
38000 persons/km²	**9400** persons/km²

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
23	**10**

Nitrogen Dioxide	Carbon Monoxide
10	**5**

National Clean Air Programme (NCAP) of India

Airshed: Anpara (UP)

NCAP cities (1)
Non NCAP cities (1)

Airshed size	Total population
50x30 ~1-km grids	**0.6** million

Urban pop share	Urban area share
67%	**19%**

Maximum pop density	Average pop density
28300 persons/km^2	**1300** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
10	**6**

Nitrogen Dioxide	Carbon Monoxide
8	**2**

National Clean Air Programme (NCAP) of India

Airshed: Bareily (UP)

NCAP cities (1)

Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.8** million

Urban pop share	Urban area share
40%	**10%**

Maximum pop density	Average pop density
28500 persons/km^2	**7700** persons/km^2

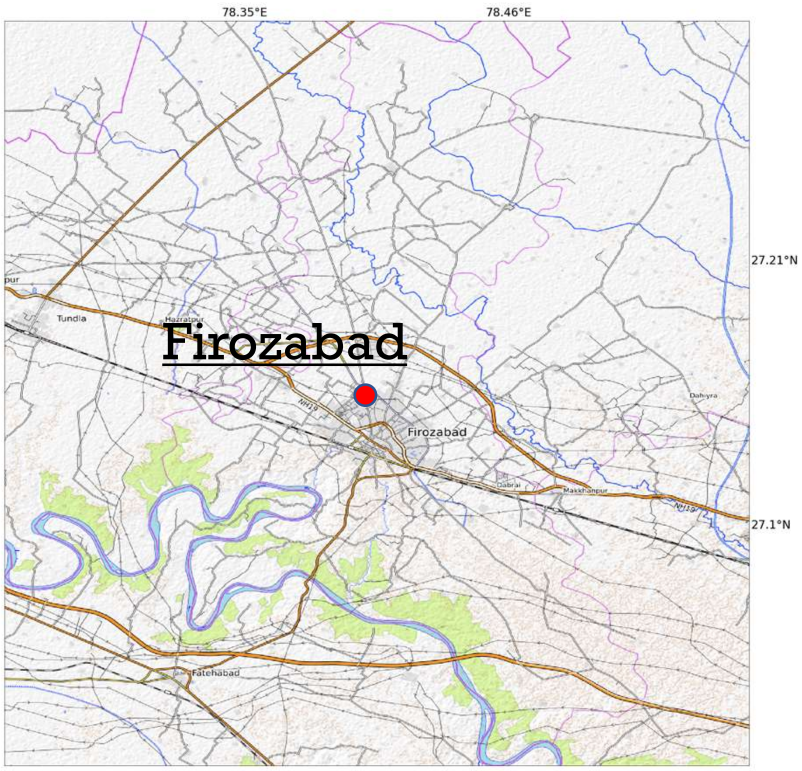
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
20	**9**

Nitrogen Dioxide	Carbon Monoxide
10	**4**

National Clean Air Programme (NCAP) of India

Airshed: Firozabad (UP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1.1** million
Urban pop share **41%**	Urban area share **7%**
Maximum pop density **28900** persons/km^2	Average pop density **6700** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
17	**8**
Nitrogen Dioxide **10**	Carbon Monoxide **3**

National Clean Air Programme (NCAP) of India

Airshed: Gajraula (UP)

NCAP cities (1)

Non NCAP cities (0)

Airshed size
30x30
~1-km grids

Total population
0.7
million

Urban pop share
13%

Urban area share
2%

Maximum pop density
30400
persons/km^2

Average pop density
4900
persons/km^2

Minimum air monitors needed

Particulate matter
13

Sulphur Dioxide
7

Nitrogen Dioxide
9

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India
Airshed: Jhansi (UP)

NCAP cities (1)
Non NCAP cities (0)

Airshed size
40x30
~1-km grids

Total population
0.8
million

Urban pop share
46%

Urban area share
8%

Maximum pop density
15100
persons/km^2

Average pop density
3500
persons/km^2

Minimum air monitors needed

Particulate matter
12

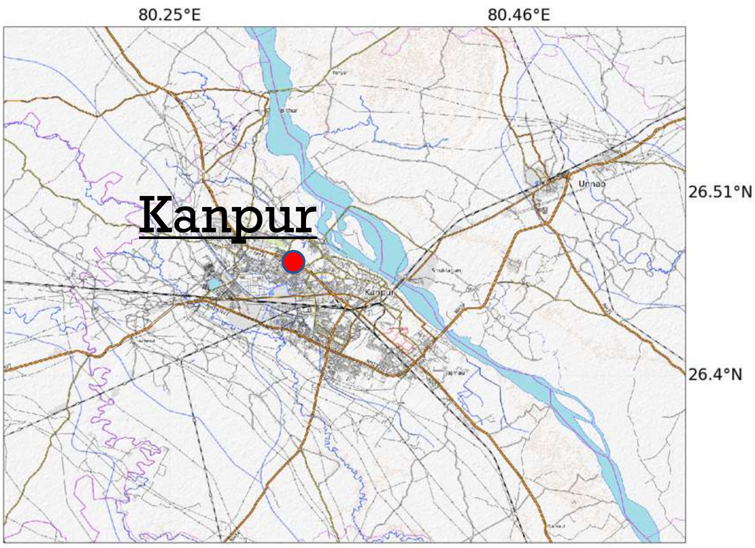
Sulphur Dioxide
7

Nitrogen Dioxide
9

Carbon Monoxide
3

National Clean Air Programme (NCAP) of India

Airshed: Kanpur (UP)



NCAP cities (1)

Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
4.4
million

Urban pop share
68%

Urban area share
14%

Maximum pop density
49000
persons/km^2

Average pop density
11800
persons/km^2

Minimum air monitors needed

Particulate matter
34

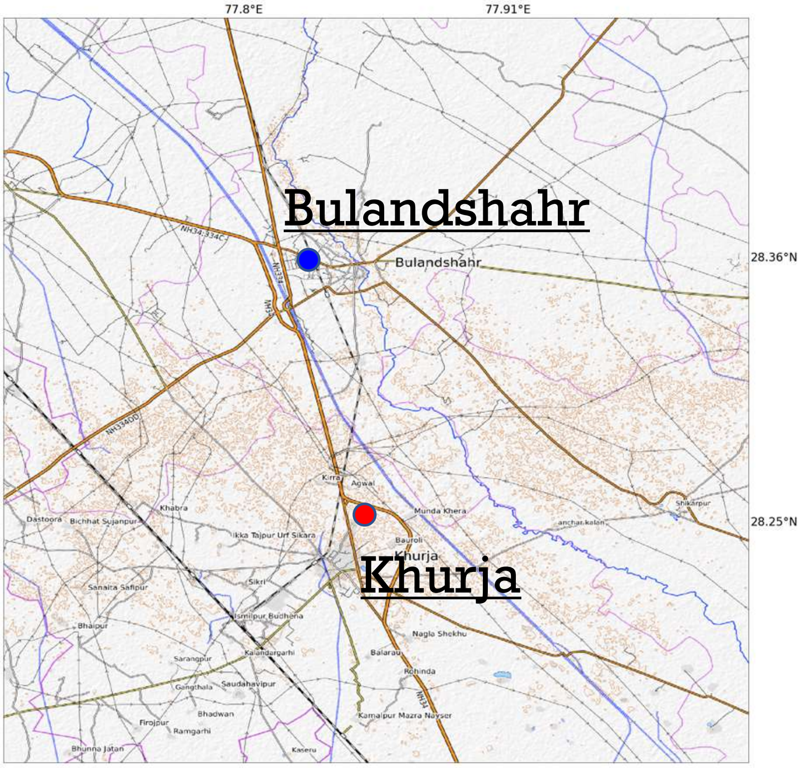
Sulphur Dioxide
13

Nitrogen Dioxide
10

Carbon Monoxide
8

National Clean Air Programme (NCAP) of India

Airshed: Khurja (UP)



NCAP cities (1)

Non NCAP cities (1)

Airshed size	Total population
30x30 ~1-km grids	**1.2** million

Urban pop share	Urban area share
24%	**4%**

Maximum pop density	Average pop density
28400 persons/km^2	**7100** persons/km^2

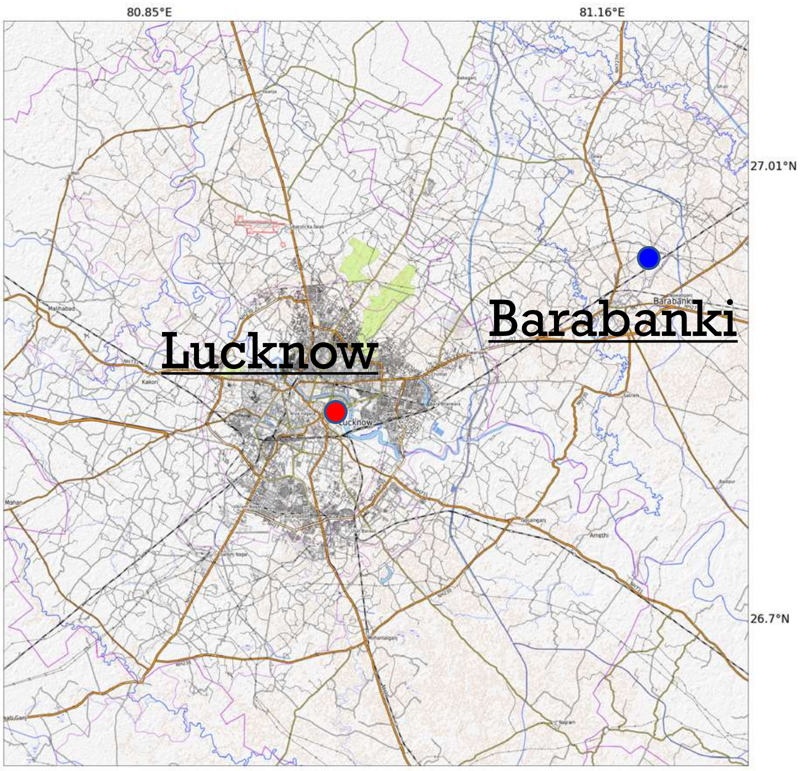
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
17	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Lucknow (UP)



NCAP cities (1)

Non NCAP cities (1)

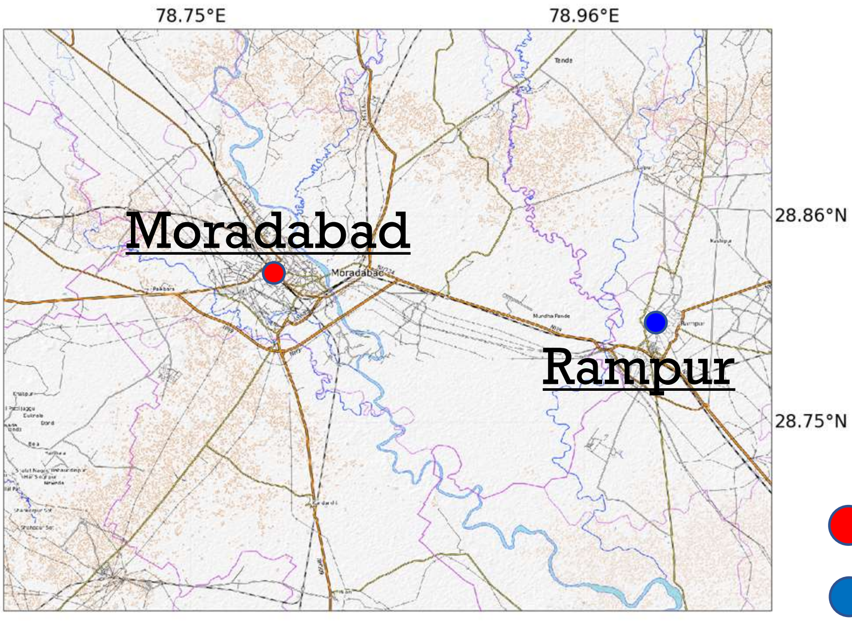
Airshed size	Total population
50x50 ~1-km grids	**4.2** million
Urban pop share **57%**	Urban area share **9%**
Maximum pop density **39900** persons/km²	Average pop density **9600** persons/km²

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
30	**13**
Nitrogen Dioxide	**Carbon Monoxide**
10	**8**

National Clean Air Programme (NCAP) of India

Airshed: Moradabad (UP)



NCAP cities (1)
Non NCAP cities (1)

Airshed size	Total population
40x30 ~1-km grids	**1.8** million

Urban pop share	Urban area share
39%	**7%**

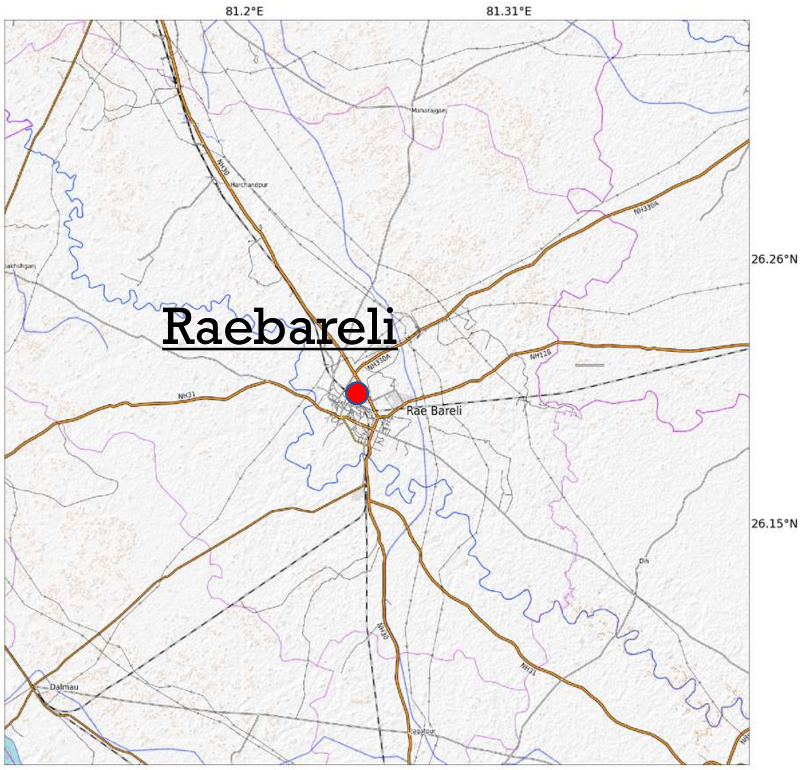
Maximum pop density	Average pop density
26700 persons/km²	**7300** persons/km²

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
18	**9**

Nitrogen Dioxide	Carbon Monoxide
10	**4**

National Clean Air Programme (NCAP) of India
Airshed: Raebareli (UP)



NCAP cities (1)
Non NCAP cities (0)

Airshed size	Total population
30x30 ~1-km grids	**1** million

Urban pop share	Urban area share
16%	**3%**

Maximum pop density	Average pop density
28900 persons/km^2	**5500** persons/km^2

Minimum air monitors needed

Particulate matter	Sulphur Dioxide
14	**8**

Nitrogen Dioxide	Carbon Monoxide
10	**3**

National Clean Air Programme (NCAP) of India

Airshed: Varanasi (UP)

NCAP cities (1)

Non NCAP cities (0)

Airshed size
40x40
~1-km grids

Total population
3.4
million

Urban pop share
33%

Urban area share
10%

Maximum pop density
37900
persons/km^2

Average pop density
6600
persons/km^2

Minimum air monitors needed

Particulate matter
24

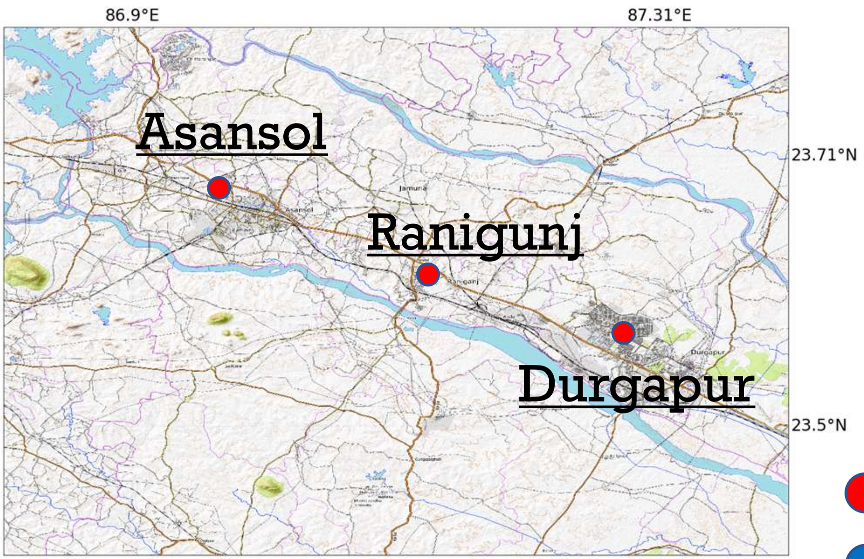
Sulphur Dioxide
12

Nitrogen Dioxide
10

Carbon Monoxide
7

National Clean Air Programme (NCAP) of India

Airshed: Asansol (WB)



NCAP cities (3)

Non NCAP cities (0)

Airshed size	Total population
60x40 ~1-km grids	**3.1** million

Urban pop share	Urban area share
70%	**45%**

Maximum pop density	Average pop density
22500 persons/km^2	**1800** persons/km^2

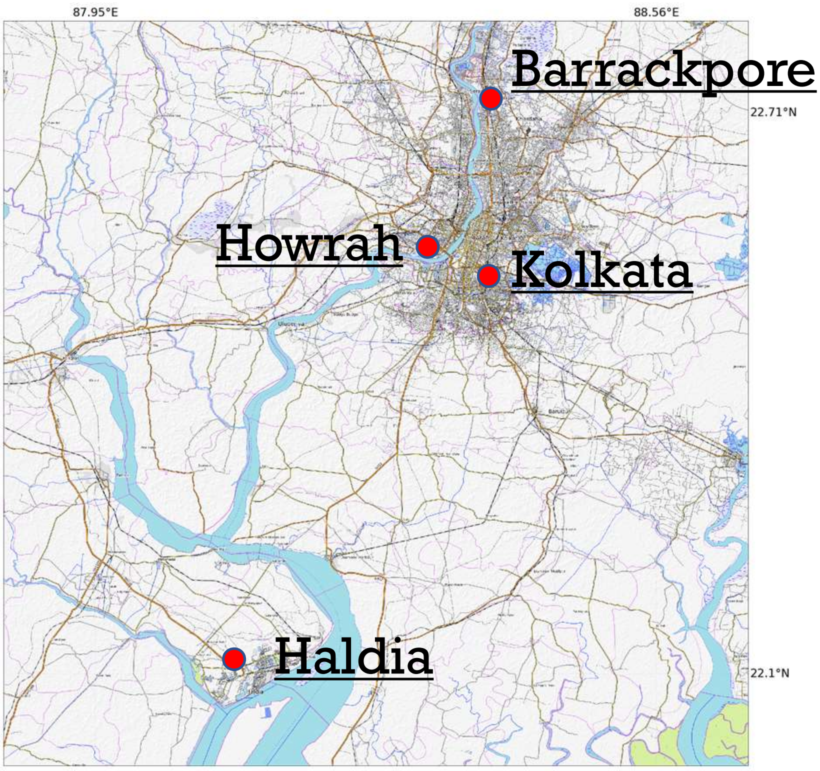
Minimum air monitors needed

Particulate matter	Sulphur Dioxide
19	**11**

Nitrogen Dioxide	Carbon Monoxide
10	**6**

National Clean Air Programme (NCAP) of India

Airshed: Kolkata (WB)



NCAP cities (4)
Non NCAP cities (0)

Airshed size
80x80
~1-km grids

Total population
19.6
million

Urban pop share
54%

Urban area share
14%

Maximum pop density
101100
persons/km^2

Average pop density
10900
persons/km^2

Minimum air monitors needed

Particulate matter
74

Sulphur Dioxide
20

Nitrogen Dioxide
10

Carbon Monoxide
16

Annex 1: Proposed and planned apportionment studies under NCAP and their status as of August 2020

Table 6: Proposed and planned apportionment studies under NCAP and their status as of August 2020. Source: Central Pollution Control Board, New Delhi, India

State	No. of cities	Non-attainment cities	Institutions conducting the study	Remarks
Andhra Pradesh	13	Vijayawada	Andhra Pradesh Pollution Control Board + Indian Institute of Technology (IIT) – Tirupati.	Study initiated
		Anantapur, Chitoor, Eluru, Guntur, Kadapa, Kurnool, Nellore, Ongole, Rajahmundry, Srikakulam, Visakhapatnam, Vizianagaram		Proposal stage
Assam	5	Guwahati, Nagaon, Nalbari, Sibsagar, Silchar	IIT-Guwahati	Memorandum of understanding (MoU) signed
Bihar	3	Gaya, Patna, Muzzafarpur	Asian Development Research Institute (ADRI), Centre for Study of Science, technology and Policy (CSTEP) and Urban Emissions	Ongoing
Chandigarh	1	Chandigarh		Proposal stage
Chhattisgarh	3	Bhilai, Korba, Raipur	IIT Kanpur	Proposal stage
Delhi	1	Delhi	CPCB, IIT-Kanpur, and The Energy Research Institute (TERI)	Studies conducted in 2010, 2016 and 2018 respectively
Gujarat	3	Surat, Ahmedabad	TERI and Gujarat Environment Management Institute	Study initiated
		Vadodara		Proposal stage
Himachal Pradesh	7	Baddi, Damtal, Kala Amb, Nalagarh, Paonta Sahib, Parwanoo, Sunder Nagar	IIT-Kanpur	Study initiated
Jammu and Kashmir	2	Jammu, Srinagar		Proposal stage
Jharkhand	1	Dhanbad	National Environmental Engineering Research Institute (NEERI)	Study initiated
Karnataka	4	Bengaluru	CSTEP	Study initiated
		Hubli-Dharwad, Devanagere, Gulbarga		Proposal stage
Madhya Pradesh	6	Bhopal, Indore	Automotive Research Association of India (ARAI), Pune	Study initiated
		Gwalior	IIT-Kanpur	Study initiated
		Dewas, Sagar, Ujjain		
Maharashtra	18	Mumbai, Pune	NEERI and IIT-Bombay	Completed
		Akola, Amravati, Auranagbad, Badlapur, Chandrapur, Jalgaon, Jalna, Kolhapur,	NEERI and IIT-Bombay	Study initiated

		Lathur, Nagpur, Nashik, Navi Mumbai, Sangli, Solapur, Thane, Ulhasnagar		
Meghalaya	1	Byrnihat		Not initiated
Nagaland	2	Dimapur, Kohima		Not initiated
Odisha	7	Angul, Talcher, Rourkela, Cuttack, Balasore, Bhubneshwar, Kalinga Nagar		Proposal stage
Punjab	10	Amritsar, Ludhiana	Punjab State Council for Science and Technology (PSCST) +TERI	Study initiated
		Dera Bassi, Dera Baba Nanak, Jalandhar, Khanna, Mandi, Gobindgarh, Naya Nangal, Patiala	IIT-Delhi	MoU signed
Rajasthan	5	Jaipur	IIT-Kanpur	Completed
		Jodhpur, Kota, Udaipur, Alwar		Not initiated
Tamil Nadu	2	Tirchy, Thootukuddi		Proposal stage
Telangana	4	Hyderabad	NEERI + Environment Protection Training and Research Institute (EPTRI)	Study initiated
		Nalgonda, Patencheru, Sangareddy		Not initiated
Uttar Pradesh	15	Ghaziabad	IIT-Delhi	Study initiated
		Agra, Allahabad, Kanpur, Lucknow, Varanasi	IIT-Kanpur	Study initiated
		Anpara, Bareily, Firozabad, Gajraula, Jhansi, Khurja, Moradabad, Noida, Raebareli		Not initiated
Uttarakhand	3	Rishikesh, Kashipur, Dehradun		Proposal stage
West Bengal	7	Kolkata	NEERI	Study initiated
		Asansol, Barrackpore, Durgapur, Haldia, Howrah, Ranigunj		Not initiated

Annex 2: Receptor model limitations

Receptor modelling involves quantitative assessment of source contributions using the source profiles to reproduce the total mass on the ambient filter for all the elements, ions, and carbon species (Watson, 1984). A variety of receptor models and methodologies are available with varying levels of benefits and limitations, e.g., CMB, enrichment factors, multiple linear regression, eigen vector analysis, time series, and PMF (see external Supplementary Material). Several early studies used unweighted models such as principal component analysis, which leads to less than adequate statistical resolution among sources than weighted models such as PMF and chemical mass balance (CMB) (Belis et al., 2014; Cesari et al., 2016). The latter models are strongly recommended for receptor modelling (Watson, 1984; Watson et al., 2002; Hopke, 2008; CPCB, 2011; Pant and Harrison, 2012; Hopke, 2016). CMB and PMF are the most used models. CMB is a MS Windows-based menu-driven model, with a library of source profiles from across the world for all the sectors at varying degree of granularity (Watson et al., 1997; Chow et al., 2015). A comparative table listing the benefits and limitations of various receptor models is included in the external Supplementary Material.

While the models are generic and are designed to run with any amount of the inputs, it is important to understand the shortfalls of the process.

Sampling sites

Most studies conduct sampling at 1-4 sites, often in urban areas with little information on regional background conditions. The number of sampling sites and number of sampling days need to be proportional to the demographic and commercial size of the city and represent seasonality in weather and pollution trends. Furthermore, statistical models such as the Positive Matrix Factorization (PMF) require at least 100 samples for matching of ambient samples and source chemical profiles (Hopke, 2016).

Particle size distribution

Most receptor modelling studies before 2015 lacked size fractionation of particulate matter and focused primarily on measuring and analysing TSP or PM_{10}. The lack of size separation also led to a lack of understanding of insights to be gained from crude separation of crustal/soil/road dust/construction sources (coarse particles) from those associated with high temperature processes like fuel combustion, metallurgical industries (fine particles) and gas-to-particle conversion to form secondary pollutants (also fine particles). This is due to the lack of sampling equipment and a lack of regulation on $PM_{2.5}$. $PM_{2.5}$ was first included in the list of criteria pollutants for mandatory measurements in the national air quality standards issued in 2009 and $PM_{2.5}$ measurements were included in the list of national ambient monitoring programme in 2016 (NAMP, 2020).

Source profile library

Since the term "*source*" in receptor modelling refers to a chemical profile, often distinguished only by the share of ions, metals, and carbon content, it can be difficult to separate sources using the same fuel. For example, biomass burning in an open field and the same biomass used for cooking will exhibit similar chemical signatures. Similarly, diesel combustion in a heavy-duty truck, bus, car, and a generator set; waste burnt at the landfill and at kerbside; coal combustion in a steel plant and thermal power plant; dust from the resuspension on the roads and construction activity; and petrol combustion in a car and a motorcycle. Use of molecular markers can help distinguish between some of these sources but such analyses are often more demanding in terms of instrumentation and analytical capabilities in a laboratory. As such, in most cases, ambient samples in most studies are analysed for elements, ions and carbon (organic and elemental carbon) (Patil et al., 2013). Most studies also used the existing source profiles, some from the six-city study using the source samples collected in 2006-07 (CPCB, 2011; Patil et al., 2013), some from individual studies (Matawle et al., 2014; Matawle et al., 2015; Pervez and Matawle, 2016; Samiksha et al., 2017; Bano et al., 2018; Pervez et al., 2018) and some from outside India. Since Patil et al (2013) (Patil et al., 2013), no new large scale studies have been conducted in India to establish a profile library. There is a need for new source profiles to represent the new fuel mix and emission regulations in place. For example, the vehicle fuel standard in 2006-07 was Bharat-I and II with high sulphur content as compared to the fuel available in 2020, which is Bharat-VI with less than 15 ppm sulphur.

Source profile selection

Use of appropriate profiles is crucial and requires prior understanding of the emission loads and influential sources in the immediate vicinity of the sampling location. For example, liquified petroleum gas (LPG) combustion for domestic cooking was identified as a key source for $PM_{2.5}$ in six cities, likely due to missing sources profiles or incorrect interpretation of source profiles (CPCB, 2011; Pant and Harrison, 2012), (CPCB, 2011), which goes against the conventional wisdom of promoting LPG as the cleanest fuel for urban and rural cooking in India (Jain et al., 2018; Pillarisetti et al., 2019; Gupta et al., 2020). This is a result of overemphasizing one profile or missing other key sources in the vicinity of the sampling site.

Secondary particle characterization

Several studies listed the secondary aerosols as a source, as sulphates, nitrates, and ammonium (CPCB, 2011; Gargava and Rajagopalan, 2016). In theory, these secondary components also need to be apportioned to sources of SO_2, NO_2, and ammonia gases. For example, SO_2 mostly coming from coal and diesel combustion; NO_2 from vehicle exhaust; and ammonia from agricultural activities. The secondary particles are a result of chemical transformation during the long-range transport and ignoring these sources result in neglecting the influence of the regional sources (Abdalmogith and Harrison, 2005; Guttikunda et al., 2019).

Annex 3: Summary of APnA City Program

A complementary exercise with information from top-down and bottom-up approaches can enrich the overall understanding of the sources in the airshed (Guttikunda and Kopakka, 2013; Guttikunda et al., 2013). Use of emission inventories was not common in the published receptor modelling studies. Baseline emission loads information is useful in determining the right source profiles for receptor modelling and selection of sampling “hotspot” sites. However, most Indian Tier-2 and Tier-3 cities (medium and small scale cities with population more than 1 million) do not have an official emissions inventory for the primary pollutants ($PM_{2.5}$, SO_2, NO_2, and CO) to feed this step. There are several global and regional emissions inventories (see annex 4) but often, the spatial resolution of such inventories is not appropriate for hotspot analysis in urban airsheds.

Guttikunda et al. (2019) presents an application of the bottom-up emissions modelling approach, data resources, and a summary of estimated source apportionment for 50 airsheds covering 60 cities, under the Air Pollution knowledge Assessments (APnA) city program (Guttikunda et al., 2019; UEinfo, 2019).

This study established a baseline emissions inventory at 1-km resolution for the cities and at 25-km resolution for the Indian Subcontinent, using a database compiled from statistics, census, energy, industrial, and environmental departments (UEinfo, 2020). Combined with local and regional meteorological data (NCEP, 2018) and CAMx regional chemical transport modelling system, the contributions of sources inside and outside the city airsheds were quantified.

Table 7: Summary of estimated source contributions (as %) under the APnA city program, including the contribution of sources outside the city airsheds (A = all transport; B = residential; C = industries; D = all dust; E = open waste burning; F= diesel generator sets; G = brick manufacturing; H = sea salt; and I = outside/regional contribution) (UEinfo, 2019)

	City/Airshed	All transport (A)	All residential (B)	Industries (C)	All dust (D)	Waste burning (E)	Gensets (F)	Brick kilns (G)	Seasalt (H)	Outside (I)
1	Agartala	17.5	14.9	4.3	15.3	8.3	2.7	2.1		34.9
2	Ahmedabad-Gandhi Nagar	14.9	6.6	12.4	17.7	8.4	6.5	0.7		32.8
3	Allahabad	18.6	12.5	6.2	14.9	4.0	4.1	3.2		36.6
4	Asansol-Durgapur	12.5	7.1	8.5	16.2	4.9	4.2	13.9		32.7
5	Aurangabad	10.8	4.3	18.7	10.7	12.0	6.7	1.9		34.9
6	Dharwad-Hubli	21.6	5.6	9.2	14.7	8.5	1.7	0.7		38.0
7	Dhanbad-Bokaro	12.2	4.1	12.5	29.2	2.6	3.0	4.3		32.2
8	Gaya	23.1	10.0	0.9	17.3	3.6	4.4	4.7		36.1
9	Guwahati-Dispur	36.5	6.8	5.2	27.0	6.8	1.7	0.8		15.1

	City/Airshed	All transport (A)	All residential (B)	Industries (C)	All dust (D)	Waste burning (E)	Gensets (F)	Brick kilns (G)	Seasalt (H)	Outside (I)
10	Gwalior	12.7	9.3	12.2	12.9	4.8	2.5	4.2		41.4
11	Hyderabad	16.5	4.8	14.8	18.6	12.9	6.8	0.2		25.3
12	Jamshedpur	19.5	6.6	25.8	15.0	3.0	3.7	2.2		24.1
13	Jodhpur	19.9	6.1	6.6	25.5	3.8	2.1	0.0		36.0
14	Kolkata-Howarh	13.5	8.6	17.6	12.5	12.8	9.4	6.7		19.0
15	Kota	16.7	8.0	19.5	12.5	4.7	1.4	0.5		36.6
16	Lucknow	13.0	24.3	4.3	13.9	7.5	3.3	3.5		30.1
17	Madurai	23.4	3.5	13.6	19.0	15.0	3.6	0.0		22.0
18	Mumbai	16.4	3.2	15.0	12.6	3.8	1.9	2.3	12.1	32.6
19	Nashik	12.1	6.6	15.8	13.2	8.7	3.6	0.9		39.1
20	Panjim-Vasco-Margao	22.6	0.6	4.5	12.6	2.8	2.6	0.0	17.0	37.3
21	Puducherry-Cuddalore	9.7	1.2	27.8	6.7	8.9	7.8	0.6	7.3	30.0
22	Rajkot	19.0	5.1	20.9	16.4	6.9	2.2	0.0		29.6
23	Shimla	17.4	11.8	0.2	11.8	5.5	1.0	0.0		52.2
24	Srinagar	9.8	41.3	0.8	8.2	6.4	7.4	1.8		24.4
25	Surat	16.4	1.7	31.4	10.3	9.8	3.3	0.3	5.6	21.2
26	Thiruvananthapuram	37.0	5.5	9.4	17.4	6.6	5.4	0.0	3.2	15.4
27	Tiruchirapalli	19.0	3.9	28.2	16.2	7.9	4.4	0.0		20.5
28	Vadodara	20.8	4.7	8.0	17.2	7.6	5.8	0.6		35.4
29	Vijayawada-Guntur-Tenali	22.7	3.5	11.7	19.7	9.3	5.9	1.4		25.8
30	Visakhapatnam	19.3	3.3	23.5	10.9	8.1	2.3	0.0	4.8	27.8
31	Agra	13.9	23.8	0.2	10.7	12.4	2.7	0		35.9
32	Amritsar-Tarn Taran	10.5	10.6	7.3	7.1	6.1	3.1	2.1		52.7
33	Bengaluru	26.5	9.8	2.1	23.0	16.1	4.0	2.5		15.6
34	Bhopal	14.1	10.2	2.8	17.1	8.7	4.9	0.0		41.8
35	Bhubaneswar	17.0	15.9	0.6	20.8	5.7	3.6	4.0		32.0
36	Chandigarh-Patiala-Ambala	10.6	11.4	1.3	12.6	8.9	2.6	1.3		50.8
37	Chennai	24.5	3.6	12.8	23.5	15.5	1.6	3.1	1.8	13.3
38	Coimbatore	18.3	6.4	11.1	13.7	14.1	2.4	1.0		32.5
39	Dehradun	14.2	14.3	1.3	4.4	19.6	3.8	0.4		41.7
40	Indore	26.9	8.1	2.4	22.7	7.8	2.0	2.0		27.8
41	Jaipur	24.1	13.4	2.4	17.5	8.4	2.2	1.7		29.9
42	Kanpur	13.7	33.8	6.5	8.9	8.8	4.1	1.2		22.5
43	Kochi	20.2	9.5	4.1	16.3	3.8	4.5	3.8	16.5	20.9
44	Ludhiana-Phillaur	16.3	7.8	7.9	12.3	9.2	2.6	2.8		40.7
45	Nagpur	17.2	6.8	26.7	10.9	11.6	1.8	3.2		21.4
46	Patna	14.8	14.6	11.2	12.1	12.9	5.4	9.3		19.2
47	Pune-Pimpri Chinchwad	24.0	5.8	9.8	23.4	6.4	2.8	2.6		24.7
48	Raipur-Durg-Bhillai	17.2	11.8	22.8	11.5	6.2	2.8	1.4		25.8
49	Ranchi	21.1	18.0	1.1	14.1	12.2	1.3	3.2		28.5
50	Varanasi	13.5	20.9	0.2	8.2	16.2	3.3	6.1		31.2

In the APnA program, minimum airshed size was 30 km x 30 km for the Tier-3 cities and the largest is 80 km x 80 km for Tier 1 cities like Delhi, Mumbai, and Kolkata, with satellite cities which mutually contribute to their commercial, industrial, transport, and economic activities. In the cities, most of the contributions is apportioned to vehicle exhaust; dust from resuspension on the roads and construction activities; domestic needs for cooking, lighting, and heating; open waste burning; and small-, medium-, and heavy-industries. In the Indo-Gangetic Plain, the contribution of the sources outside the airshed ranged between 30 to 40. In the state of Punjab, this is more than 50 due to regional sources like dust storms during the Spring months of Mar-May (Sarkar et al., 2019) and open fires during the post-harvest months of May-Jun and Oct-Nov (Jethva et al., 2018), space heating for most of the winter months across the state during Oct-Feb (Chowdhury et al., 2019), and brick manufacturing for most of the non-monsoonal months (Tibrewal et al., 2019). Under right meteorological conditions, these regional sources are significant contributors to the winter haze problem over the Indo-Gangetic Plain (Cusworth et al., 2018). In South India, the shares ranged between 15 for a coastal city like Chennai to 30 for the inland cities. While the contribution of the sources outside the city boundaries is substantial for all Indian cities, this can only be ascertained in emissions-based approach and it is mathematically difficult to differentiate in sampling-based approach.

The lack of an official emissions inventory for the country has led to the use of multiple global, regional, and national inventories for various studies ranging from understanding air quality in the cities to evaluating strategies for air pollution management to estimating health impacts. A summary of available global, regional, and national emissions inventories is included in annex 5.

Other bottom-up emissions modelling applications include using global emissions inventories and global chemical transport models to apportion source contributions to annual ambient $PM_{2.5}$ pollution and associated health impacts at the national and state level (Guo et al., 2017; GBD-MAPS, 2018; Guo et al., 2019; Purohit et al., 2019; Reddington et al., 2019). Due to their high population density and high annual average $PM_{2.5}$ pollution levels, states in the Indo-Gangetic plains record the highest number of estimated premature deaths. Coal and biomass burning for cooking and space heating; dust from resuspension on the roads, construction activities and wind erosion; coal combustion in the industries (including power plants) and vehicle exhaust in the city grids were the largest sources of concern. The global emissions inventory used in GBD-MAPS (2018) was supplemented with regional emissions information from the Speciated Multi-pollutant generator (SMoG-India) database (Pandey et al., 2014; Sadavarte and Venkataraman, 2014; Sarkar et al., 2016; Venkataraman et al., 2018; Tibrewal et al., 2019).

Annex 4: Raw & Processed Data Repository

This is a repository of links with information directly relevant for emissions and pollution analysis in India covering

A. Official national and state level portals; guidelines, acts, and rules documents
B. Ambient air quality monitoring
C. Satellite retrievals and tools
D. Global and regional health impact analysis and tools
E. Compiled statistics, maps, and other geospatial databases
F. Compiled databases on energy, emissions, meteorology, and reanalysis fields
G. Compiled statistics on Indian energy sectors

(Last accessed and updated in January 2021)

Updated links will be available @ https://www.urbanemissions.info

A. Official national and state level portals; guidelines, acts, and rules documents

National Clean Air Programme (NCAP)

- Draft NCAP proposal (2018)
- Final NCAP proposal (2019)
- City by city approved action plans are available here or here
- NCAP budget and pollution tracker (by CarbonCopy)
- A review of the 102 approved action plans – conducted by Urban Emissions and CEEW, July 2020. Final publication here.
- A review of 10 approved action plans – conducted by NRDC, January 2020

Official portals

- Ministry of Environment, Forests, and Climate Change (MoEFCC)
- National Green Tribunal (NGT)
- Environment Pollution (Protection & Control) Authority (EPCA)
- Central Pollution Control Board (CPCB)
- State Pollution Control Boards
    - [Andhra Pradesh] [Arunachal Pradesh] [Assam] [Bihar] [Chhattisgarh] [Goa] [Gujarat] [Haryana] [Himachal Pradesh] [Jharkhand] [Karnataka] [Kerala] [Madhya Pradesh] [Maharashtra] [Manipur] [Meghalaya] [Mizoram] [Nagaland] [Odisha] [Punjab] [Rajasthan] [Sikkim] [Tamil Nadu] [Telangana] [Tripura] [Uttar Pradesh] [Uttarakhand] [West Bengal]
- Pollution Control Committees
    - [Andaman & Nicobar Islands] [Chandigarh] [Dadra, Nagar Haveli, Daman, & Diu]
    - [Delhi] [Jammu & Kashmir] [Ladakh] [Lakshadweep] [Puducherry]
- National Environmental Engineering Research Institute (CSIR-NEERI)

Acts and Rules

- Air (Prevention and Control of Pollution) Act, 1981, amended 1987
    - Air (Prevention and Control of Pollution) Rules, 1982
    - Air (Prevention and Control of Pollution) Rules, 1983
- Environment (Protection) Act, 1986 and Rules thereunder
- National Green Tribunal Act, 2010
- National Ambient Air Quality Standards, amended 2009

Environmental Standards

- 17 major polluting industries
    - Aluminium Smelter, Caustic Soda, Cement, Copper Smelter, Distilleries, Dyes & Dye Intermediates, Fertiliser, Integrated Iron & Steel, Tanneries, Pesticides, Petrochemicals, Drugs & Pharmaceuticals, Pulp & Paper, Oil Refineries, Sugar, Thermal Power Plants, Zinc Smelter
- Effluent emission standards are listed @CPCB and @MoEFCC. Here is a summary for the heavy industry
    - [Bricks] [Cement] [Coal mines] [Coal washeries] [Copper, Lead, and Zinc smelting]
    - [Fertilizers] [Glass] [Iron and Steel] [Paper and Pulp] [Pesticides] [Petrochemicals]
    - [Sewage Treatment] [Sugar] [Tanneries] [Textiles] [Thermal power plants]

B. Ambient air quality monitoring

- 101 style blog piece on air monitoring in India
- Guidelines and technical specifications
    - 2003 – guidelines for ambient air monitoring
    - 2015 – technical specifications for continuous ambient air quality monitoring stations (CAAQMS)
    - 2018 – technical specifications for continuous emissions monitoring (CEMS)
- Number of monitoring states recommended by state and by district (based on the guidelines published by CPCB, 2003)
- National Ambient Monitoring Program (NAMP) – manual monitoring network operated and maintained by CPCB, India
    - Table of monitoring stations (as of July 2020)
    - Annual summary of air quality and number of monitoring days (2013, 2014, 2015, 2016, 2017, 2018)
    - Monthly AQI bulletins
    - Compiled NAMP air quality data (as excel) for 2011-2015
- Continuous Ambient Air Quality Monitoring System (CAAQMS) – real-time monitoring network operated and maintained by CPCB, India
    - How to access real-time and archived CAAQMS data?
- System of Air Quality and Weather Forecasting And Research (SAFAR) – real-time monitoring network operated and maintained by IITM, Pune, India
- A global summary of outdoor ambient air quality data by WHO (2018)
    - A review piece of WHO data included for India (2018)
- openaq.org – aggregator of official real-time monitoring data across the globe (blog piece on how to access data)
- IQair – aggregator of official and unofficial data across the globle
- Breezo.in – aggregator of official real-time monitoring data in India
- AirVeda – unofficial network of low-cost sensors
- AQI.in – unofficial network of low-cost sensors
- Purple Air – unofficial network of low-cost sensors
- Clarity – unofficial network of low-cost sensors
- Full resource links with illustrations

C. Satellite retrievals and tools

- Indian National Satellite System (INSAT) series
    - RAPID portal to visualize real-time INSAT products (IMD, Delhi)
    - Satellite derived PM2.5 (by ISRO, Dehradun)

    - Radar maps (IMD, Delhi)
    - Customized satellite maps for the Indian Subcontinent (IMD, Delhi)
- Geostationary Environment Monitoring Spectrometer (GEMS) – hourly air quality over East Asia and part Indian Subcontinent (new)
- Multi-Angle Imager for Aerosols (MAIA) (new)
- Tropospheric Monitoring Instrument (TROPOMI) – NO2, SO2, Ozone, HCHO, and CH4
- Active fire counts database from VIIRS satellite
- Active burned area product from MODIS satellite
- Fires visualization portal by NASA
- ACE-FTS and MAESTRO – 50+ gaseous species
- Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)
- Global Ozone Monitoring Experiment (GOME-2) – total column SO2, O3, NO2, and cloud parameters
- Measurement of Pollution in the Troposphere (MOPITT) – CO and CH4
- Total Ozone Mapping Spectrometer (TOMS) – Ozone
- Ozone Monitoring Instrument (OMI) – near real time SO2, O3, and AOD
- Moderate Resolution Imaging Spectroradiometer (MODIS)
    - near real time Aerosol Optical Depth (AOD)
    - Leaf Area Index (LAI) data sets were generated by reprocessing the MODIS version 6 LAI products for 2000 to 2019at multiple resolutions
- Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) – multiple gases
- Optical Spectograph and Infrared Imaging System (OSIRIS) – O3 and NO2
- Multi-angle Imaging Spectrometer (MISR) – dust storms and aerosols
- Global Precipitation Measurements (GPM)
- Data centers and access methods
    - World Data Center (WDC)
    - Earth Data (NASA)
    - Data access methods (NASA)
    - Copernicus open access hub (ESA)
    - Aura Validation Data Center (AVDC, NASA)
    - The Wisconsin Horizontal Interpolation Program for Satellites (WHIPS)
    - Atmospheric Tool Box (ATB) for Sentinel-5P products
    - Google Earth Engine (GEE) for Sentinel-5P products

D. Global and regional health impact analysis and tools

- Visualization portal for 1990-2018 global burden of disease estimates (IHME-GBD)
    - Resource links to methodology and inputs
- Visualization portal for State of the Global Air (SOGA) by Health Effects Institute (HEI)
    - India factsheet and more
- India state-level disease burden initiative by ICMR and PHFI (2019)
    - State-level reports (PHFI)
- Burden of disease attributable to major sources of air pollution in India (GBDMAPS-India) by HEI
- Air Quality Life Index (AQLI) by U.Chicago
- Health impacts analysis tools
    - Household Air Pollution Intervention Tool (HAPIT)
    - Air pollution health effects online tool by TERI
    - CO-Benefits Risk Assessment (COBRA) health impacts screening and mapping tool by USEPA
    - Environmental BENefits MAPping and analysis program (BENMAP) by USEPA
    - AirCounts tool by Abt Associates
    - Tool for health risk assessment of air pollution – AirQ+ by WHO
    - FAst Scenario Screening Tool (FASST) by EU
    - Greenhouse gas – Air pollution INteractions and Synergies (GAINS) by IIASA
    - The Long-range Energy Alternatives Planning – Integrated Benefits Calculator (LEAP-IBC) by SEI
    - Simple Internative Models for better air quality (SIM-air) by Urban Emissions

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E. Compiled statistics, maps, and other geospatial databases

Compiled national and state level statistics

- Census India (2011)
- Indiastats.com (paid statistics service)
- Statista.com (paid statistics service)
- Statistical Year Book (SYB) of India by MoSPI
- Energy Statistics of India by MoSPI
- Directorate of Statistics by state
    - [Andhra Pradesh] [Assam] [Bihar] [Chandigarh] [Chhattisgarh] [Delhi] [Goa] [Gujarat] [Haryana] [Himachal Pradesh] [Jammu & Kashmir] [Jharkhand] [Karnataka] [Kerala] [Madhya Pradesh] [Maharashtra] [Manipur] [Meghalaya] [Mizoram] [Nagaland] [Odisha] [Puducherry] [Punjab] [Rajasthan] [Sikkim] [Tamil Nadu] [Telangana] [Tripura] [Uttarakhand] [Uttar Pradesh] [West Bengal]

Compiled GIS data and maps

- Community created maps of India by datameet
- Openstreetmaps (GIS)
- Mapcruzin.com (GIS)
- Global Human Settlements (GHS) – urban built areas
- Land cover data 1992-2015 (ESA)
- Gridded Population
    - Global database GPW from SEDAC
    - Global database Landscan from ORNL
    - India database for 2011-2050 at 0.25° resolution from Urban Emissions

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F. Compiled databases on energy, emissions, meteorology, and reanalysis fields

Compiled energy databases

- India energy dashboard by Niti Aayog
- India Energy Security Scenarios (IESS) by Niti Aayog
- GHG Platform India (GPI) by multiple agencies
- International Energy Agency (IEA)
- Greenhouse gas – Air pollution INteractions and Synergies (GAINS) by IIASA

Compiled emission databases

- MIX regional emissions database for Asia
- REAS regional emissions database for Asia
- EDGAR global emissions inventory
- CAMS global emissions inventory
- ECCAD global compilation of emissions and ancillary data
- SAFAR India emissions inventory by Indian Institute of Tropical Meteorology (contact)
- SMoG-India emissions inventory by Indian Institute of Technology, Bombay
- OMI-HTAPv2.2 SO2 global emissions inventory 2005-2019 (NASA)
- Greenhouse gas – Air pollution INteractions and Synergies (GAINS) by IIASA
- MEGAN global biogenic emissions
- Forest and agricultural fires
    - Fire emissions Inventory from NCAR (FINN) by UCAR
    - Global fire emissions database (GFED)
    - Global fire emissions database (IS4FIRES)
    - Blended global fire emissions database (GBBEPx V3) by NOAA
    - Global quick fire emissions database (QFED) by NASA
    - Global fire assimilation system (GFAS) by ECMWF

Compiled meteorological fields

- Indian Meteorological Department (IMD)
- Climate Explorer by KNMI for stationwise data
- NCEP global reanalysis fields (long-term achives)
- Global Forecast System (GFS) fields (short-term archives)
- Windy (open visualization portal)
- Earth Nullschool (open visualization portal)
- Compiled meteorological data for Indian districts (from Urban Emissions)

Compiled modeled reanalysis fields

- MOZART global model by UCAR
- CAM-chem global community earth system model by UCAR
- CAMS global reanalysis model by ECMWF
- MERRA-2 global reanalysis model by NASA
- SAANS India reanalysis model by IIT-Delhi
- Global PM2.5 reanalysis by WUSTL
    - Extracted India database for 1998-2018 from Urban Emissions

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G. Compiled statistics on Indian energy sectors

Industry

- Annual Survey of Industries (ASI) by the Ministry of Statistics and Programme Implementation (MoSPI)
- Annual reports by MOSPI
- Annual reports by the Ministry of Steel
- Annual reports by the Ministry of Chemicals and Fertilizers
- Annual reports by the Ministry of Mines
- Annual reports by the Cement Manufacturers Association
- Annual reports by the Ministry of Micro, Small, and Medium Enterprises
- Annual reports by the Ministry of Textiles
- Annual reports by the Ministry of Coal
- Annual reports by the Ministry of Petroleum and Natural Gas
- Annual reports by the Department of Heavy Industry
- Annual reports by the Department of Animal Husbandry and Dairy
- Annual reports by the Department of Fisheries
- Annual reports by the Department of Pharmaceuticals
- Annual reports by the Department of Chemical and Petro-chemicals

Power Plants

- Official portals
    - Ministry of Power (MoP)
    - Ministry of Petroleum and Natural Gas (MoPNG)
    - Ministry of New and Renewable Energy (MNRE)
    - Ministry of Coal (MoC)
    - Central Electrical Authority (CEA) daily reports
    - National Power Portal (NPP) dashboard
    - Merit order dispatch of Electricity for Rejuvenating Income and Transparency (MERIT) by MoP
- Other portals
    - Coal India Limited (CIL)
    - Gas Authority of India Limited (GAIL)
    - Solar Energy Corporation of India (SECI)
    - National energy policy (Niti Aayog)
    - India Energy Review (IEA)
- Wikipedia
    - Electricity sector in India
    - Energy policy in India
    - Renewable energy in India

- Solar power in India
- Regulations
  - Central Electricity Regulatory Corporation – current regulations
  - India Electricity Act (2003)
  - Environmental Standards for Ambient Air, Automobiles, Fuels, Industries and Noise (CPCB, 2000)
  - Industry effluent emission standards (CPCB)
  - Online monitoring of industrial emissions & effluent (CPCB)
- Power plants list
  - Global power plants database (WRI)
  - Global power plants database (GEO)
  - Global power plants database (Carbon Brief)
  - Existing power plants in India (Wikipedia)
  - Existing and proposed power plants in India (GEM-wiki)
  - Existing power companies in India (GEM-wiki)
  - Plant and unit level generation data (CEEW)
  - Hourly load curves 2012-2015 (CEEW)
  - Electricity generation and carbon tracker – dashboard by Brookings India
- Regional Load Dispatch Centers
  - Northern (NRLDC)
  - Sorthern (SRLDC)
  - Eastern (ERLDC)
  - Western (WRLDC)
  - NorthEastern (NERLDC)
- State Load Dispatch Centers
  - [Andhra Pradesh] [Assam] [Chhattisgarh] [Delhi] [Gujarat] [Himachal Pradesh]
  - [Karnataka] [Kerala] [Madhya Pradesh] [Maharashtra] [Odisha] [Punjab]
  - [Rajasthan] [Tamil Nadu] [Uttar Pradesh] [Uttarakhand] [West Bengal]
- Non-governmental institutions
  - Brookings India
  - Center for Science and Environment (CSE)
  - Center for Study of Science Technology and Policy (CSTEP)
  - Council for Energy Environment and Water (CEEW)
  - GHG Platform India (GPI)
  - Institute for Energy Economics and Financial Analysis (IEEFA)

Transport (road)

- National Transport Development Policy Committee (NTDPC) report – Moving India to 2032
- Annual reports by the Ministry of Road Transport and Highways
- Annual reports by the Ministry of Petroleum and Natural Gas
- Urban transport reports by the Ministry of Housing and Urban Affairs
- AMRUT/JNNURM city development reports
- Smart Cities Mission – city development reports
- Google directions API for traffic speeds (paid service)
  - Google mobility statistics during COVID-19
- Tom Tom traffic index (paid service)

Transport (rail, aviation, and shipping)

- Shipping – full resource links
- Aviation global emissions inventory by EDGAR
- Departures and arrivals information by AirSewa
- Railway train schedules
- Departures and arrivals information by flightstats (paid service)
- Cargo tonnage by rail and aviation by indiastats.com (paid service)

Open waste burning

- Global trash burning emissions inventory by UCAR
- waste management in India (database)
- Gridded open waste burning emissions in India (2019)

Annex 5: Emission Inventories

Table 8: Global & regional emission inventories covering the Indian Subcontinent

Reference	Database	Remarks
(Pandey et al., 2014; Sadavarte and Venkataraman, 2014; Sarkar et al., 2016; Venkataraman et al., 2018)	Anthropogenic sources Speciated Multi-Pollutant Generator (SMoG) for India https://sites.google.com/site/profchandralab/resources/smog-india-v1	Species: SO_2, NO_x, CO, NMVOC (speciated for CB06 and SAPC99), $PM_{2.5}$, BC, OC, and minerals Years: 2005 and 2014 Spatial resolution: 0.25° by 0.25° Temporal resolution: Annual Version 1.0 was used in (GBD-MAPS, 2018)
(Li et al., 2017)	Anthropogenic sources Model Inter-Comparison Study for Asia (MIX) http://www.meicmodel.com/dataset-mix.html	Species: SO_2, NO_x, CO, NMVOC (speciated for CB06 and SAPC99), PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 2008 and 2010 Spatial resolution: 0.25° by 0.25° Temporal resolution: Monthly
(Kurokawa et al., 2013)	Anthropogenic sources Regional Emission inventory in ASia (REAS) https://www.nies.go.jp/REAS/	Species: SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 1950-2015 Spatial resolution: 0.25° by 0.25° Temporal resolution: Monthly
(Purohit et al., 2019)	Anthropogenic sources Greenhouse Gas - Air Pollution Interactions and Synergies (GAINS) https://gains.iiasa.ac.at/gains/	Species: SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 2015 Spatial resolution: 0.5° by 0.5° Temporal resolution: Annual
(Crippa et al., 2020)	Anthropogenic sources EDGAR v5.0 Global Air Pollutant Emissions https://edgar.jrc.ec.europa.eu/overview.php?v=50_AP	Species: SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 1970-2015 Spatial resolution: 0.1° by 0.1° Temporal resolution: Annual
(Granier et al., 2019)	Anthropogenic, natural, and open fire sources Copernicus Atmospheric Monitoring Service (CAMS) https://atmosphere.copernicus.eu/emissions-products	Species: SO_2, NO_x, CO, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 2000-2008 Spatial resolution: 0.1° by 0.1° Temporal resolution: Annual
(Liu et al., 2018)	Anthropogenic and volcanic sources OMI-HTAPv2.2 satellite-derived and bottom-up emissions https://avdc.gsfc.nasa.gov/pub/data/project/OMI_HTAP_emis/v1.1/	Species: SO_2 Years: 2005-2019 Spatial resolution: 0.1° by 0.1° Temporal resolution: Monthly
(Wiedinmyer et al., 2011)	Open fire sources Fire INventory from NCAR (FINN) http://bai.acom.ucar.edu/Data/fire/	Species: (open fires only) SO_2, NO_x, CO, NMVOC (speciated), PM_{10}, $PM_{2.5}$, BC, OC, NH_3, and CO_2 Years: 2000-2019 Spatial resolution: 0.1° by 0.1° Temporal resolution: Daily

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