Clean Air Project in India

Detailed report on

Strategies for improving air quality monitoring

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Strategies for improving air quality monitoring - executive summary

The existing air quality monitoring networks have been assessed in relation to CPCB guidelines over four Indian cities (Kanpur, Lucknow, Pune and Nashik) under the CAP India project. The analysis is based on existing monitoring measurements, secondary literature, available satellite data, and site visits conducted for all four CAP-India cities. Each monitoring station in the exiting network was evaluated and metadata has been created for each station to identify its monitoring objective (associated with evaluating population exposure, compliance with the national standards, and source characterization)for each of the stations. Gaps were identified with respect to the number and location of monitoring sites required to meet each monitoring objective in the guidelines, and new locations for monitoring sites are proposed. Finally, as CPCB guidelines have been drafted by closely following Western (WHO and US) guidelines, some aspects that that should be revised in future years to be more suitable for the style of urban development in India are proposed.

The present air quality monitoring networks are especially inadequate in characterizing population exposure in the city. Current sites are situated to predominantly focus on measuring air pollutants at the pedestrian exposure sites. Detailed analysis of the micro-environment of the monitoring sites indicates the presence of line, point and area sources in the majority of the sites which might reduce the site representability. The construction and demolition work associated with the rapid growth of the cities often interferes with the existing site type classification. Monitoring sites for measuring average air quality, trends and long-term health exposure are rare. A fraction of the monitoring sites measure $PM_{2.5}$, which is undoubtedly the most important air pollutant in the Indian context.

Possible new sites for monitoring were identified using night-time light data, satellite-derived $PM_{2.5}$, existing emission inventory, land-use patterns and other secondary open-sourced data. Over Lucknow, Pune and Nashik, setting up stations at highly populated areas are recommended to fulfill the knowledge gaps on the average population exposure. Over Kanpur, it was recommended to incorporate stations to measure short-term pollution exposure in traffic and industrial sites. Rapidly developing peri-urban regions were identified using night-time anomaly and recommendations were provided for setting up monitoring stations in these regions.

Contents

1. City Profiles

Under the CAP-India project, we have evaluated the existing air quality network over four Indian cities; Kanpur, Lucknow, Pune and Nashik. The north-Indian city of Kanpur and Lucknow is situated in the middle of the heavily polluted Indo-Gangetic Plain (IGP). Stretching from Pakistan to Bangladesh, IGP is extremely fertile and home to more than 100 major cities and urban establishments over the Indian sub-continent. Agricultural activity, presence of major industry and powerplants over IGP results in higher aerosol loading as compared to the other part of India. Nashik and Kanpur are located middle of the great north Indian Haze and receive regionally transported pollutants from the upper IGP region. Pune and Nashik, on the other hand, are located in the Deccan Plateau in the western part of India, known for their faster rate of development. The urban expansion and population migration to both the city has been found to be unprecedented in recent decades and so does the number of on-road vehicles and construction works. Developmental patterns also differ among these cities; urban agglomeration clearly the dominating process over Lucknow and Pune whereas, urban edge expansion and outlying are more common over Kanpur and Nashik.

1.1 Lucknow

The capital city of the Indian state of Uttar Pradesh, Lucknow is also one of the most populous cities (14th) and a major urban agglomeration center (12th) over India. The decadal incremental rate of the population over Lucknow is 25.4% as observed from the last Census 2011. Lucknow is located in the middle Indo Gangetic Plain region and had a high population density of 5500 per sq. km. Unlike the North Indian state capitals, Lucknow does not have major industrial establishments, rather the city relies on secondary and tertiary sectors like IT, Garments, aeronautics and tools manufacturing. The expansion of the city was limited to the left bank (south) of the river Gomti and mostly consisted of residential areas (known as Chawk) and market areas (known as Bazar). The “old” part of the city started to expand after the establishment of the bridge over the river and the northward development of the city began. The road network of the “old” part of Lucknow was often irregular, narrow and zigzag. During the 1980s, the build-up regions were primarily confined to the north and south bank of the river Gomti. The urban sprawling began during the late 80s with the advent of the new intra-city and inter-city transport network. Planned colonies and industrial areas were beginning to form scattered in the peri-urban region and urban agglomeration of build-up areas took place. The land-cover changes for the city Lucknow has been represented in Fig 1 which suggests the growth of build-up area and reduction of cropland inside the city. In two decades, the build-up area has been increased by 3.2 times, and the peri-urban part area has completely transformed into an urbanized landscape.

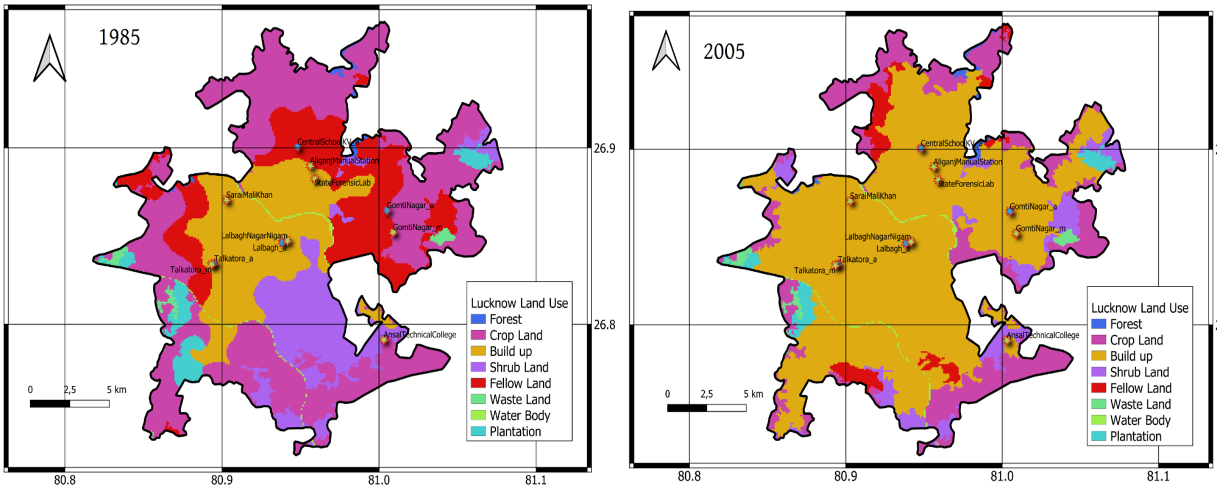

Fig 1: Land use changes over Lucknow region from 1985 (left) to 2005 (right) showing the expansion of build-up areas over the city.

The Pollution Control Board city-wise report over Lucknow identified Transport, road dust, construction, and biomass burning as major sources of air pollution in the city. Due to its spatial location in the middle IGP region, it is safe to assume that Lucknow received a fair amount of transported aerosol. Lucknow has 11 air quality monitors, fewer than the population-based approximation of required monitors as recommended by CPCB (2003) (Table 1).

1.2 Kanpur

Kanpur, a metropolitan city in the middle IGP region, is an important financial and industrial center of the Northan part of India. Kanpur is one of the most populous cities (12th in India) and noted urban agglomeration center (11th in-country) over India. Known for its textile and leather industries, Kanpur was recognized as the most polluted city in the world by WHO in 2018. Kanpur host the largest industrial hub in the entire IGP and the major industries are cotton-textile, jute, paper and leather-based industries, mineral, metal, chemical. agro and furniture. There are ten industrial clusters spanning across the city that hosts 17444 industrial units.

The land-use cover changes over the Kanpur city have been represented in Fig 2, clearly depicting the reduction of crop and fallow land over the city and expansion of the built-up area. Kanpur has a decadal population growth rate of 9.9% and additionally, migration to Kanpur due to the presence of the industrial centers, also promoted the expansion of the urban built-up areas.

According to the Uttar Pradesh Pollution Control Board (UPPCB) action plan for controlling the air pollution, the PM_{10} concentration over Kanpur is exceeded by a factor of 2-4 times as compared to the CPCB standards (60µg m^{-3}) over all the monitoring sites. The major sources of air pollutants are industrial, vehicular, Road and construction dust and waste burning. The number of present monitoring stations over Kanpur is twice as low as the CPCB recommendation.

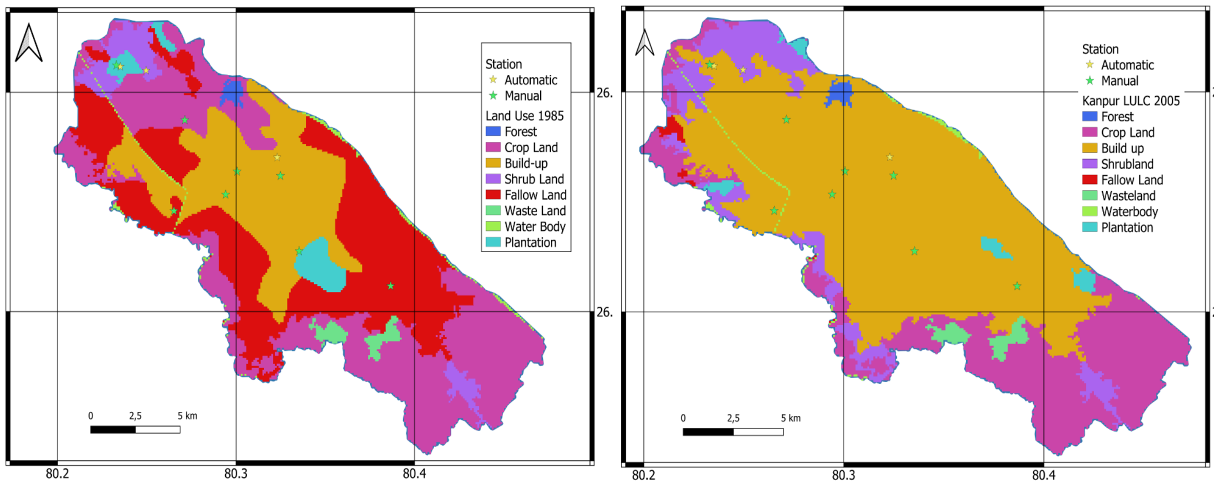

Fig 2: Land use changes over Kanpur from 1985 (left) to 2005 (right) indicating urban expansion over the city

1.3 Pune

Located in the Decaen plateau, Pune is the second-largest city in Maharashtra and 7th most populous city in India. Located at the altitude of 560m AMSL, Pune is a hilly city with undulated topography. The effective area of the city for the study consist of two municipal regions; Pune and Pimpri-Chinchwad. Although, Pune has been known as an educational and IT hub, several polluting industrial clusters are located in and around the city. Large industrial clusters in regions like Talegaon, Pimpri-Chinchwad, Bhosari, Ranjangaon, Chakan hosts forging and automotive engines industrial units, manufacturing units and food processing units.

The city of Pune is currently witnessing Population immigration, urban agglomeration and almost a 70% developmental rate in the Pimpri-Chinchwad municipality in the last decade. The expansion of urban built-up areas as well as the urban agglomeration can be observed from the land-use changes over Pune (Fig 3). The Action Plans for Control of Air Pollution by the Maharashtra Pollution Control Board identified Vehicular, road and construction dust and diesel generators from the industry as the major air polluting sources over the city. Previous data indicate a slightly decreasing trend in both PM_{10} and $PM_{2.5}$ concentrations over Pune city over time, although the concentrations are well above the Indian standards. The total number of air pollutants monitoring stations over Pune is 19, one shorter than the CPCB recommended number. Pune is a part of SARAR Network (System of Air Quality and Weather Forecasting And

Research) for air quality monitoring and therefore, parallel to the Pollution Control Board monitors, SAFAR monitors also provide air quality information over the city.

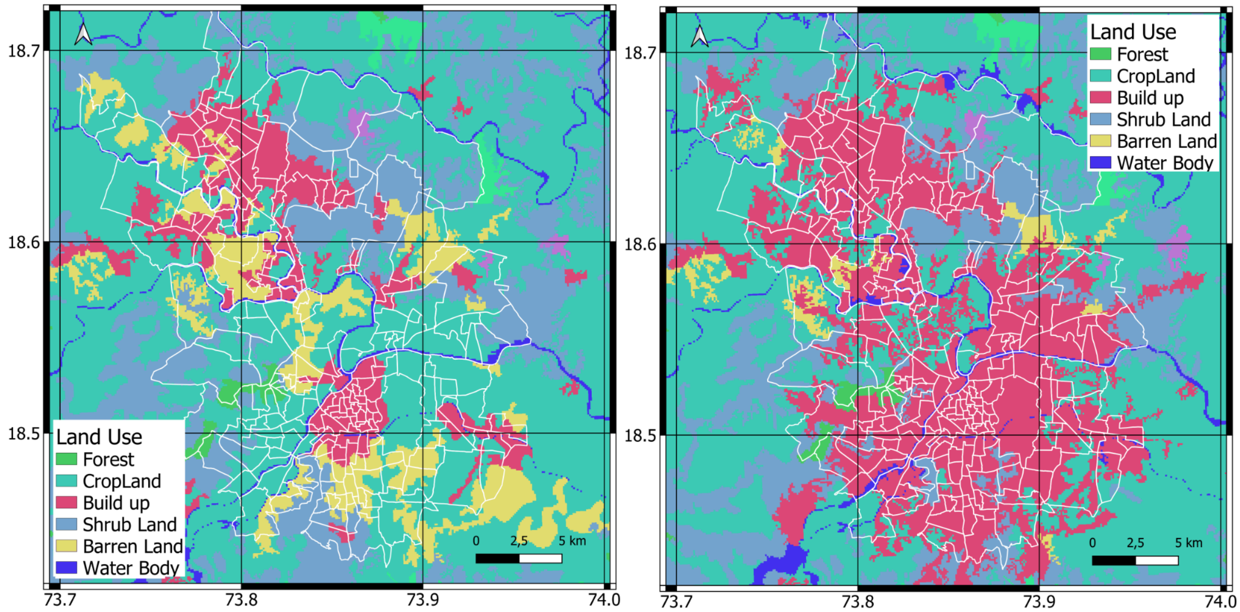

Fig 3: Land use changes over Pune region from 1985 (left) to 2005 (right) indicating urban expansion over the city

1.4 Nashik

Located on the bank of river Godavari, Nashik is the fourth largest city of the Indian state of Maharashtra and also one of the fastest-growing Indian cities. Known for its scenic beauty and tourist attraction, Nashik is a weekend gateway for the resident of Mumbai and Pune. Nashik has had a population growth rate of 38% in the last two decades and the urban agglomeration can be observed in the land-use changes as represented in Fig 4. It can be seen that the urban build-up on the southern and south-eastern banks of Godavari has been spread rapidly in past decades. A significant decrease in cropland area can be visible as the city expands.

Nashik is named the "Wine Capital of India" and hosts almost half of the wineries in India. Aeronautics and automobile are also two major polluting industrial sectors in Nashik spanning through two major Industrial clusters; Satpur and Ambad. According to the action plan for control of air pollution by the Maharashtra Pollution Control Board, the major pollution sources over the city are Transport, road and construction dust, biomass burning, diesel generators and tourist activity. The PM_{10} concentration over different stations over Nashik has exceeded Indian Standards in almost all months.

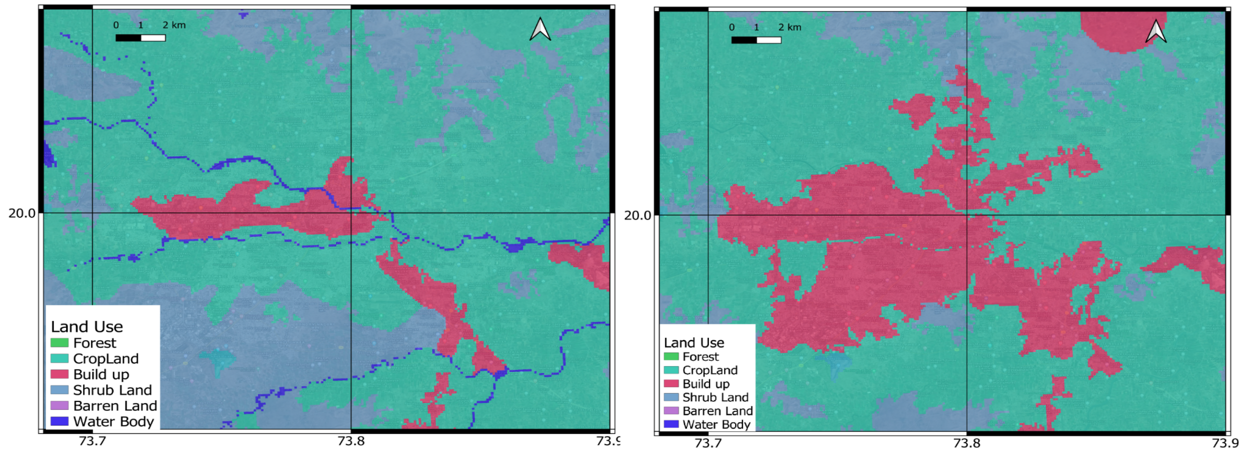

Fig 1.4: Land-use change in Nashik from 1985 (left) to 2005 (right) from (Roy et al., 2016).

Table 1: Summary of the cities and the present air quality monitoring networks

	Lucknow	Kanpur	Pune	Nashik
Area (Sq km)	631	403	665	267
Population (Millions)	3.5	4.6	4.8	1.6
AQ monitor Number (Automatic)	11 (4)	9 (3)	19 (12)	5 (1)
Ideal number of AQ monitors[1]	10	11	13	7
Ideal number of AQ monitors[2]	17	19	20	12

[1]EU Directive (2008), [2]CPCB (2003)

2. Assessment of existing monitoring network – challenges and solutions

2.1 Inter-city heterogeneity of $PM_{2.5}$

High resolution (1km × 1km) Aerosol Optical Depth (AOD) derived $PM_{2.5}$ over four Indian Cities have been mapped using Dey et al., (2020) dataset for 2019 and pixels with maximum and minimum values over the cities were extracted. The maximum-minimum differences are plotted for four cities in Fig 5. Clearly, there is a difference between the cities in IGP and cities in Western India. The inter-city heterogeneity cannot be resolved for IGP cities whereas spatial variation within the city can be observed for Pune and Nashik. However, although Kanpur and Lucknow do not show much spatial heterogeneity in satellite-derived AOD data, the ground-based station over the region clearly indicate the presence of inter-city heterogeneity. The low-cost sensor network over Kanpur reported the annual average $PM_{2.5}$ concentration varies from 73 µg m^{-3} to 142 µg m^{-3} (Atmos, 2019). Seasonal variation of spatial heterogeneity of $PM_{2.5}$

over Kanpur was reported by Sharma (2010). A similar observation was found in Lucknow where the average $PM_{2.5}$ concentration in winter varies from 147 µg m^{-3} to 280 µg m^{-3} (Pandey et al., 2012). Without spatially resolved satellite data, identifying pollution hotspots over the cities would be difficult. Over Pune and Nashik, satellite data, as well as ground-based observation, suggest high variability in different parts of the city.

The traditional approach of setting up air quality monitoring sites in residential, commercial and industrial areas relies upon distinguished homogenous land-use zones over the cities. For mixed land-use zones in CAP-India cities, we have recommended setting up air quality monitors in heavily polluted areas and urban background sites. Over Nashik and Pune, satellite data has been used to identify highly polluted areas. Over Kanpur and Lucknow, pollution hotspots were identified using emission inventories and available campaign data. Recommended urban background sites were selected based on Night Time Light data and ground-based information.

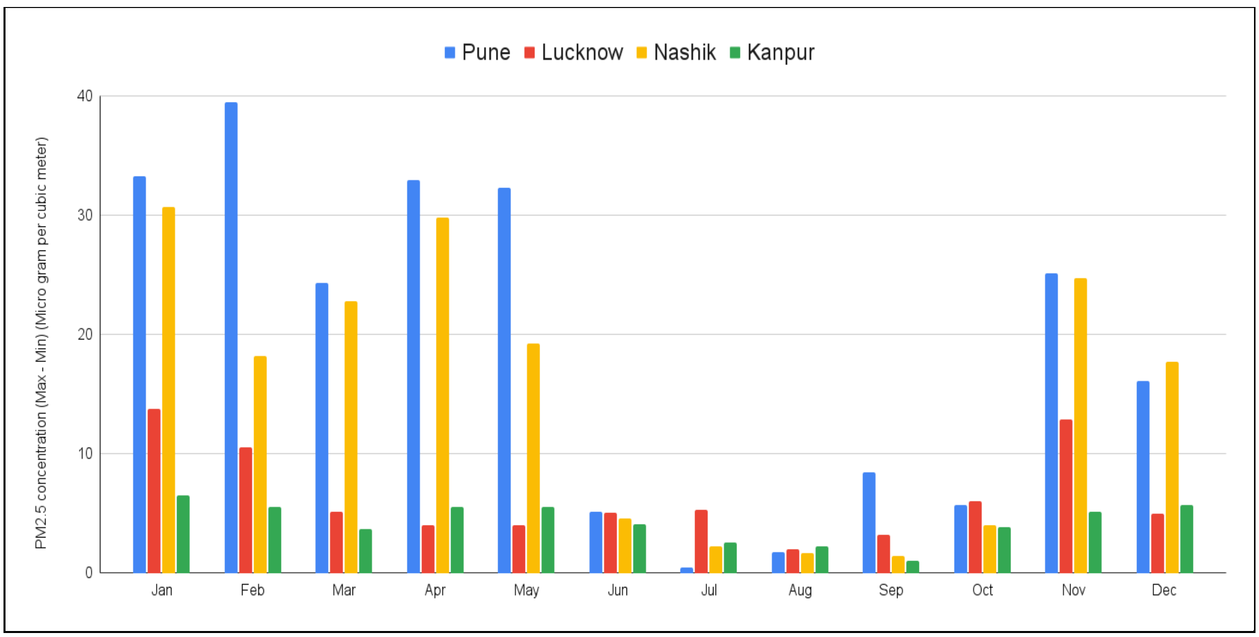

Fig 5: Monthly variation of maximum and minimum concentration difference of satellite-derived $PM_{2.5}$ in four CAP-India cities

2.2 Predominance of mixed land-use

Identifying the priority area of air quality measurement is more convenient in a well-planned city with separate land-use zones i.e., residential, industrial, commercial, etc. However, mixed land-use patterns dominate in the CAP-India cities where the simultaneous occurrence of residential, commercial and industrial areas can be observed (Annexure). The mixed land-use zones over these cities are limiting the representativeness of the air quality monitoring station.

The land-use zones for the existing stations in all four cities have been clearly indicated the simultaneous occurrence of industrial clusters, commercial places and numerous point and line sources near residential stations. Not only that, the presence of bare fields and traffic junctions near the majority of the monitoring stations can also be visible from the land-use zone map which might influence the observations. Randomly distributed low-income neighborhoods (slums) contribute 12.8% to 40.2% to the total population over these four CAP-India cities (Census, 2011) which added additional complexity in the mosaic land-use zones. Therefore, classifying AQ monitoring stations following CPCB (2003) guidelines in such a complex land-use pattern is extremely difficult and is an area that can be considered for reevaluation in coming years. Under the CAP-India project, we have created metadata for each of the existing stations describing the micro-environment in four cities which will help in better interpretation of the data.

2.3 Lack of $PM_{2.5}$ monitors

For all CAP-India cities, the number of manual monitoring stations is higher as compared to the automated monitoring station. Lucknow and Kanpur have 4 and 3 automated monitoring stations with continuous $PM_{2.5}$ measurement. Only one continuous monitoring station is present for both Pune and Nashik. The manual air quality station, under the aegis of the National Air Quality Monitoring Programme, is supposed to measure $PM_{2.5}$ at a regular interval. However, the CPCB report (2020) clearly indicates the insufficient measurement of $PM_{2.5}$ in the manual stations. Over Pune and Nashik, none of the manual monitoring stations measure $PM_{2.5}$. Over Kanpur, $PM_{2.5}$ sampling is carried out over only one manual station, out of eight. The majority of manual monitoring stations over Lucknow measure $PM_{2.5}$, however, the sampling frequency ranges from 30-50 per year. $PM_{2.5}$ instruments are specifically operated during the post-monsoon and winter months. $PM_{2.5}$ is the most important air pollutants as compared to other gaseous and particulate counterparts causing a million death in 2019 as reported by the Global Burden of Disease study (Pandey et al. 2021). CPCB (2020) report clearly suggest that SO_2 and NO_2 concentration does not exceed National Ambient Air Quality Standards over all four CAP-India city except for Pune where NO_2 was found to be slightly higher in some stations. In absence of $PM_{2.5}$ measurement at the manual stations, the spatial distribution of $PM_{2.5}$ over all four cities becomes limited. Therefore, focusing in the $PM_{2.5}$ measurement would help to address the gap of knowledge over all four CAP-India cities. The $PM_{2.5}$ monitors can be placed in the existing manual stations and sampling at the regular interval should be carried out.

2.4 Inadequate representative stations

The existing stations over four cities have been classified in to different categories and represented in Fig 6. The mixed land-use pattern and co-located sources make the site classification difficult. For example, commercial sites and construction sites are often located near busy traffic junctions. For the measurement of pedestrian exposure, it is important to keep the sampling inlet to the breathing height. However, in the present monitoring network, the pedestrian exposure sites are usually located on the first/second floor (~ 10-15m above the ground) of the building beside the road junction. Residential areas are often located near traffic junctions, industry and busy commercial places. It is difficult to classify site type using CPCB (2003) air quality monitoring guidelines as true “Residential”, “Commercial” or “Industrial” sites possibly does not exist. City-wise metadata has been generated for all the existing stations over CAP-India Cities (Annexure).

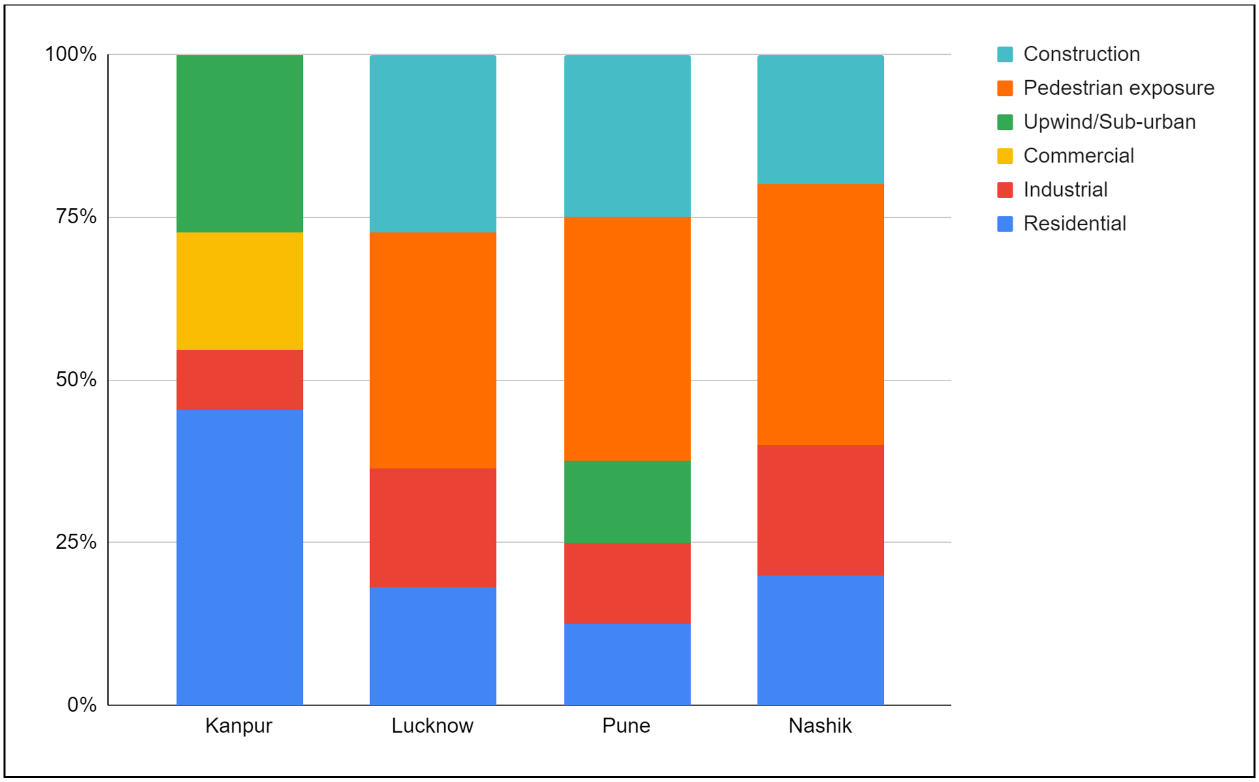

Fig 6: Percentage of station types over CAP-India cities

The dominant station type over Pune, Lucknow and Nashik are pedestrian exposure and construction station. More than 50% of the stations over these cities are either located in close proximity of road (<20m) or construction sites (<50m). The residential sites over all four cities are scarce and often the most populated places do not have air quality monitoring stations. We have used Night-Time Light data as a proxy for outdated and low-resolution Census data (2011) to identify places with higher populations and validated through ground-based observations.

The government of India has launched the Smart city mission which focuses on retrofitting and redevelopment of 100 Indian cities, including the CAP-India cities. The construction and demolition work around these cities has become a regular event and the type of sites might be influenced by the aerosol generated in the procedure. Stakeholder engagement with Urban Local Bodies and acquisitions of long-term developmental plans over a region is necessary information before deploying an air quality monitoring station.

Kanpur and Lucknow are both located in Indo-Gangetic Plain and long-range transport are one of the known source of air pollution here (Rajput et al., 2016). The absence of stations in an upwind location for Lucknow city can be noted from the site classification. Kanpur, on the other hand, has an adequate number of background and residential stations but does not have stations to measure pedestrian exposure.

Recommendations are given for strategically placing monitoring sites to distinguish local and non-local sources of air pollutants, especially over Kanpur and Lucknow in IGP.

2.5 Insufficient inter-agency co-operation

The air pollution monitoring over CAP-India cities is conducted by Governmental bodies, academic institutions and civil society organizations. Lack of inter-agency cooperation between these three verticals can lead to loss of important resources. System of Air Quality and Weather Forecasting and Research (SAFAR) has its own air quality monitoring in five Indian cities and it is run by the Indian Institute of Tropical Meteorology, Pune. Over Pune, SAFAR has eleven online monitoring stations and they have a very strict “no data sharing policy” with other organizations (Indian Express, 2017). Even though the SAFAR network provides real-time data and forecasts through mobile applications, the historical data is inaccessible to the general public as well as others agencies. Moreover, due to the lack of inter-agency cooperation, some of the SAFAR stations and CPCB stations over Pune coincide. Proximally located more than one station results in inefficient resource allocation.

2.6 The coincidence and proximity of automatic and manual stations

Automated and manual stations are often co-located over Lucknow, Pune and Kanpur. Over Lucknow, Talkatora and Lalbagh host both automatic and manual monitoring stations simultaneously. Similar co-occurrence can be noted over Pune and Kanpur, where both automatic and manual stations are present within close proximity over Bhosari, Hadapsar and IIT Kanpur. As the manual stations mostly measure gravimetric PM_{10}, SO_2 and NO_2, having two types of stations in the same location also results in inefficient resource allocation. If installed for the purpose of data validation the two should be collocated at exactly the same site.

2.7 Monitoring stations at the government buildings

With the exception of Kanpur, most of the monitoring stations in all three CAP-India cities are located in governmental buildings. For example, all but one station over Nashik, Pune and Lucknow are located in government offices, parks or educational institutes owned by the government. From a logistical point of view, commissioning air quality monitoring stations in governmental buildings is important due to the accessibility of electrical appliances, security and legal procedures. However, putting air quality monitors in only government buildings restricted the scope of exploring different micro-environments and land-use patterns. The governmental buildings are strategically placed in locations with higher accessibility; i.e. near major road junctions. The classification of monitoring stations over Nashik, Pune and Lucknow indicates the prevalence of pedestrian exposure stations. In Kanpur, the majority of the stations are located in the residential neighborhood measuring the average air quality. Putting an air quality station in a citizen complex is logistically trivial, even though it may open the scope of public participation in air quality management which evidently improves citizen sensitization.

3. Framework for air quality monitoring

Overall this work has led to a series of recommendations for augmenting, the existing network over all four cities toward does not fulfill the monitoring air quality monitoring objectives outlined by CPCB. The evaluation of the existing air quality network over four CAP-India cities indicates that the present monitoring stations are predominantly measuring air pollutants in highly polluted areas, but measurements in the residential areas and background stations are lacking. Therefore, gap of knowledge exists on long-term population exposure and regional contribution of air pollutants. The mixed land-use pattern over all four cities has added extra complexity while classifying the existing sites.

The CPCB (2003) guidelines have outlined multiple air quality measurement objectives which we broadly classified into three; monitoring population exposure, measurements for compliance with the national standards and characterization of sources. The proposed framework for improving air quality monitoring begins with an assessment of the existing air quality network over the city (Fig 7). Each current station is categorized according to the representative air quality monitoring objectives, and new sites are proposed to fulfill specific objectives. For example, in Pune, Nashik and Lucknow, the majority of the existing stations are located in busy traffic environments, fulfilling the objective of short-term population exposure. On the other hand, the majority of the stations in Kanpur, located away from any major sources in calm residential areas, fulfilling the objective of long-term population exposure. All the existing stations in four CAP-India cities have been evaluated and listed in the individual city report (Annexure). Some general findings and recommendations are summarized below.

The spatial distributions of population density and particulate matter air pollution are rapidly changing and not mapped accurately by conventional methods. Readily available night-time light data and satellite-derived aerosol optical depth (AOD) are used to supplement census and ground-based measurements to identify population and pollution hotspots, and priority for new sites is given to those which are high in both. Also, a significant proportion of the population is living in the slums or low-income neighborhoods of Pune (32.5%), Lucknow (40.2%), Nashik (12.8%) and Kanpur (15.4%). While setting up stations in highly populated areas, it is also important to consider diverse residential micro-environment; i.e. high, middle and low-income neighborhoods. Over Kanpur and Lucknow, satellite data were unable to identify air pollution hotspots. We have used an existing emission inventory over Kanpur and previous spatially resolved studies in Lucknow to identify hotspot regions. To improve this evaluation, it is recommended to conduct a campaign-mode study on the spatial distribution of $PM_{2.5}$ before setting up a new monitoring station.

Monitors should also be placed to characterize important sources (industrial clusters, powerplants, and so on) and contrasted with urban background sites, which are also generally absent. An important source for many cities (e.g., over IGP) is long-range transport. For these cities, monitors upwind are necessary to identify the increment of local pollution contributions.

In placing new monitors (or evaluating existing ones), the specific micro-environment of each station needs to be considered to meet the respective objectives. For example, a station placed in a highly-populated area to characterize exposure should be located far from known line and point sources which might influence the monitoring objective. Finally, all four cities are experiencing city-wide construction and demolition works as a part of the Smart City Mission which changes the representative type class of monitoring stations. Inter-agency co-operation with the Urban Local Bodies, on future city planning, is necessary to establish long-term air quality measurement.

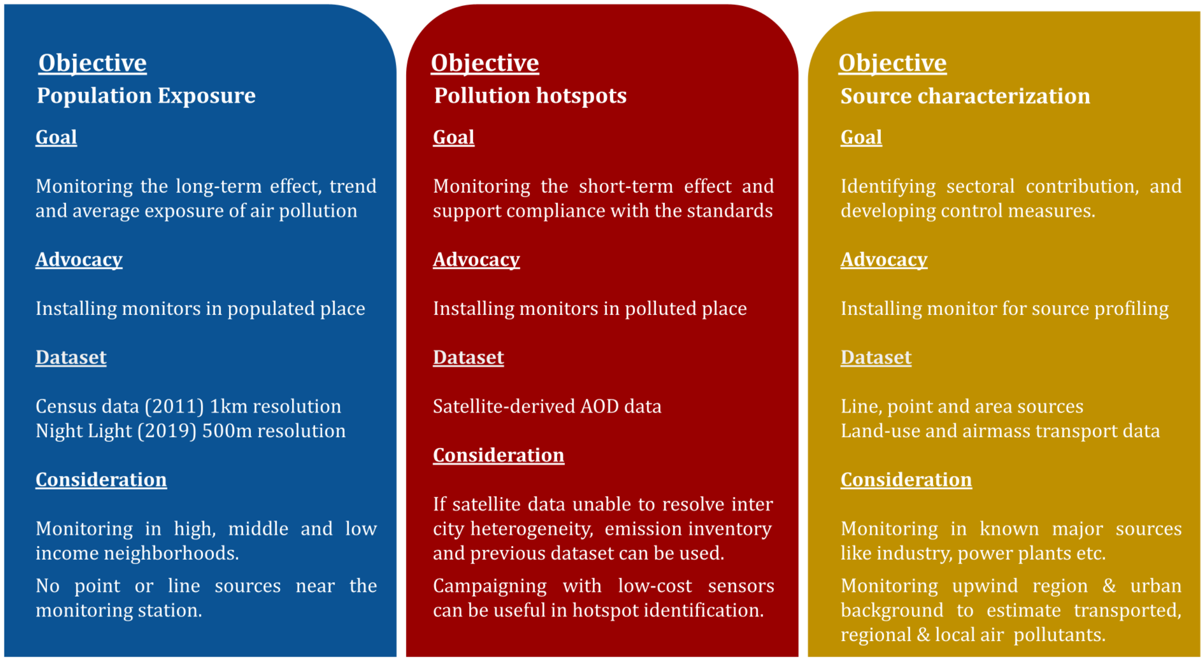

Fig 7: Framework used for determining air quality monitoring sites in CAP-India cities.

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