Status of air quality monitoring in India: Spatial spread, population coverage and data completeness

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When compliance with the National Ambient Air Quality Standards and the clean air targets under the National Clean Air Programme requires robust air quality monitoring for trend assessment, only 12 per cent of the of 4041 Census cities and towns have air quality monitoring systems and only 200 cities monitor all six key criteria pollutants.

This leaves nearly 47 per cent of the country's population outside the maximum radius of air quality monitoring grid (manual and real time combined) and 62 per cent are outside that of real time monitoring network.

This has emerged from the new assessment by the Centre for Science and Environment (CSE) of the status of air quality monitoring grid in the country.

Limited air quality monitoring makes it challenging to identify non-attainment status of a vast number of towns/ cities and regions and also impedes effective evaluation of clean air action and improvement in air quality needed for evaluation of performance of clean air action especially under the 15th Finance Commission grant. More harmful PM2.5 and ozone are not considered for compliance under NCAP due to limited monitoring and data. It is necessary to ensure more equitable distribution of monitors and adoption of hybrid monitoring with standardized and certified air sensor network and satellite based monitoring with appropriate protocol for maximum and cost effective coverage of population to support action.

The current monitoring network also faces the challenge of inadequate data generation, lack of data completeness and poor quality control of monitoring. This makes air quality trend assessment difficult to establish compliance with clean air targets. The current urban monitoring grid is highly concentrated in a few big cities and there are vast areas in other regions with no monitoring. This needs to be rationalized to cover wider population and habitats to support implementation of clean air action plans, provide information to public about the daily risks and design emergency response and longer term action.

Urban Lab at the Centre for Science and Environment (CSE) has analysed the existing air quality monitoring network from the perspective of adequacy of the network and air quality data. It has analysed the spatial spread, population coverage and data completeness of ambient air quality monitoring in India. The objective is to understand the state of monitoring quantitatively and qualitatively, and highlight gaps in the current network. This state-wise analysis aims to inform state-level action air quality monitoring which is largely the responsibility of state pollution control boards and committees.

This has considered two separate ambient air quality monitoring networks in India - National Air Quality Monitoring Programme (NAMP) that comprises only manual monitoring stations and CAAQMS (Continuous Ambient Air Quality Monitoring System) that comprise of only real time monitoring stations.

This assessment has also analyzed data completeness for PM2.5 i.e how adequate and complete the data generation is to enable proper air quality trend assessment. This analysis is based on the publicly available data from CPCB websites and publications as of 31 December 2022. This analysis covers 883 manual stations under NAMP and 409 real time stations under CAAQMS.

Monitoring stations' coordinates have made use of Google Maps API based on their address information (generally mentioned as locality in a city/ state) available from CPCB website and publications. These are approximate location and not exact geographical coordinate of the stations as CPCB does not provide that information.

To be able to assess the extent of population coverage by the monitoring grid, population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, of the School of Geography and Environmental Sciences at the University of Southampton. State and district boundaries are as of June 2022 and includes 28 states and 8 union territories (UTs), with a total of 36 entities. The states and union territories are further subdivided into 755 districts. Since then 11 more districts have been carved out but these are not included in this analysis.

Key findings

Official guidelines recommending monitoring requirement: It is first important to understand what are the official recommendations and specifications for setting up monitoring stations for different regulated pollutants. The Indian Standard 5182 Methods for Measurement of Air Pollution - Part 14 : Guidelines for Planning the Sampling of Atmosphere: 2000 (Reaffirmed Year : 2019) [reffered as *IS 2182: Part 14* from here onwards] recommend the minimum number of monitoring stations for cities and towns are to be set up as per their population size.

Towns smaller than 100,000 inhabitants require a minimum of four particulate matter (PM) monitoring stations, three for sulphur dioxide (SO2) monitoring stations, four for nitrogen dioxide (NO2) monitoring and one for CO and oxidants like surface ozone. Number of stations increases telescopically as the population of the towns and cities increase and this is based on factors defined in the standard itself (See *Table 1: Recommended minimum number of stations as per IS 5182: Part 14*).

As per 2011 census, India has 4041 satutory towns. As per the UN population data base for 2020 about 63 census towns have more than a million inhabitants. As per the IS 5182, these million plus cities require 959 PM mointors, 643 SO2 monitors, 630 NO2 monitors and 320 monitors for CO and surface ozone each (See *Graph 1: Number of monitoring stations required in India as per IS 5182: Part 14*).

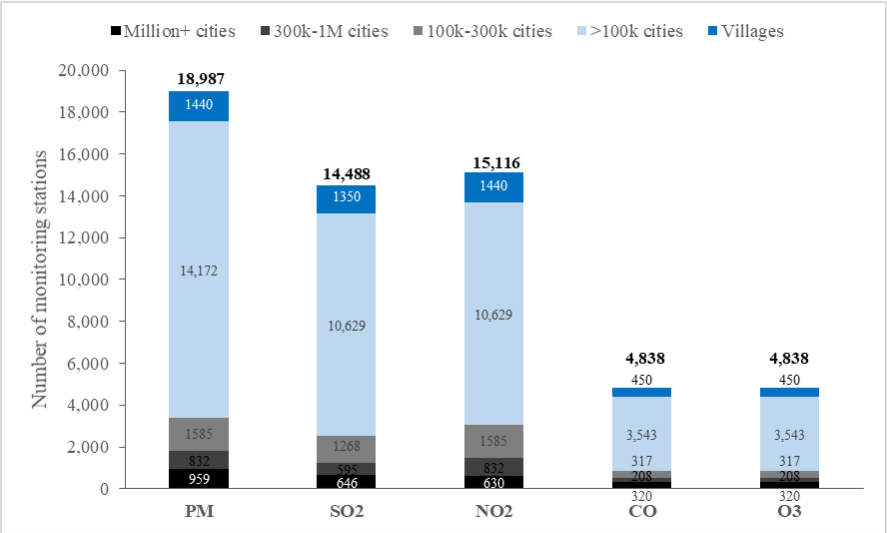
Cities with population in the range of 100,000 and a million need 2,417 PM mointors, 1,863 SO2 monitors, 2,417 NO2 monitors and 525 mointors for CO and surface ozone each. The requirement for small towns with population less than 100,000 is staggering and adds up to 14,172 PM mointors, 10,629 SO2 monitors, 10,629 NO2 monitors and 3,543 mointors for CO and surface ozone each.

Table 1: Recommended minimum number of stations as per IS 5182: Part 14

Pollutant	Population of Evaluation Area	Minimum No. of AAQ Monitoring Station
SPM (Hi-Vol.)	<100 000	4
	100 000- 1000 000	4+0.6 per 100 000 population
	1000 000 – 5000 000	7.5 + 0.25 per 100 000 population
	>5000 000	12 + 0.16 per 100 000 population
SO_2 (Bubbler)	<100 000	3
	100 000- 1 000 000	2.5+0.5 per 100 000 population
	1000 000 - 10 000 000	6+0.15 per 100 000 population
	>10 000 000	20
NO_2 (Bubbler)	<100 000	4
	100 000- 1000 000	4+0.6 per 100 000 population
	>1000 000	10
CO	<100 000	1
	100 000- 5 000 000	1+0.15 per 100 000 population
	>5 000 000	6+0.05 per 100 000 population
Oxidants	-do-	-do-

Source: Indian Standard 5182 Methods for Measurement of Air Pollution - Part 14 : Guidelines for Planning the Sampling of Atmosphere: 2000 (Reaffirmed Year : 2019)

Graph 1: Number of monitoring stations required as per the guidelines IS 5182: Part 14

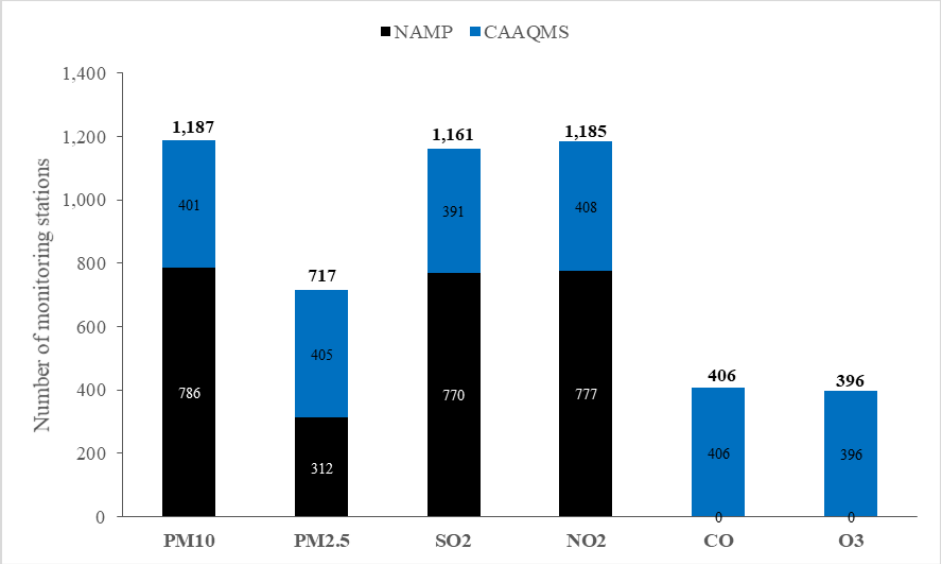


Source: CSE analysis

Rural moitoring: IS 5182: Part 14 does not provide a design matrix for monitoring in rural areas. For this analysis CSE has used the telescopic factors given in the standard for calculating mointoring station requirement per 100,000 population to estimate minimum monitoring needed for rural population. Following factors were used -- for PM and NO2 factor of 0.15 per 100,000 population; for SO2 0.15 per 100,000 population; and for CO and surface ozone 0.05 per 100,000 population. Given that the rural population of India in 2020 as per UN population estitmate stood at 900,099,113 (about 900 million) the minimum monitoring requirement works out to be 1,440 PM mointors, 1,350 SO2 monitors, 1,440 NO2 monitors and 450 mointors for CO and surface ozone each (See *Graph 1: Number of monitoring stations required as per the guidelines IS 5182: Part 14*).

Falling short of the recommended target: The capacity of monitoring that exists in India as of 1 January 2023 barely adds up to 6-8 per cent of the minimum monitoring recommended as per IS 5182: Part 14. There are only 1,187 PM10 mointors, 717 PM2.5 monitors, 1,161 SO2 monitors, 1,185 NO2 monitors, 406 CO mointors and 396 surface ozone monitors (See *Graph:2 Number of monitoring stations in India as of 1 January 2023*).

Graph 2: Number of monitoring stations in India as of 1 January 2023



Note: As per 1 January 2023. Based on CPCB data.
Source: CSE analysis

Regulated or criteria pollutants included for regular monitoring: The National Ambient Air Quality Standards (NAAQS) that define the regulatory standards for pollutants determine the inclusion of the range of pollutants to be monitored. NAAQS is defined for 12 pollutants of which PM10, PM2.5, NO2, SO2, carbon-monoxide (CO), ozone (O3), ammonia (NH3), and lead (Pb) have been considered. The remaining namely ammonia, benzene, benzopyrene, lead, arsenic and nickel, have not been investigated in detail but an attempt has been made to understand the status of their monitoring. Ammonia and benzene are monitored at most CAAQMS stations that monitor CO and ground-level ozone. No records could be found in public domain regarding their monitoring at NAMP stations.

Lead, arsenic and nickel are monitored as a fraction of PM10 and are only undertaken as special monitoring done for Diwali by CPCB. Latest Diwali special monitoring report available in public domain is from 2020 and it reports lead, arsenic and nickel monitoring was undertaken at 18 NAMP stations in eight cities. This special monitoring is done for only 15 days (Diwali day and seven days before and after Diwali). This monitoring involves chemical assessment of collected PM10 samples therefore it is only possible at manual monitoring stations as most regular CAAQMS stations do not sample PM10 in a fashion that can allow this chemical assessment. No public records could be found for benzopyrene monitoring.

The six criteria pollutants that are more ubiquitous and represent the overall air quality health. There are also group of air toxins that need to be eliminated from the air and are monitored at a limited scale and are regulated by setting trace level targets.

Technical specification for monitoring of each pollutant is defined. While PM10, NO2, and SO2 are most widely monitored comparatively the monitoring of PM2.5 is not as extensive and that of ozone is very limited.

PM10 has the highest number of stations followed by NO2 and SO2. The PM2.5 is much lower and that of ozone is very inadequate. (See Table 2: Pollutant-wise total number of monitoring stations in the country).

Table 2: Pollutant-wise total number of monitoring stations in the country

	NAMP	CAAQMS	Total
SO2	770	391	1161
NO2	777	408	1185
PM10	786	401	1187
PM2.5	312	405	717
O3	0	396	396
CO	0	406	406

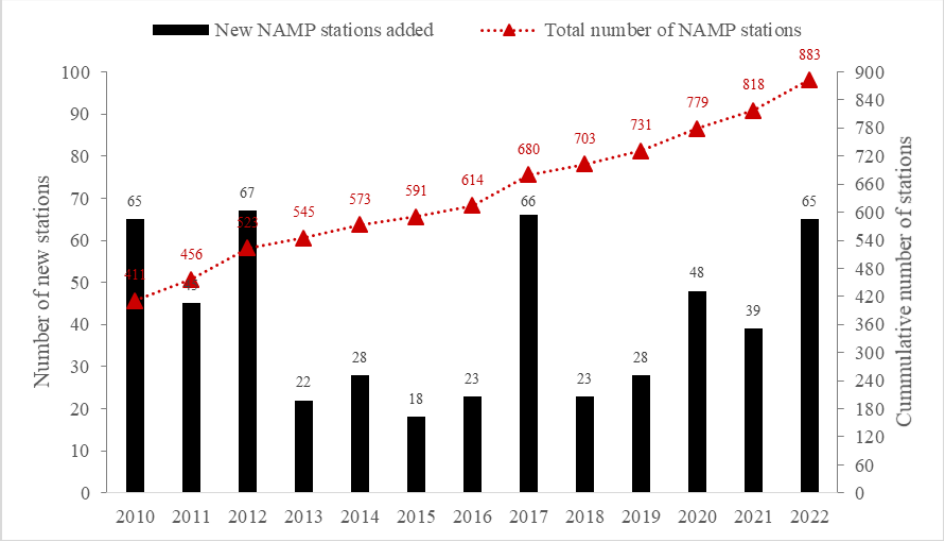
Source: CSE analysis based on CPCB data

Number of manual monitoring stations have doubled since 2010: According to CPCB there are 883 operating manual stations in 379 cities/towns in 28 states and 7 Union Territories (UTs) of the country. This information is based on 15 September 2022 update by CPCB on their website.

Manual ambient air quality monitoring network includes 818 operating stations covering 352 cities/towns in 29 States and 6 UTs in 2020-21 as per the CPCB´s Annual Report 2020-21. About 65 new manual stations and 27 new cities have been added to the network in 2021-22 (See *Graph 3: Growth in manual (NAMP) stations 2010-2022*).

CPCB has not published station-wise monitoring data after NAMP 2020 report. As a result it is not possible to assess if all the stations on record are functioning or not. For instance, 2020 NAMP report had monitoring information from only 711 stations despite 818 stations listed on record for that year. In fact there are at least 20 stations on the CPCB´s list which have not reported any monitoring data in last five years. For example, the Curchorem Station in Goa has been shut since August 2018[i] but has not been removed from CPCB´s list of NAMP stations.

Graph 3: Growth in manual (NAMP) stations 2010-2022

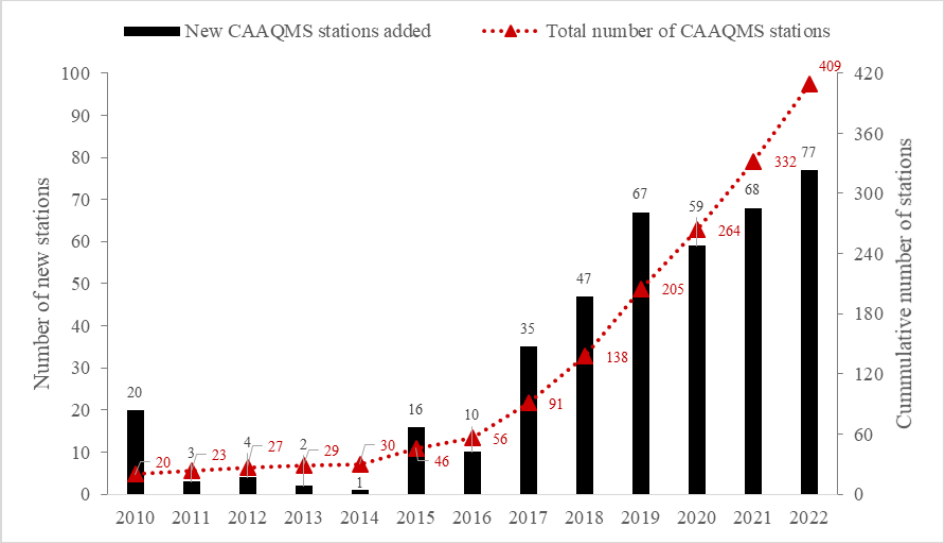


Source: CSE analysis of CPCB data

Number of real time monitoring stations have grown 20-fold since 2010: There were 409 real time CAAQMS stations in the country spread across 209 cities/towns in 27 states and 4 Union Territories of the country. Of these 77 stations were added in 2022 itself (See *Graph 4: Growth in real time (CAAQMS) stations 2010-2022*). As of 22 February 2023, 23 new stations and 18 new cities have been added to the network, taking total count to 423 spread across 221 cities.

Dysfunctional stations are still included the list. It is therefore not always possible to assess actual operating stations in the country. For example, at least four stations have not reported any monitoring data in last few years. These include Airoli station in Navi Mumbai, Bandra station in Mumbai, PWD Grounds station in Vijaywada and Nishant Ganj station in Lucknow.

Graph 4: Growth in real time (CAAQMS) stations 2010-2022



Source: CSE analysis of CPCB data

Extent of population covered by air quality monitoring grid

Methodology adopted for estimating population coverage: Specification and design of air quality monitoring network is solely based on population in India. Therefore, it makes sense to assess the network coverage in terms of population within the influence area. Air quality reported by a station is understood to be accurate representation of ambient air in its 2km radius, while it can be considered fairly representative for ambient air 2-10km away from the station. If no major topographical or human-made features exist then the air quality reported at a station can be considered a good proxy for ambient air 10-50km away from the station. The 2019 UNICEF report "Silent Suffocation in Africa: Air Pollution is a Growing Menace, Affecting the Poorest Children the Most" uses same principle to estimate percentage of children living within a 50km radius of air monitoring stations. Therefore, people living in 2km, 10km and 50km radius (aerial distance) of each monitoring station has been considered for population coverage.[1]

Technically, an imaginary circle is drawn with the monitoring station at its center and then number of people living inside that imaginary circle is counted. In cities like Delhi and Mumbai where monitoring stations are located less than 50km apart, considerable population overlap is normal (multiple stations are covering same people due to close location of stations). This overlap is accounted and corrected for while computing the effective population coverage by the monitoring network by removing all instances of double or multiple counting.

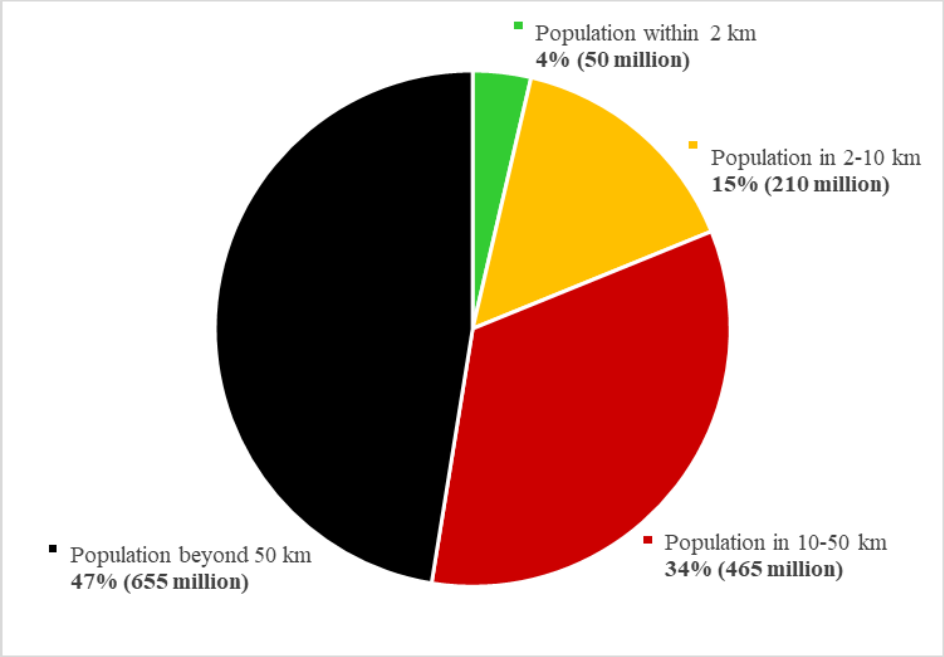
Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.[2]

47 per cent of population – close to half, - live outside the 50km radius coverage of combined manual and realtime air quality monitoring network of India: About 47 per cent of Indian population or about 655 million people lives outside 50 km radius of the air quality monitoring stations (NAMP and CAAQMS combined). Only 4 per cent of the population or about 50 million people lives within the immediate coverage zone of 2km radius of the monitoring stations (See *Graph 5: Population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022*). 15 per cent of the population lives in 2-10km radius and about 34 per cent lives in 10-50 km radius.

[1] **Population coverage:** The Center for International Earth Science Information Network (CIESIN) in partnership with UNICEF developed methodologies to assess the vulnerability of children to various climate change indicators and developed children climate risk index. CIESIN is part of Columbia Climate School at Columbia University, USA. CIESIN and UNICEF have adopted the percentage of children living within a 50km radius of realtime air quality monitoring stations as the indicator for air pollution risk communication (vis-a-vis AQI). The methodology uses a gridded population map (like the WorldPop research program) to estimate the number of children living within an imaginary 50 km (aerial distance) around a realtime air quality monitoring station. This methodology is not based on air pollution science or meteorology but is developed from an administrative perspective with the objective understanding of the reliability of realtime health risk communication. This methodology has been used in the 2019 UNICEF report "Silent Suffocation in Africa: Air Pollution is a Growing Menace, Affecting the Poorest Children the Most" and the 2021 UNICEF report "The Climate Crisis is a Child Rights Crisis: Introducing the Children's Climate Risk Index".

[2] **Population data:** The population data is sourced from the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. WorldPop has mapped populations across the globe to a 100mx100m grid by linking satellite imagery of settlements (built-up area) with gazetteer population numbers (official census data) from governments and UN agencies. Where census data are outdated or unreliable, WorldPop has been collaborating with the Bill and Melinda Gates Foundation and Oak Ridge National Laboratories to develop approaches to estimating population distributions at high spatial resolution through a combination of satellite-derived feature extractions and household surveys. This work is being done in partnership with the national governments and UN agencies.

Graph 5: Population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022



Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publicly available.
Source: CSE analysis

Only Chandigarh, Delhi and Goa have full population coverage under the combined monitoring network: Chandigarh has highest share of its population covered by monitoring stations. 40 per cent of the UT population lives within 2km radius of city´s 8 monitoring stations (5 NAMP and 3 CAAQMS) and the entire population is within 50km radius of monitoring network (See *Graph 6: State-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022* & *Map 1: State-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022*).

Delhi has the second best coverage with 26 per cent of its population residing within 2km radius of its 50 monitoring stations (10 NAMP and 40 CAAQMS). 100 per cent of Delhi´s population is covered in the 50km radius of the Monitoring network.

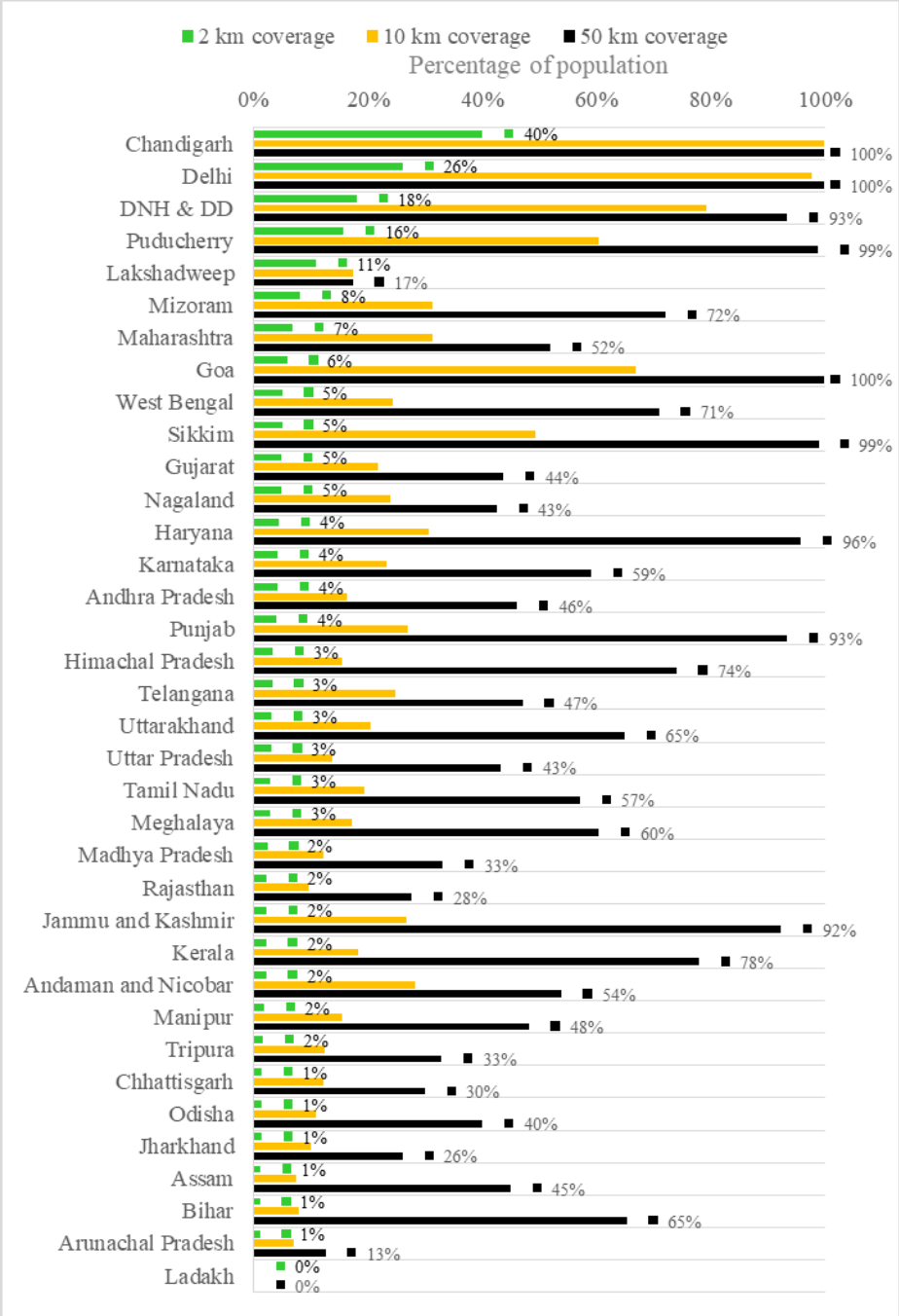
Among states, Manipur, Maharashtra and Goa have the highest direct population (within 2km radius) among states with 8 per cent, 7 per cent and 6 per cent respectively. Given the equitable distribution of its 18 monitoring stations (18 NAMP and 0 CAAQMS) Goa is able to cover 100 per cent of its population within 50km radius of monitoring grid.

States of Haryana, Punjab and UTs of J&K, Puducherry, and Dadar and Nagar Haveli and Daman and Diu have achieved over 90 per cent population coverage (within 50km radius) by equitability distributing their monitoring stations.

The 50km radius coverage for Maharashtra is just 52 per cent despite relatively high direct coverage (with 2km radius) due to poor spatial planning of the network.

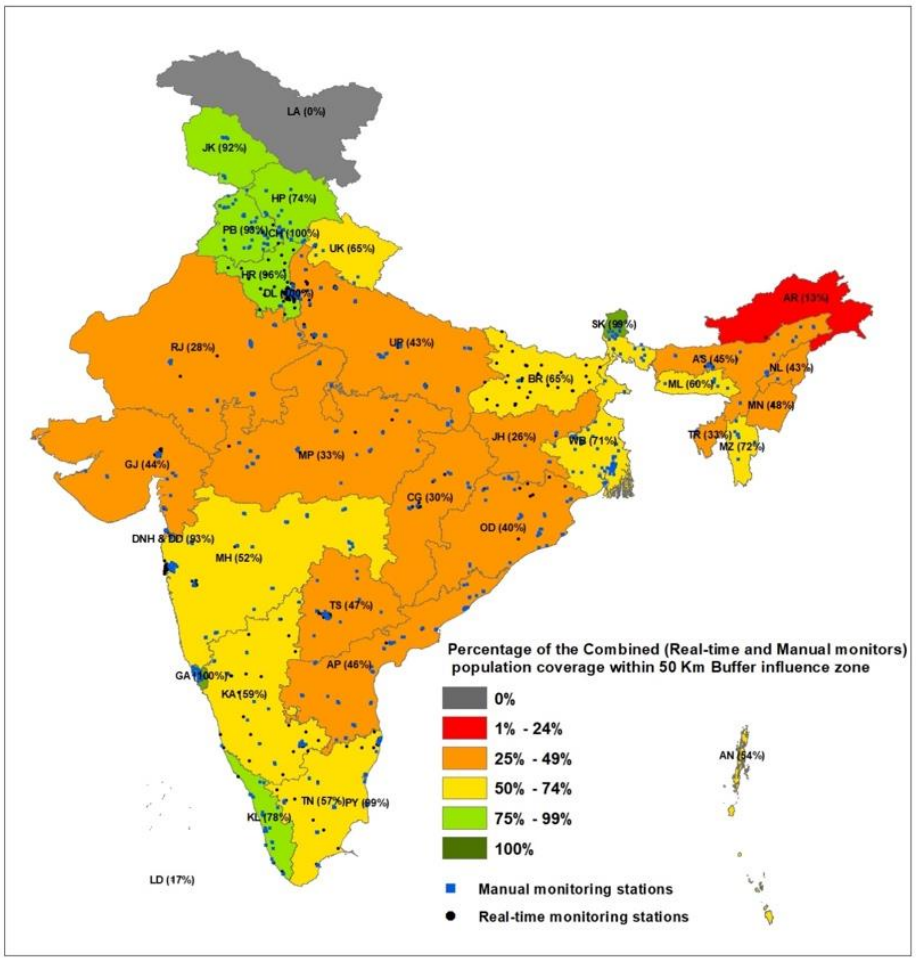
Hilly states have a different challenge where given the terrain it is difficult to earmark well defined air basins. The population is also largely concentrated in a few towns in valleys and can plan monitoring accordingly. For instance, over 20 per cent of the state population lives in the state capital of Gangtok. The states in the North-eat have special chhalnges.

Graph 6: State-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022



Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available. DND & DD stands for Dadra and Nagar Haveli and Daman and Diu.
Source: CSE analysis

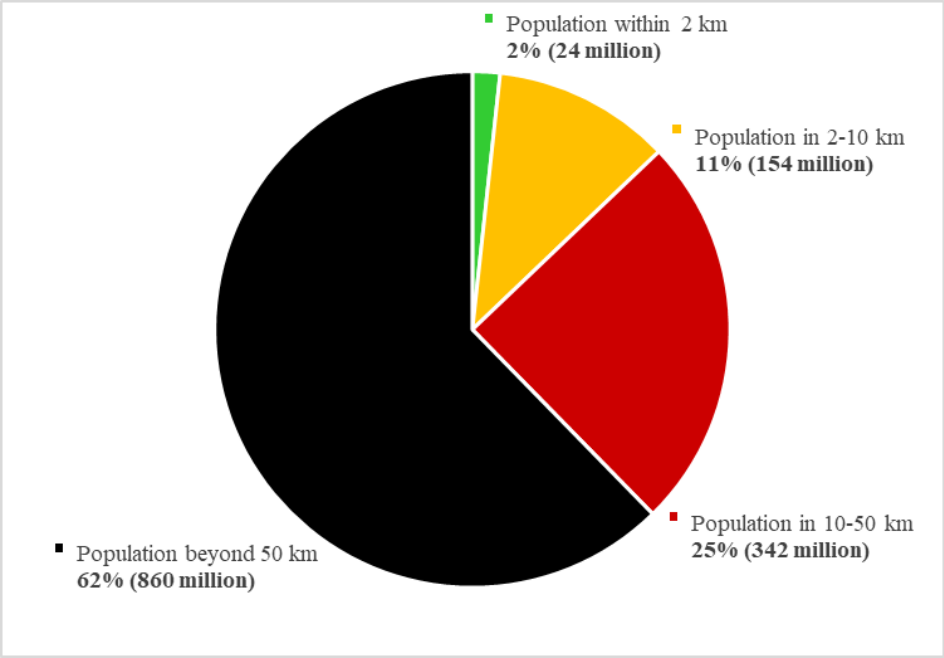
Map 1: State-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022



Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

62 per cent of people live outside the 50km radius coverage of real time air quality monitoring network of India: About 62 per cent of Indian population or about 860 million people lives outside 50 km radius of the realtime air quality monitoring stations (CAAQMS only) which is needed to get daily AQI based health notifications for pubic alert (See *Graph 7: Population coverage of realtime ambient air quality network (CAAQMS) for 2022*). Only 2 per cent of the population lives in immediate coverage zone (2km radius) of the realtime monitoring stations. 11 per cent of the population lives in 2-10km radius and about 25 per cent lives in 10-50 km radius.

Graph 7: Population coverage of real time ambient air quality network (CAAQMS) for 2022



Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Only Chandigarh and Delhi have complete population coverage under the real time monitoring network: State-UT wise Delhi has the highest share of its population covered by real time monitoring stations. 21 per cent of the UT population lives within 2km radius of city´s 40 real time monitoring stations and overall cent per cent of its population is within 50km radius of real time monitoring network (See *Graph 8: State-wise population coverage of real time ambient air quality network (CAAQMS) for 2022* & *Map 2: State-wise population coverage of real time ambient air quality network (CAAQMS) for 2022*).

Chandigarh has the second best coverage with 19 per cent of its population residing within 2km radius of its 3 realtime monitoring stations. Just like Delhi, cent per cent of Chandigarh´s population is covered in the 50km radius of the Monitoring network.

Among states, Haryana, Maharashtra and Gujarat have the highest direct population for real time monitors (within 2km radius) among states with 4 per cent, 4 per cent and 3 per cent respectively.

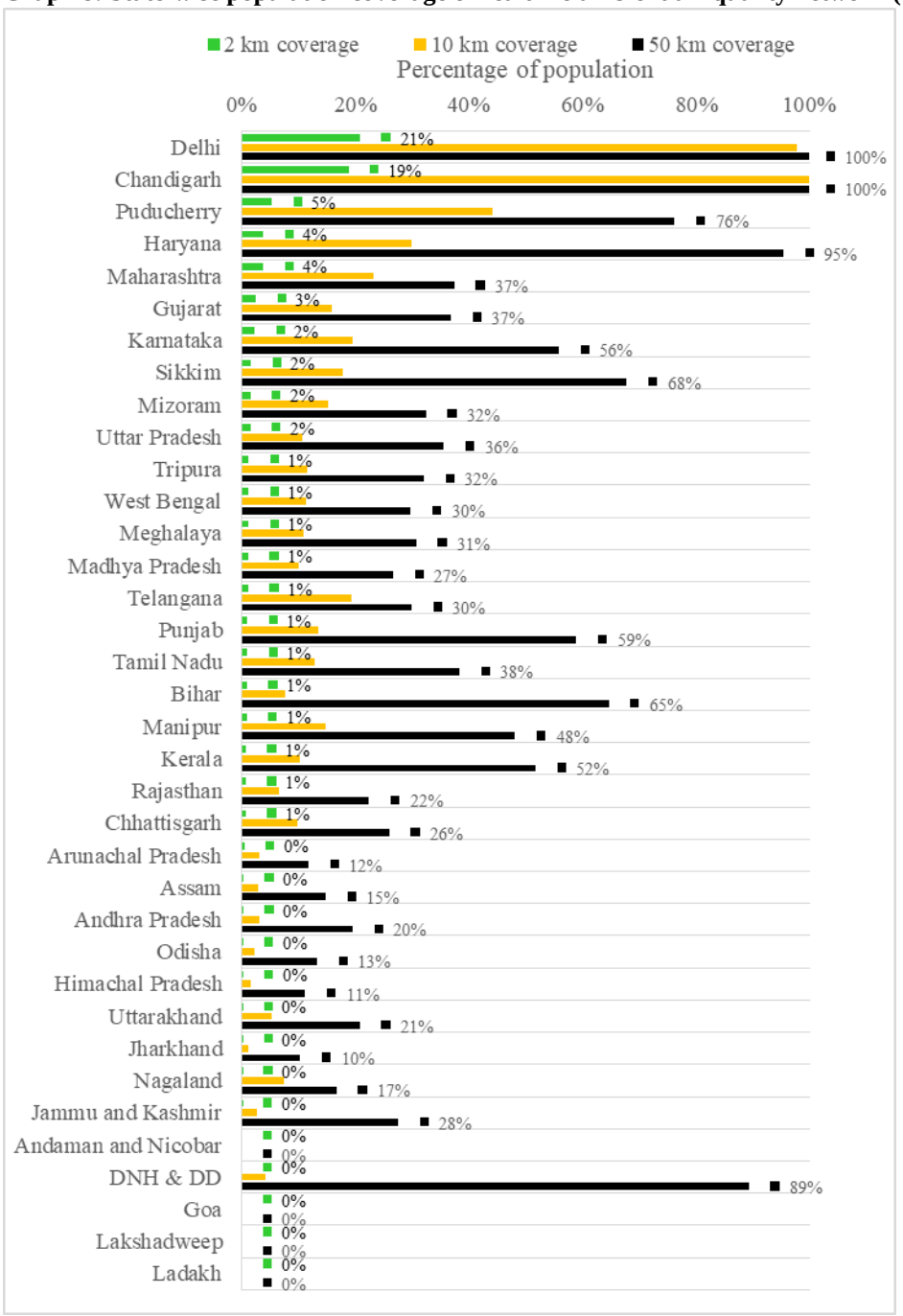
Given the equitable distribution of its 30 real time monitoring stations Haryana is able to cover 95 per cent of its population under 50km radius of monitoring grid. No other state or UT has over 90 per cent population coverage (within 50km radius).

The 50km radius coverage for Maharashtra and Gujarat is just 37 per cent each.

Arunachal Pradesh, Assam, Andhra Pradesh, Odisha, Himachal Pradesh, Uttarakhand, Jharkhand, Nagaland and Jammu and Kashmir have less than 1 per cent of their population in the direct coverage range (within 2km) of their realtime monitors.

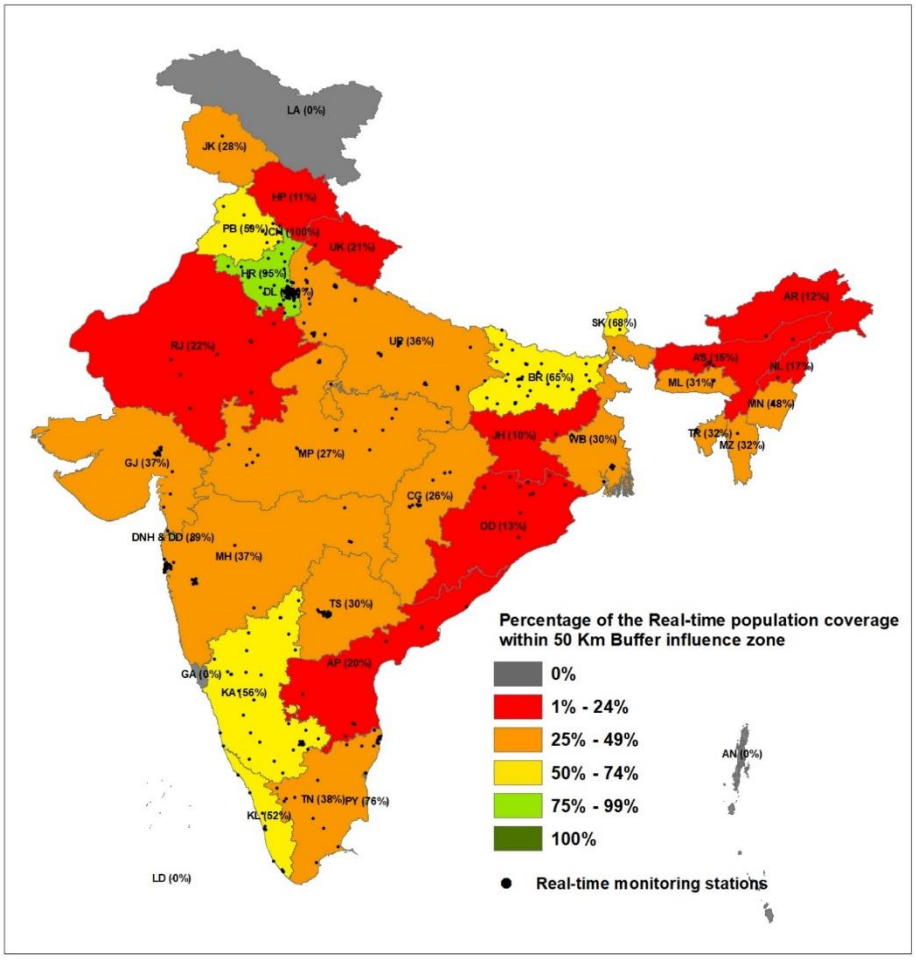
Andaman and Nicobar, DNH & DD, Goa, Lakshadweep, and Ladakh do not have any real time monitor and except DNH & DD entirety of their population fall outside the 50km radius of the closest monitoring stations in neighboring states or UTs. Interestingly, 89 per cent of the DNH & DD is covered in the 50km radius of the real time monitoring station at Vapi, Gujarat.

Graph 8: State-wise population coverage of realtime ambient air quality network (CAAQMS) for 2022



Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available. DND & DD stands for Dadra and Nagar Haveli and Daman and Diu.
Source: CSE analysis

Map 2: State-wise population coverage of real time ambient air quality network (CAAQMS) for 2022

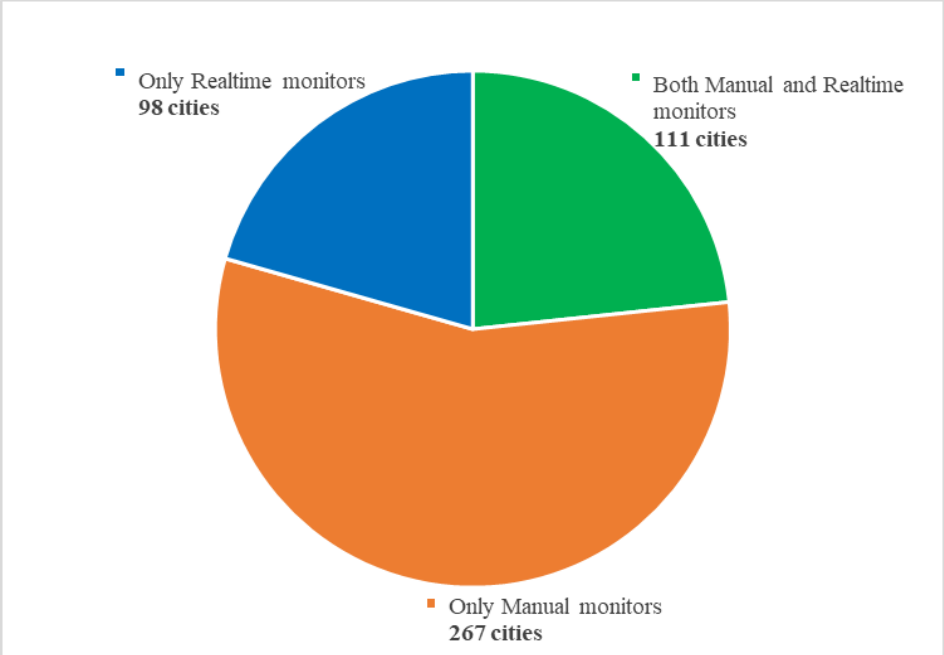


Note: Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Monitoring coverage: Cities and pollutants

Only 476 of 4041 cities/towns have air quality monitoring station (manual or realtime): There are 476 cities and towns that have air quality monitoring station (manual or real time). Majority (267 cities) only have manual stations, while 98 cities have only real time stations (See *Graph 9: City-wise distribution manual and real time ambient air quality monitoring stations (NAMP and CAAQMS) in 2022*). There are 111 cities have both manual and real time stations.

Graph 9: City-wise distribution manual and realtime ambient air quality monitoring stations (NAMP and CAAQMS) in 2022



Note: Cities are defined as per CPCB definition used in their annual NAMP reports.
Source: CSE analysis

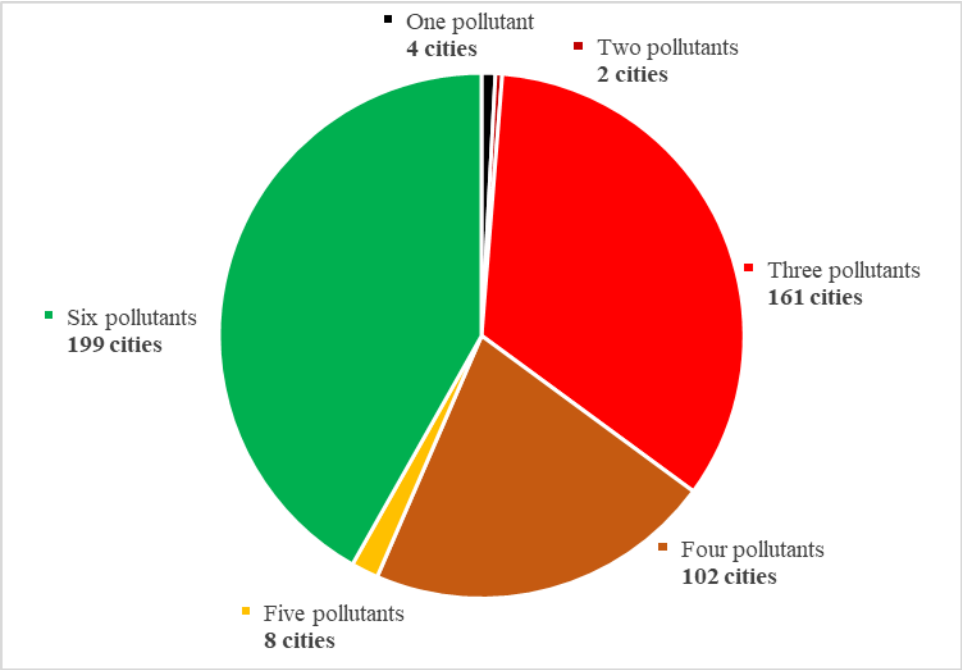
Less than 200 cities monitor all six criteria pollutants: Manual stations which are establish under NAMP are mandated to monitor three pollutants Sulphur Dioxide (SO2), Nitrogen Dioxide (NO2) and particulate matter (PM10 and PM2.5).

Realtime stations set-up under CAAQMS usually monitor six pollutants namely Sulphur Dioxide (SO2), Nitrogen Dioxide (NO2), particulate matter (PM10 and PM2.5), Carbon Monoxide (CO) and Ozone. But there are exceptions as well as many stations don't monitor all the pollutants, some never installed a particular pollutant monitor or it went defunct.

Manual stations monitoring capacity was last published in NAMP report of 2020 and since CPCB has discontinued sharing station level information. Over 100 manual monitoring stations have been added since 2020 but it is not in public domain what all pollutants these are capable of monitoring, therefore for this analysis it is assumed that these new stations are monitoring all four pollutants as mandated by NAMP. Station level data for CAAQMS stations is in public domain and updated information as of 1 Jan 2023 has been used.

199 cities are capable of monitoring all six criteria pollutants, while there are 8 cities which can monitoring five pollutants (PM2.5 monitor is the one missing in these cities). 102 cities monitor four pollutants and do not include CO and O3 monitors (See *Graph 10: Number of pollutants monitored in cities manual and real time ambient air quality monitoring stations (NAMP and CAAQMS) combined in 2022*). 161 cities monitor three pollutants and they generally miss CO, O3 and PM2.5 monitors. There are only six cities that monitor less than only one or two pollutants.

Graph 10: Number of pollutants monitored in cities manual and real time ambient air quality monitoring stations (NAMP and CAAQMS) combined in 2022



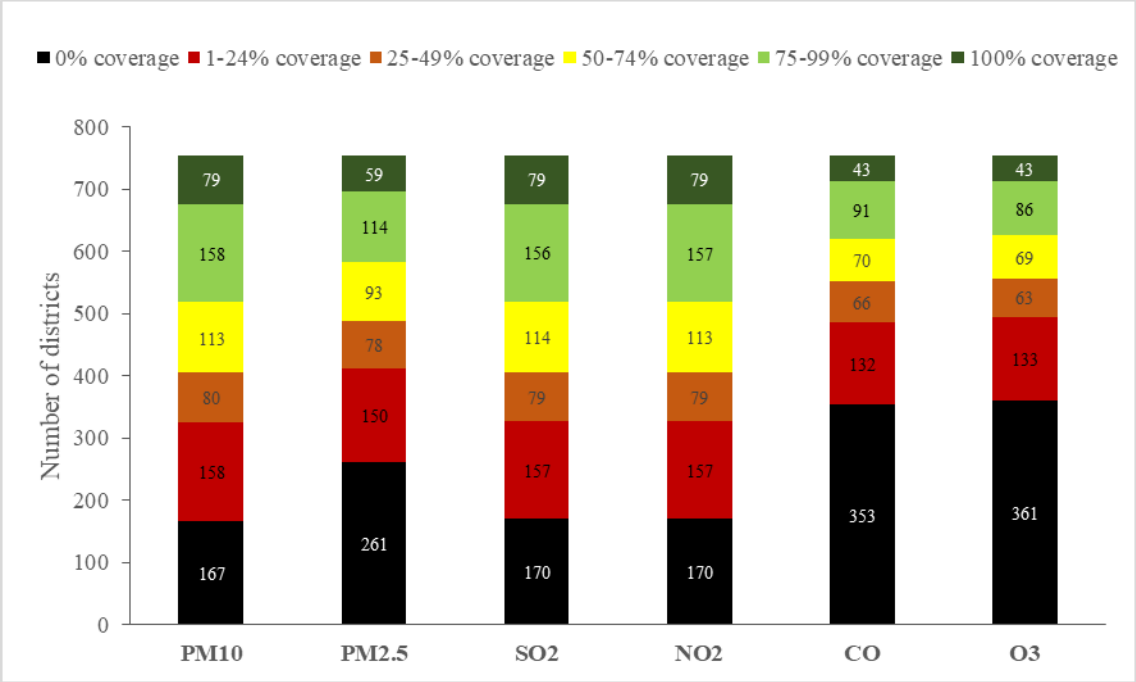
Note: Cities are defined as per CPCB definition used in their annual NAMP reports.
Source: CSE analysis

Only 43 districts have their whole population monitored for all six criteria pollutants: Considering the combined coverage of NAMP and CAAQMS networks only 43 districts have 100 per cent of their pollution within the 50km radius of each of the six criteria pollutant monitors. These districts are mostly located in Delhi-NCR (See *Graph 11: Pollutant wise district-level population coverage by combined air quality monitoring network*).

There are 237 districts where PM10 monitoring covers more than 75 per cent of their population within the 50km radius of the combined monitoring networks (See *Map 3: Pollutant wise district-level population coverage by combined air quality monitoring network*). The number fall to 173 districts for PM2.5 monitoring.

SO2 monitoring and NO2 monitoring covers more than 75 per cent of population within the 50km radius of the combined monitoring networks in 235 districts and 236 districts respectively. Numbers are much lower for CO and surface ozone monitoring as it is only done under CAAQMS network. 75 per cent or more population coverage is limited to 134 districts for CO and 129 districts for surface ozone.

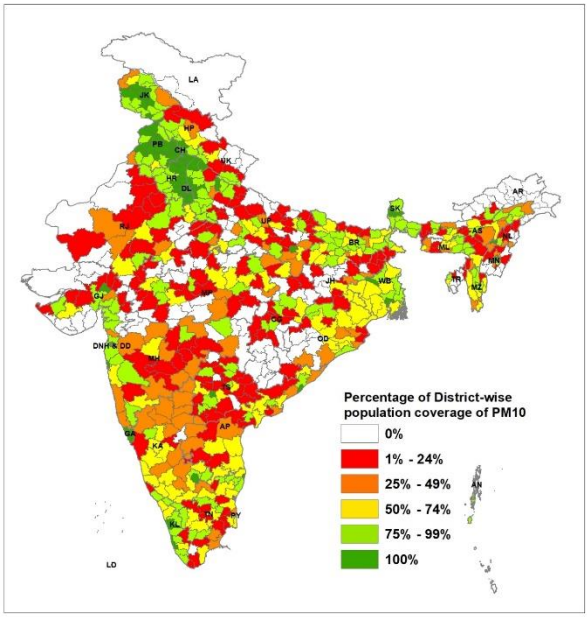
Graph 11: Pollutant wise district-level population coverage by combined air quality monitoring network



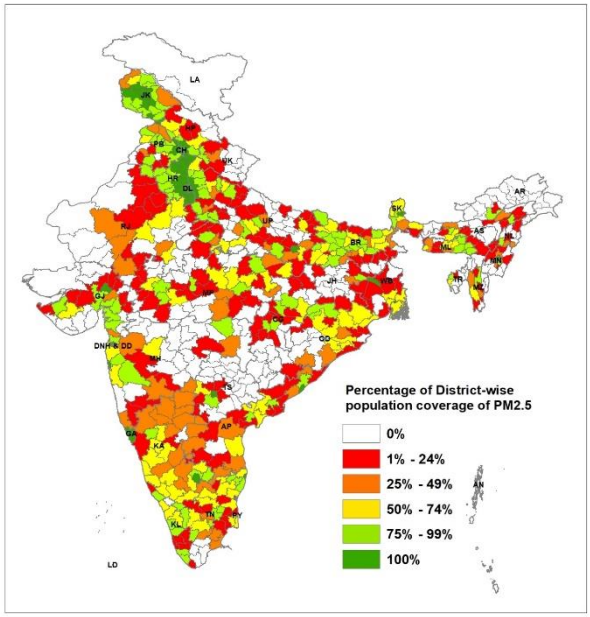
Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Map 3: Pollutant wise district-level population coverage by combined air quality monitoring network

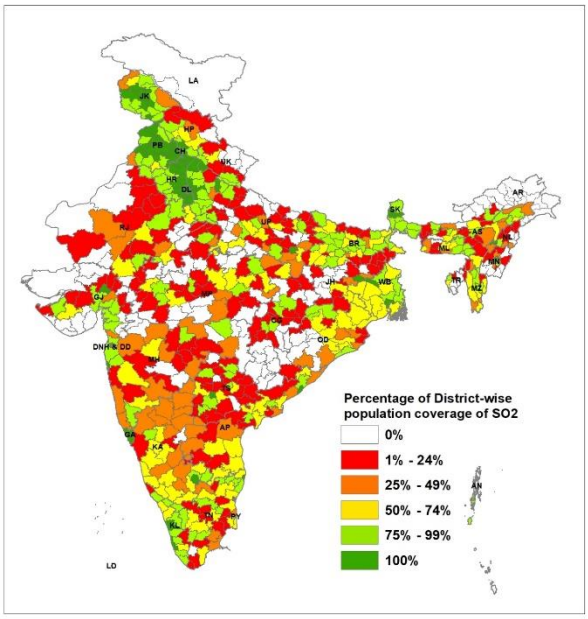
PM10



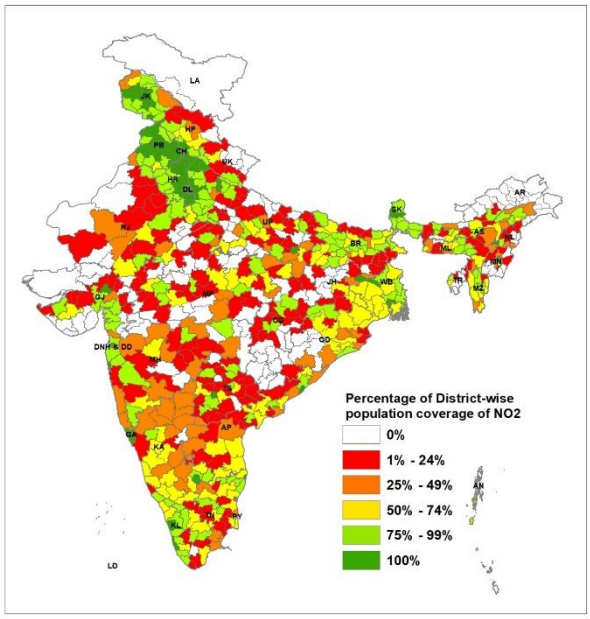
PM2.5



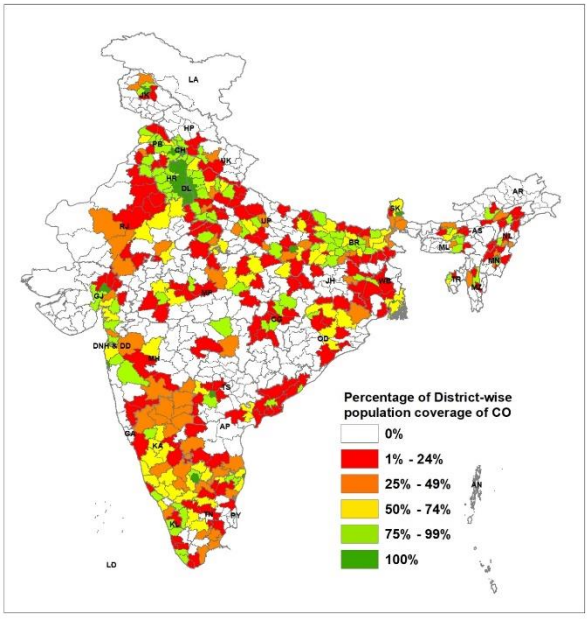
SO2



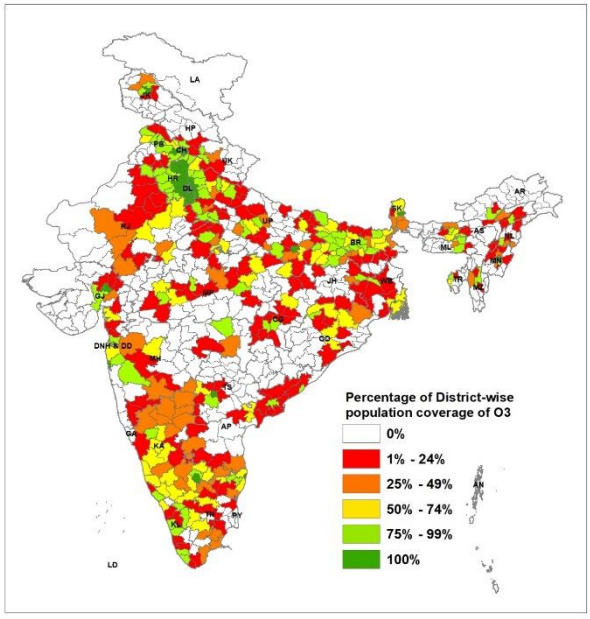
NO2



CO



O3



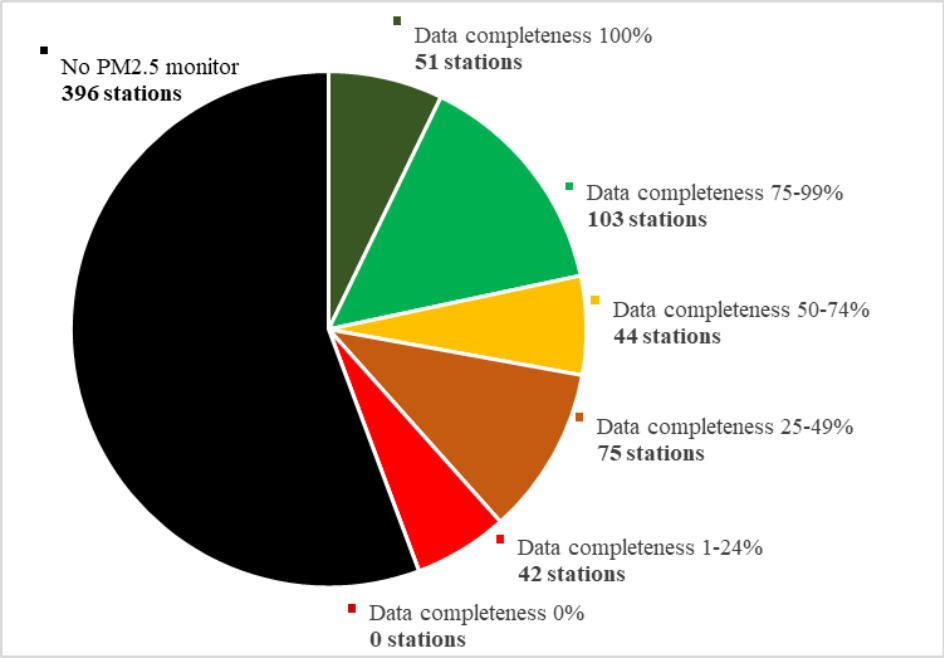
Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

How complete and adequate are the data on PM2.5 data

Less than half of the manual stations have PM2.5 monitors and only 51 stations meet the 104 days of minimum monitoring: NAAQS requires a minimum of 104 days of monitoring at manual stations with two 24hour monitoring every week of the year. CPCB has not published information on the number of monitoring days for stations after 2020. Therefore this analysis is based station level monitoring days data published in NAMP 2019 report.

Only 315 stations out of 711 stations that reported data in NAMP 2019 report had PM2.5 monitors. Out of them only 51 stations met the minimum monitoring requirement of 104 days or 100 per cent data completeness (See *Graph 12: Station-wise PM2.5 data completeness for manual ambient air quality network (NAMP) for 2019*). 103 stations reported data completeness of 75-99 per cent. Over half of the PM2.5 stations didn't even clock 52 days of monitoring in 2019.

Graph 12: Station-wise PM2.5 data completeness for manual ambient air quality network (NAMP) for 2019



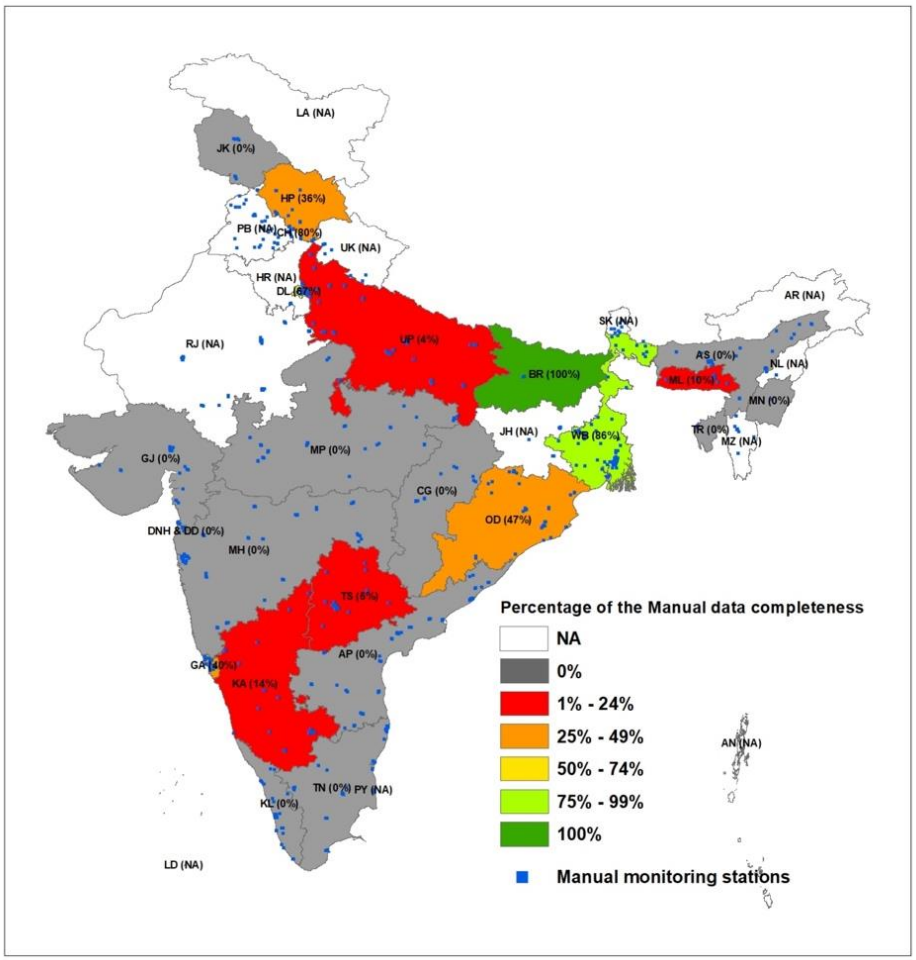
Note: Based on 2019 NAMP report of CPCB
Source: CSE analysis

Half of the manual stations meeting the minimum requirement of 104 days of monitoring a year are located in just two states: Half of the manual stations meeting the 104 days of monitoring requirement are located in just two states namely Odisha (14 stations) and West Bengal (12 stations). About 11 states and one UT that have manual PM2.5 monitors but none meet the minimum data completeness requirement.

Rest of stations meeting the minimum data completeness requirements are spread across 7 states and 2 UTs. These are Goa (6 stations), Himachal Pradesh (5 stations), Chandigarh (4 stations), Karnataka (3 stations), Bihar (2 stations). Delhi (2 stations), and one station each in Uttar Pradesh, Telangana and Meghalaya (See *Map 4: State-wise distribution of manual ambient air quality network (NAMP) meeting the PM2.5 data completeness requirement (2019)* & *Graph 13: State-wise distribution of manual ambient air quality network (NAMP) meeting the PM2.5 data completeness requirement*).

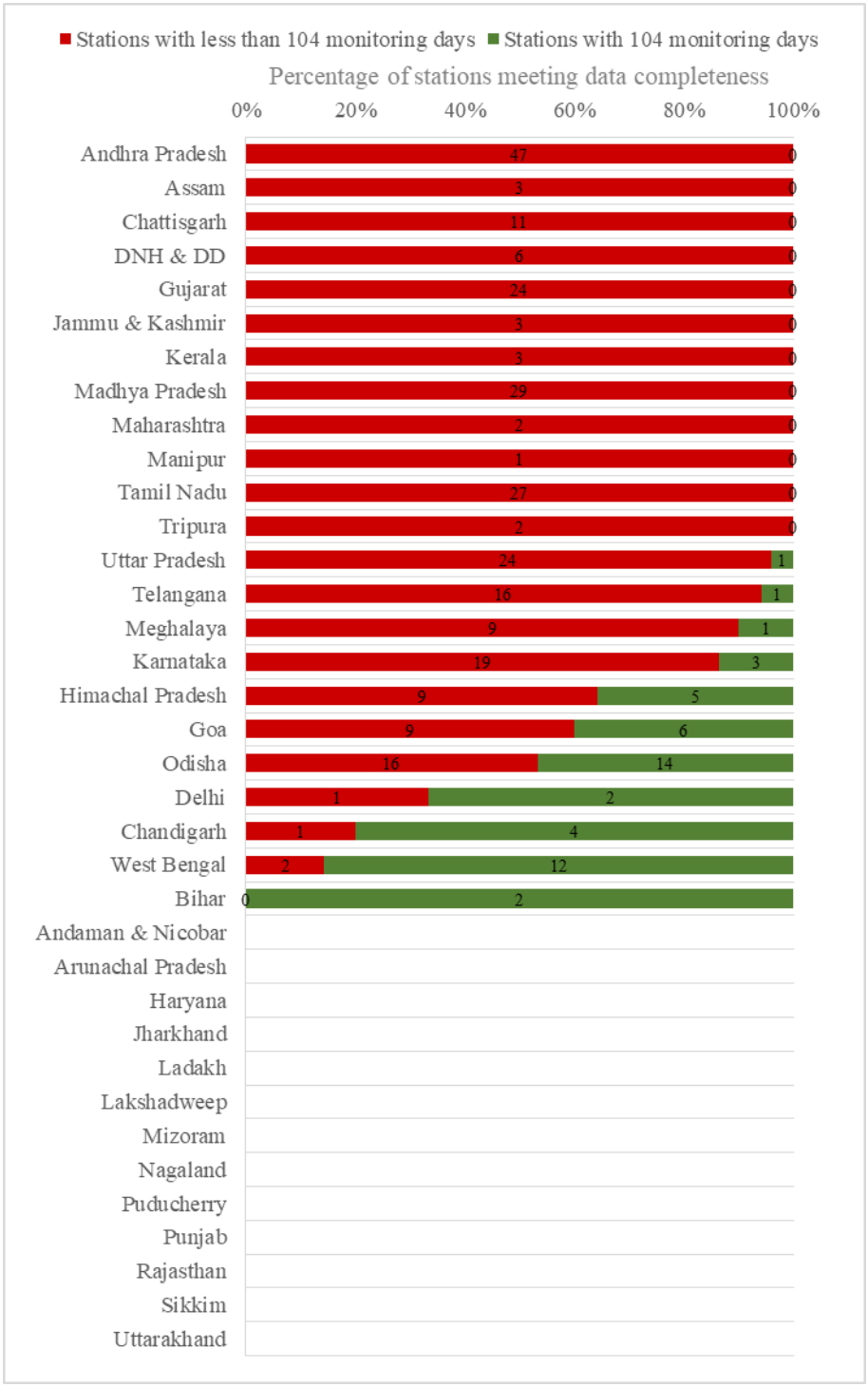
Most manual PM2.5 monitors are located in Andhra Pradesh (47 stations) and none met the minimum data completeness requirement.

Map 4: State-wise distribution of manual ambient air quality network (NAMP) meeting the PM2.5 data completeness requirement (2019)



Note: Based on 2019 NAMP report of CPCB
Source: CSE analysis

Graph 13: State-wise distribution of manual ambient air quality network (NAMP) meeting the PM2.5 data completeness requirement in 2019



Note: Based on 2019 NAMP report of CPCB
Source: CSE analysis

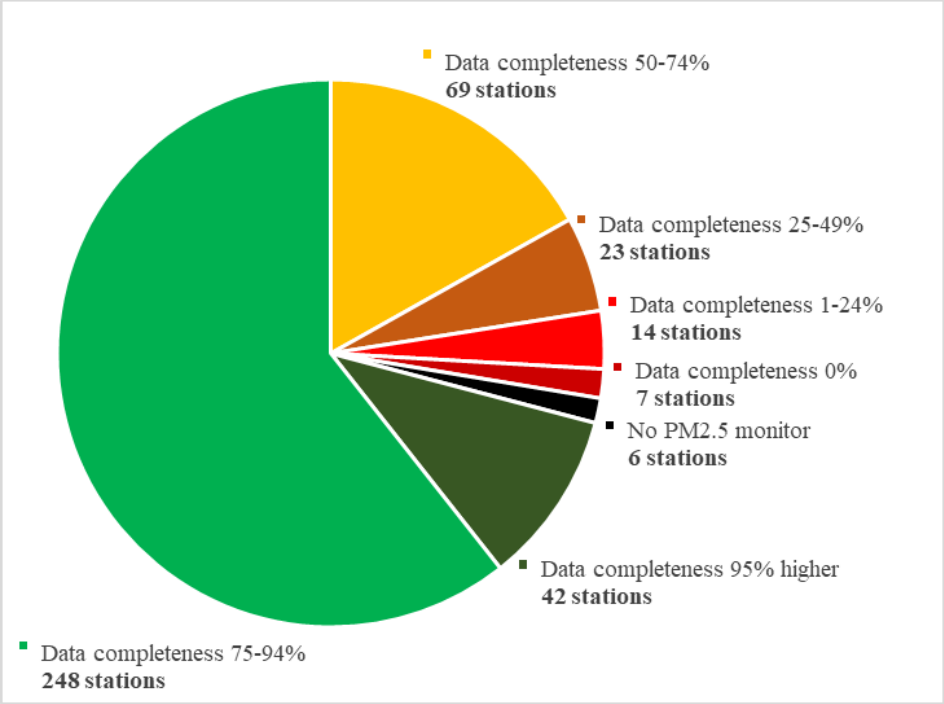
Over 70 per cent of the real time stations meet the minimum data completeness requirement: NAAQS has not defined minimum data completeness requirement for real time stations. European Union requires minimum 90 per cent of hourly values to compute valid annual average. In US, annual data completeness is set at greater than or equal to 75 per cent of scheduled monitoring.

CAAQMS requires real time stations to report data every 15 minutes. Therefore for this analysis data completeness has been calculated as to number of 15 minutes values reported by a real time PM2.5 monitor on the CPCB portal against total number of 15 minutes values expected in a year (30,040 values). For stations that have been operational for less than a year, data completeness has been computed from their start date to 31 December 2022.

290 stations out of 409 stations that reported PM2.5 data in 2022 had data completeness of 75 per cent or more. 69 stations reported data completeness of 50-74 per cent range. 37 stations report 1-49 per cent data completeness which seven stations with PM2.5 monitors reported no data (See *Graph 14: Station-wise PM2.5 data completeness for real time ambient air quality network (CAAQMS) for 2022*).

Additionally there are six stations which don't have PM2.5 monitors, these are East Arjun Nagar station in Delhi, Tata Stadium Jorapokhar station in Jharkhand, Meelavittan Thoothukudi station in Tamil Nadu, and three stations in Karnataka located at Naubad, Bidar; Brahmagiri, Udupi; and City Railway Station, Bengaluru.

Graph 14: Station-wise PM2.5 data completeness for realtime ambient air quality network (CAAQMS) for 2022



Note: Based on 15-minutely average values reported on CPCB online portal by CAAQMS stations.
Source: CSE analysis

Minimum data completeness requirement for PM2.5 was met at all stations of only 9 states-UTs: Availability of 15 minute average is important from the technical perspective as CAAQMS is designed for that granularity. But from practical purpose, daily 24-hourly averages are more critical for public communication and standard compliance. Therefore, additional analysis was undertaken to establish how many valid 24-hour averages could be computed using the raw 15-minute data being generated by these realtime stations, as statistically it is possible to generate 365 valid 24-hour averages in a year using less than 75 per cent of 15-minute values if they are distributed uniformly across all days as CPCB requires only 16 hours of data to determine a 24-hour average. Or result in lesser than 75 per cent of

days if missing data is concentrated in particular days or weeks. For this analysis, USEPA methodology for determining 24-hour average was used.

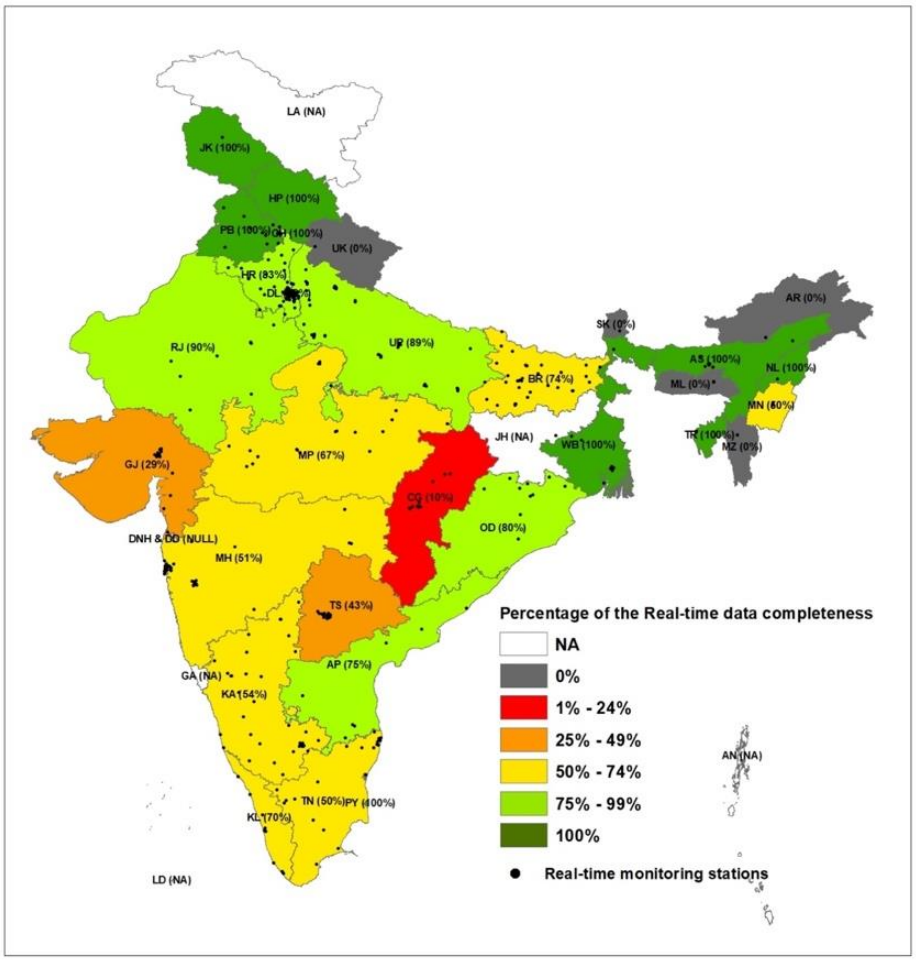
Data from 283 stations was good enough to produce 274 daily 24-hour averages or 75 per cent of the monitoring days. This is seven short of number of stations that met 75 per cent data completeness for 15-minutely values. 54 stations reported less than 183 daily 24-hour averages or 50 per cent of the monitoring days.

All stations of six states and three UTs met the 75 per cent valid 24-hour values in 2022. These are Assam, Himachal Pradesh, Nagaland, Punjab, Tripura, West Bengal, Chandigarh, Jammu & Kashmir and Puducherry.

No station in Anurachal Pradesh, Meghalaya, Mizoram, Sikkim and Uttarakhand met the 75 per cent requirement (See *Map 5: State-wise distribution of realtime ambient air quality network (CAAQMS) meeting the PM2.5 data completeness requirement (2022)* & *Graph 15: State-wise distribution of realtime ambient air quality network (CAAQMS) meeting the PM2.5 data completeness requirement (2022)*). All these states have only one station.

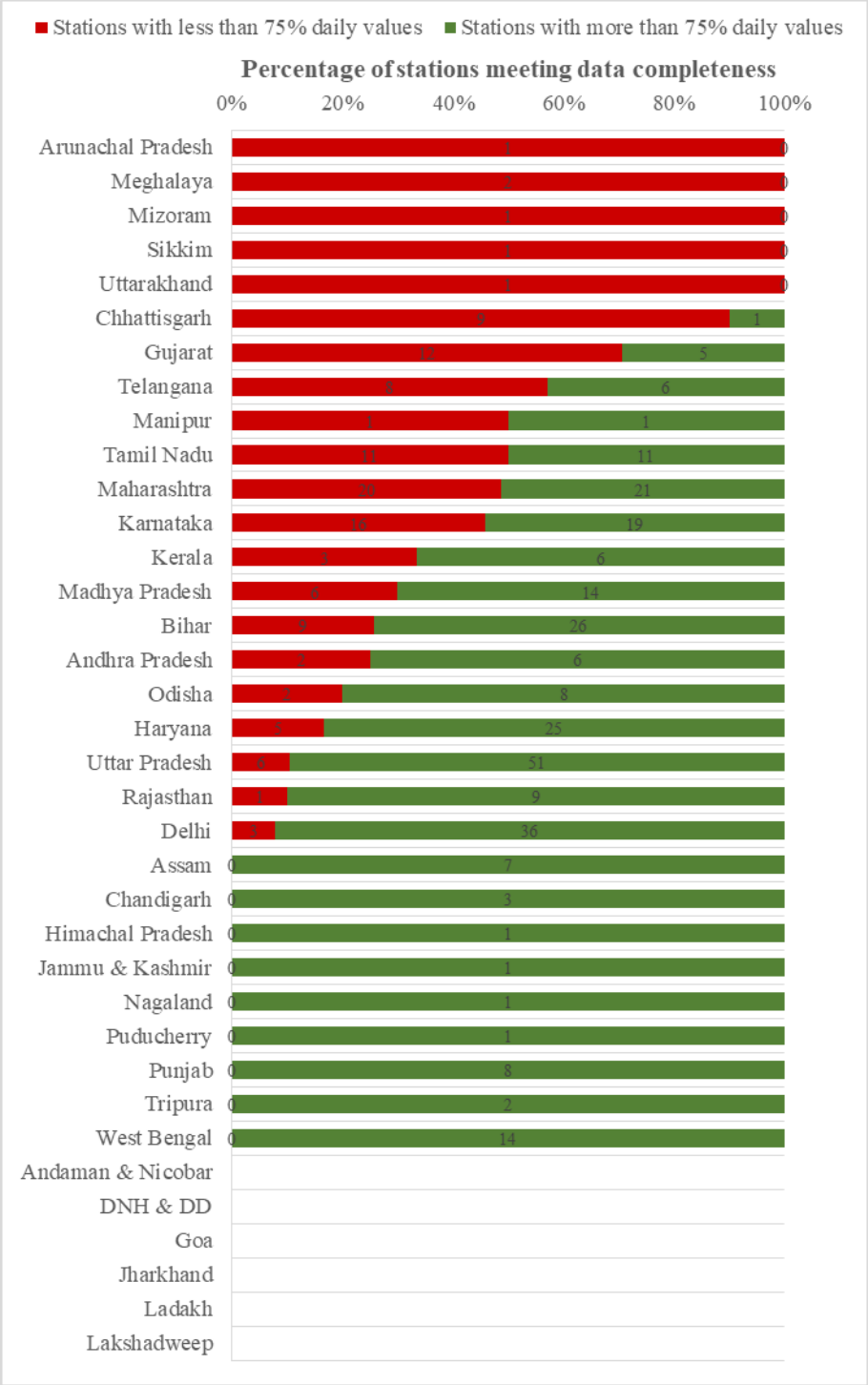
Most number of stations that do not meet the 75 per cent valid 24-hour values in 2022 are located in Maharashtra (20 stations), followed by Karnataka (16 stations) and Gujarat (12 stations).

Map 5: State-wise distribution of realtime ambient air quality network (CAAQMS) meeting the PM2.5 data completeness requirement (2022)



Note: Based on 15-minutely average values reported on CPCB online portal by CAAQMS stations.
Source: CSE analysis

Graph 15: State-wise distribution of realtime ambient air quality network (CAAQMS) meeting the PM2.5 data completeness requirement (2022)



Note: Based on 15-minutely average values reported on CPCB online portal by CAAQMS stations.
Source: CSE analysis

Way forward

Air quality monitoring is important to assess the status of growing risk, impact of clean air action on air quality, inform people and vulnerable communities about the daily pollution, and enable emergency and long term action and support health impact studies. This requires:

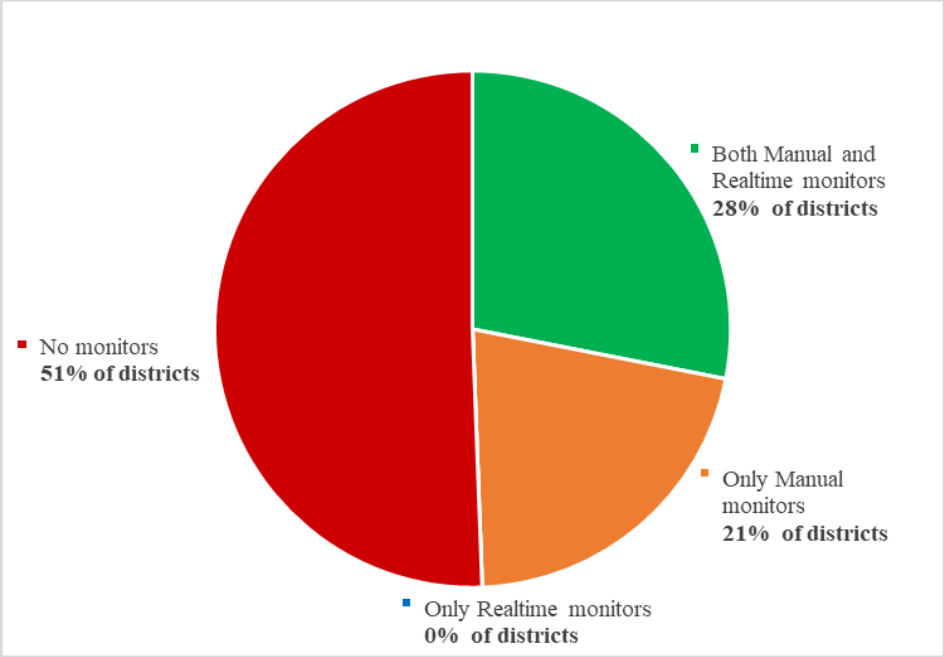
- **More equitable distribution of reference-grade regulatory air quality monitoring stations for wider population coverage and areas without monitoring**.
- **Expand monitoring network for the pollutants that pose higher public health risk - PM2.5 and ozone.**
- **Implement framework for hybrid air quality monitoring system that combines** a network of regulatory monitors with air sensors and satellite based monitoring but based on proper standardization, certification, calibration requirements and detailed protocol.
- **All communities especially vulnerable communities need to be covered.**

ANNEX

Population coverage: Districts

Over half of 755 districts have no air quality monitoring stations; manual or realtime: 161 districts have only manual monitors, while 212 districts have both manual and realtime monitors. No district has only realtime monitors while 382 districts have no monitors (See *Graph 16: District-wise distribution manual and realtime ambient air quality monitoring stations (NAMP and CAAQMS) in 2022*).

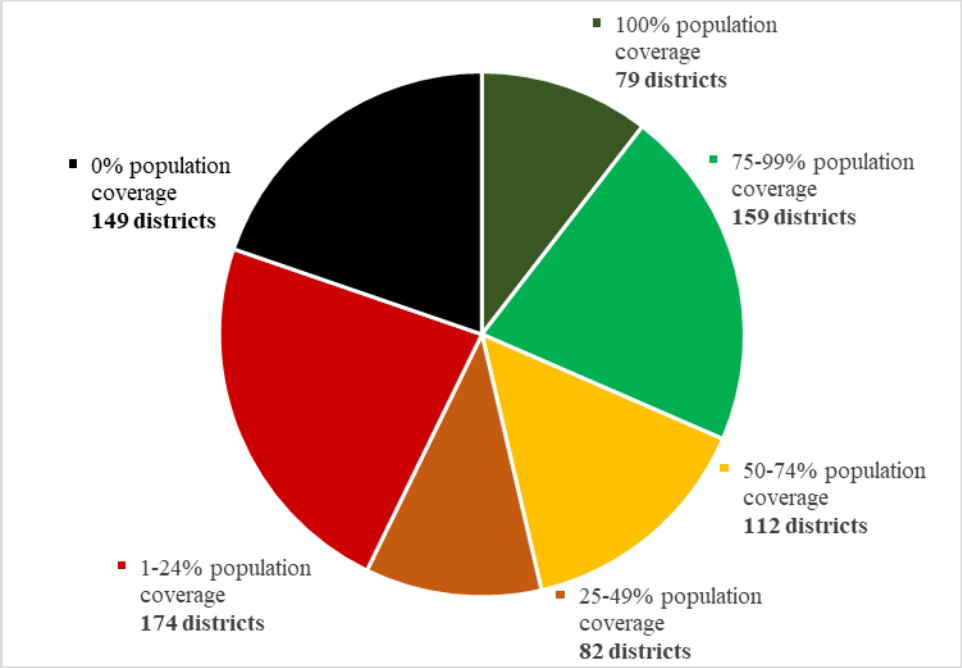
Graph 16: District-wise distribution manual and realtime ambient air quality monitoring stations (NAMP and CAAQMS) in 2022



Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Only 10 per cent of districts have their full population under monitoring coverage: Given the large geographical area of districts even presence of multiple monitors, if not spatially designed to cover maximum population. Additional population coverage analysis reveals that only 79 districts (about 10 per cent of 755 districts) have 100 per cent of their population covered under 50km radius coverage range of monitoring stations. Another 159 districts boast of 75-99 per cent population coverage. Meanwhile, there are only 149 districts that have zero population coverage as most of the districts without monitoring have some portion of their population falling under the 50km monitoring radius of monitoring stations located in neighboring districts (See *Graph 17: District-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022* & *Map 6: District-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022.*). This neighbor benefit works for 174 districts that have 1-24 per cent of their population covered under monitoring despite absence of a monitoring station under their jurisdiction.

Graph 17: District-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022



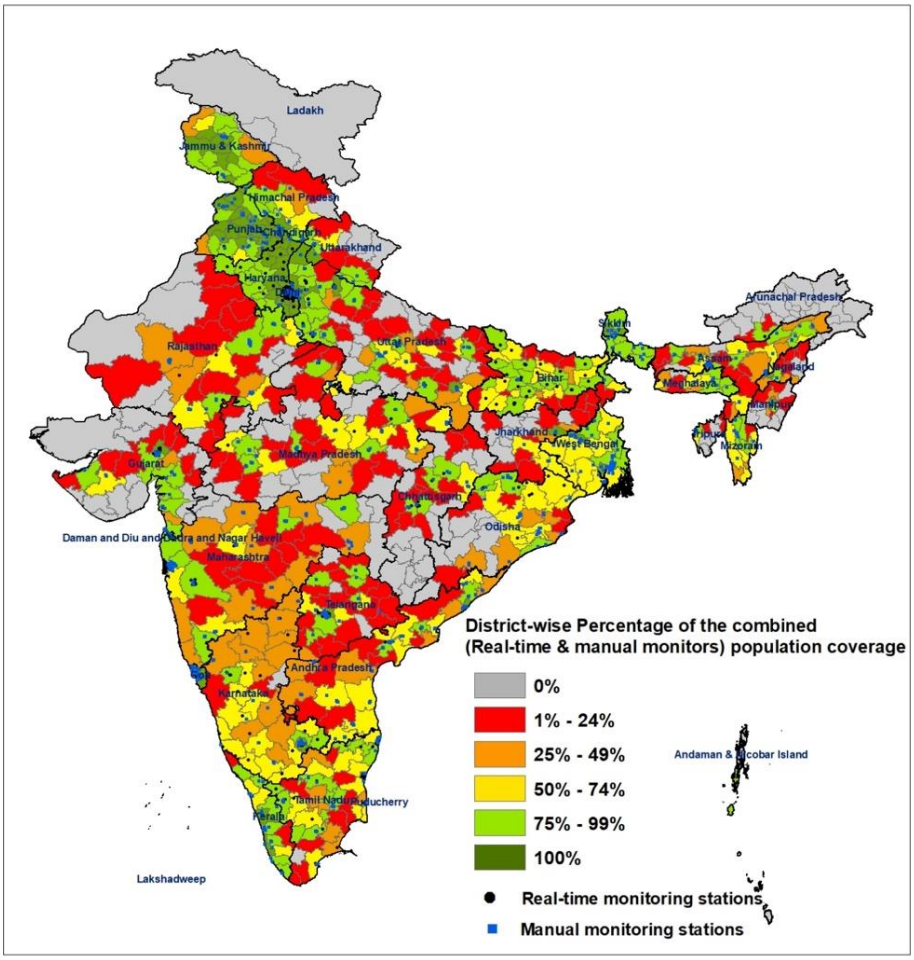
Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

22 states and UTs do not have air quality monitoring (manual or realtime) in all their districts: Only 14 states and UTs have air quality monitoring stations (manual or realtime) in all their districts. These are Bihar, Chandigarh, Delhi, Goa, Haryana, Jammu & Kashmir, Kerala, Lakshadweep, Mizoram, Puducherry, Punjab, Sikkim, West Bengal and Andhra Pradesh.

The 149 districts with zero per cent population coverage are distributed among 19 states and 3 union territories. Just five states namely Anurachal Pradesh (22 districts), Uttar Pradesh (18 districts), Madhya Pradesh (17 districts), Gujarat (14 districts) and Chhattisgarh (14 districts) account for almost 60 per cent of districts with zero population coverage (See *Graph 18: State-wise distribution of districts with ambient air quality monitoring stations (NAMP and CAAQMS) for 2022*).

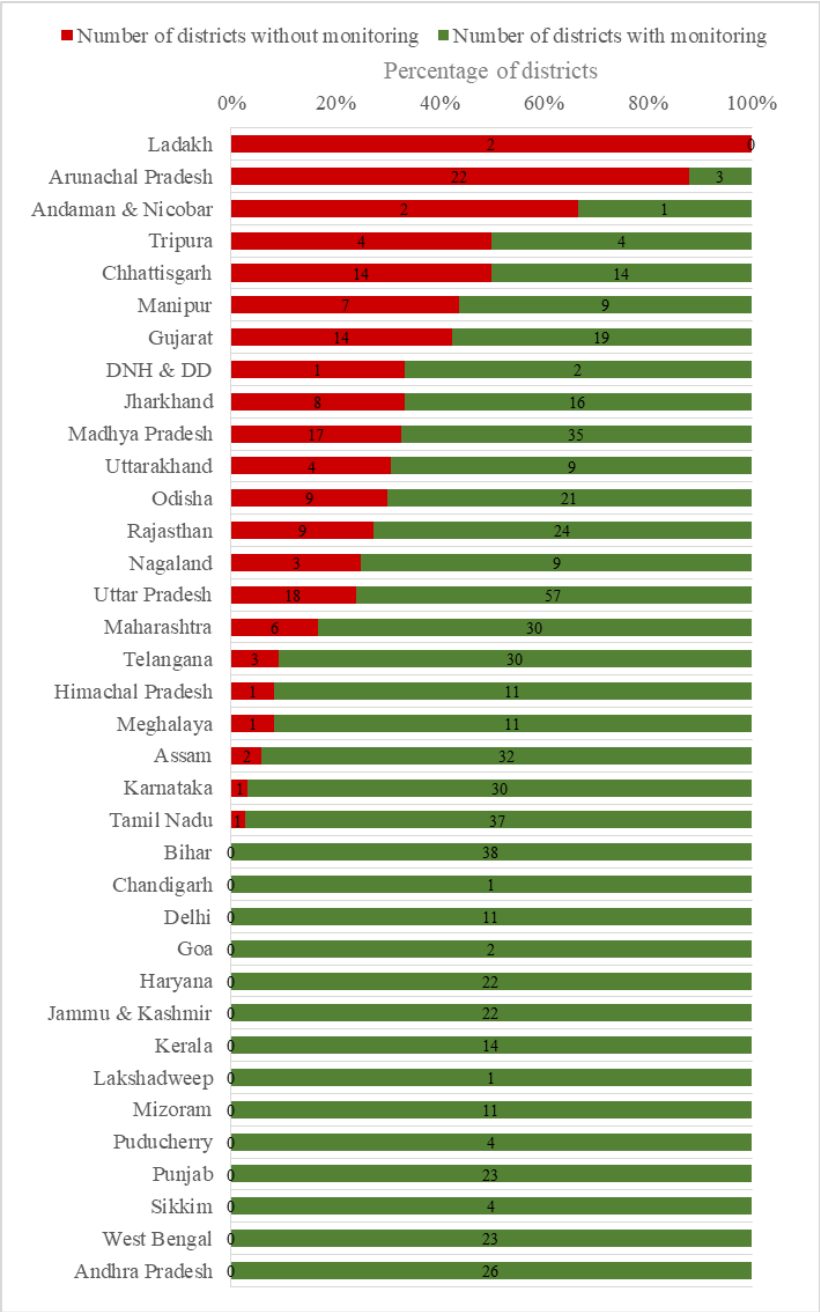
Among UTs, both districts of Ladakh and Diu district of Dadar and Nagar Haveli and Daman and Diu (DNH & DD) Union Territory has zero population coverage.

Map 6: District-wise population coverage of combined ambient air quality networks (NAMP and CAAQMS) for 2022



Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

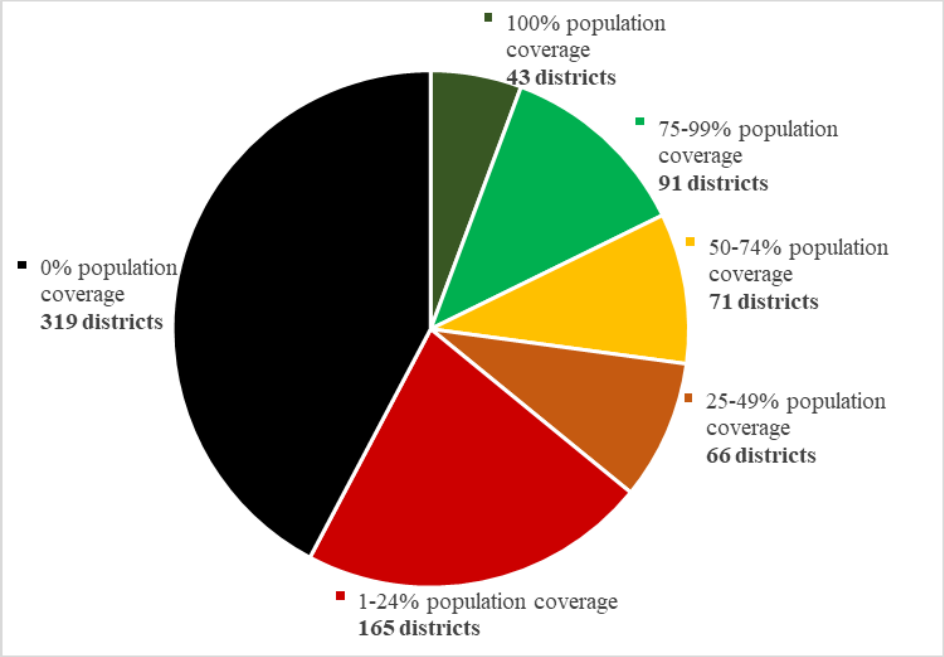
Graph 18: State-wise distribution of districts with ambient air quality monitoring stations (NAMP and CAAQMS) for 2022



Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Less than 6 per cent of districts have their full population under real time monitoring coverage: Only 212 districts have real time monitor stations. Given the large geographical area of districts even presence of multiple monitors, if not spatially designed to cover maximum population. Additional population coverage analysis reveals that only 43 districts (less than 6 per cent of 755 districts) have 100 per cent of their population covered under 50km radius coverage range of real time monitoring stations. Another 91 districts boast of 75-99 per cent population coverage. Meanwhile, there are 319 districts that have zero population coverage (See *Graph 19: District-wise population coverage of real time ambient air quality networks (CAAQMS) for 2022* & *Map 7: District-wise population coverage of realtime ambient air quality networks (CAAQMS) for 2022*). Many districts without monitoring have some portion of their population falling under the 50km monitoring radius of monitoring stations located in neighboring districts. This neighbor benefit works for 224 districts that have some percentage of their population covered under monitoring despite absence of a monitoring station under their jurisdiction. 165 districts have 1-24 per cent coverage while another 66 districts boast of 25-49 per cent coverage.

Graph 19: District-wise population coverage of realtime ambient air quality networks (CAAQMS) for 2022



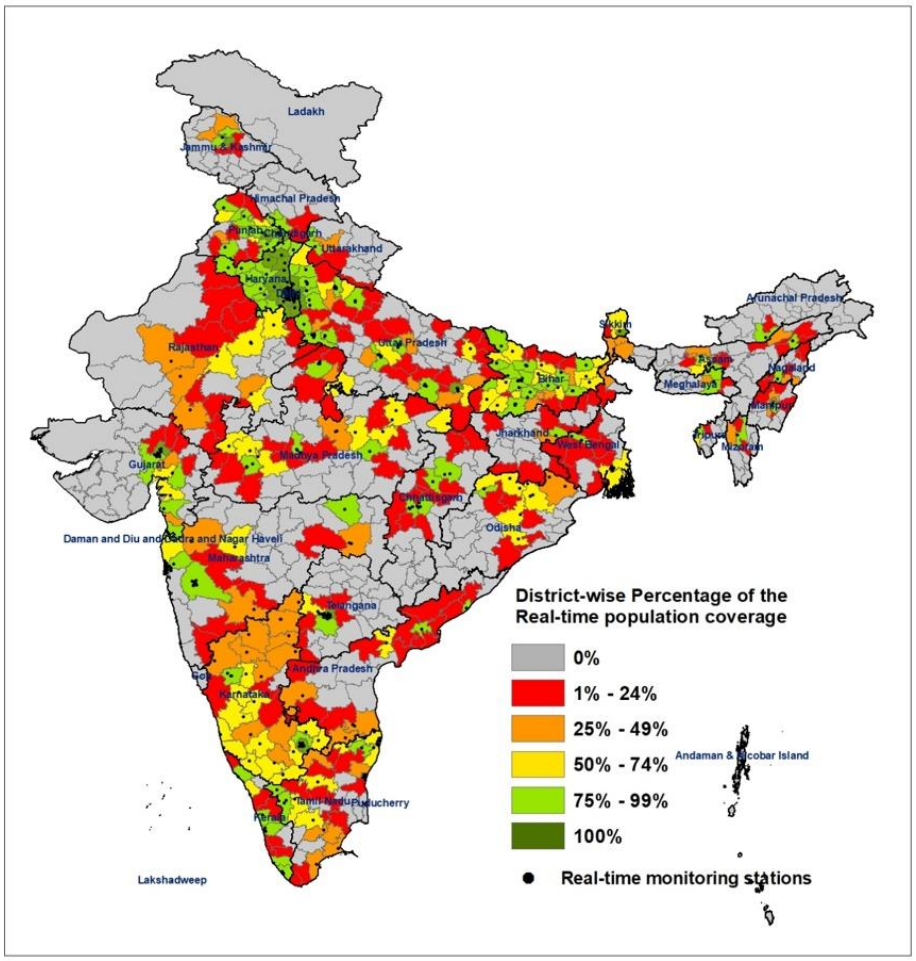
Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Only Delhi, Bihar, Haryana, Chandigarh and Sikkim have some level of realtime air quality monitoring coverage in all their districts:

There are 319 districts with zero per cent population coverage. These are distributed among 25 states and 5 union territories. Just five states namely Madhya Pradesh (25 districts), Arunachal Pradesh (23 districts), Telangana (23 districts), Uttar Pradesh (23 districts), Gujarat (20 districts) and Maharashtra (20 districts) account for almost 42 per cent of districts with zero population coverage (See *Graph 20: State-wise distribution of districts with realtime ambient air quality monitoring stations (CAAQMS) for 2022*).

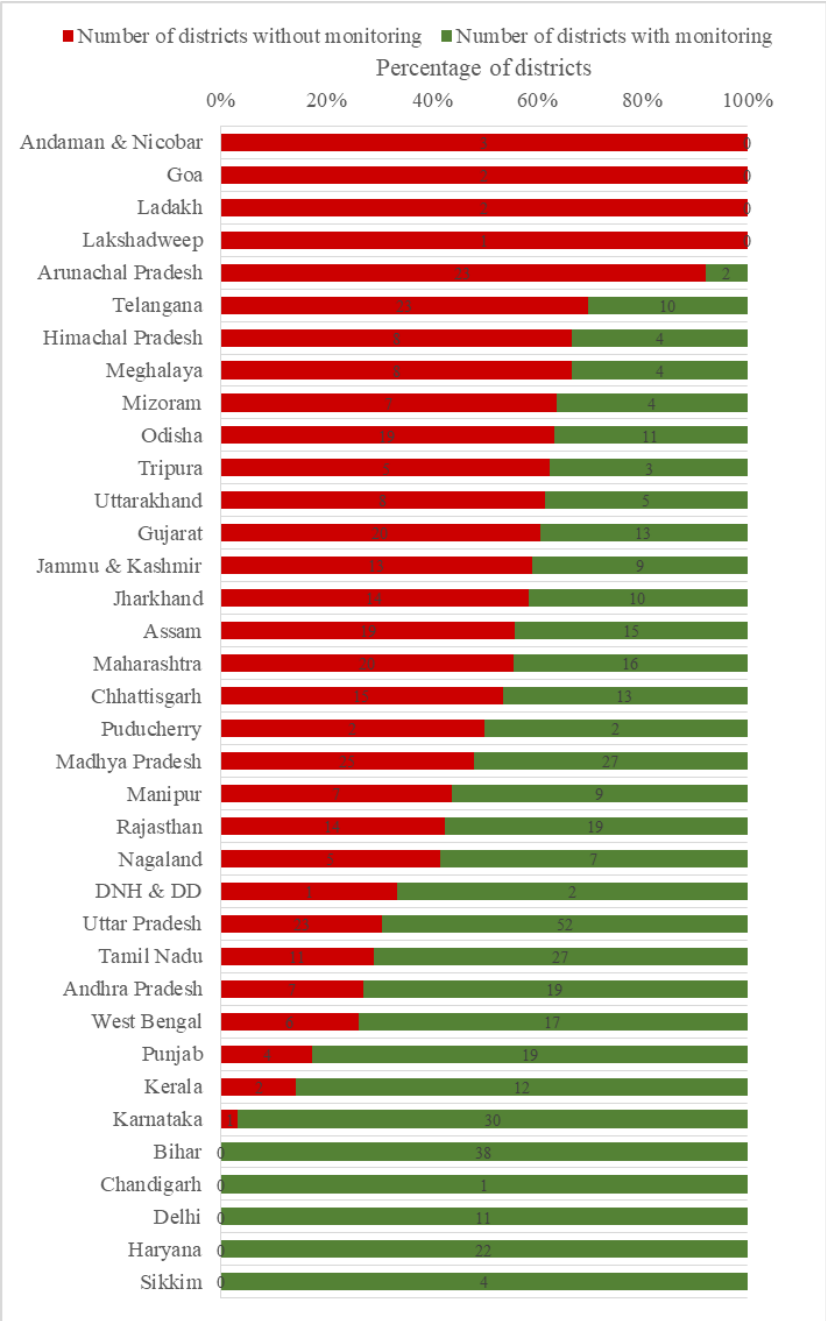
All the districts of Goa and union territories of Ladakh, Andaman & Nicobar and Lakshadeep have zero population coverage.

Map 7: District-wise population coverage of realtime ambient air quality networks (CAAQMS) for 2022



Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

Graph 20: State-wise distribution of districts with realtime ambient air quality monitoring stations (CAAQMS) for 2022



Note: Based June 2022 district boundaries when total number of districts in India stood at 755. Population estimates are based on the 100mx100m spatial distribution of population in 2020 developed by the WorldPop research programme, based in the School of Geography and Environmental Sciences at the University of Southampton. Monitoring locations are approximation based on information available from CPCB website and publications, it is not exact geographical co-ordinate of the stations as that information is not publically available.
Source: CSE analysis

[i] http://goaspcb.gov.in/Media/Default/uploads/APRIL%202018%20TO%20MARCH%202019.pdf