Catalysing Local Action for Clean Air

A Guidebook to Map Hyperlocal Sources of Air Pollution

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Identification and management of pollution hotspots is crucial for effective mitigation efforts and to overcome resource constraints faced by Urban Local Bodies (ULBs) in tackling the city's total pollution sources.

Image: CEEW

Executive summary

As a comprehensive long-term measure of pollution control in Indian cities, the Ministry of Environment, Forests, and Climate Change (MoEF&CC) introduced the *National Clean Air Programme* (NCAP) as a national strategy to tackle air pollution in 2019. As part of NCAP, the country's most polluted cities, known as non-attainment cities (NACs), were identified. City-specific strategies were to be devised for reducing pollution levels in these cities. To strengthen its commitment towards tackling air pollution, the Government of India included a budget outlay for air quality management in urban local bodies (ULBs) in the union budgets for 2020 and 2021. The State Pollution Control Boards (SPCBs) created city-specific action plans for each of the NACs by incorporating a series of measures to improve air quality. The utilisation of only 26 per cent of the allocated funds for clean air plans in 89 non-attainment and 42 million-plus cities as of March 2022 points a need for improvement in the implementation of city-specific action plans (Lok Sabha XVII/Question882/2022).

ULBs are grappling with lack of actionable data, which is one of the causes of their inaction. A city-level source apportionment study is needed to target primary polluting sources of the city. But less than 30 per cent of NACs have completed source apportionment studies under NCAP (Prana Portal, n.d.). Even a complete source apportionment study is insufficient, as it only provides contribution from sectoral sources and not detailed data on local causal sources and activities that cause pollution. Therefore, cities need to explore ways to generate high-quality pollution source information periodically and quickly.

We present an alternative approach to generating hyperlocal information on the causes of pollution in a city. The methodology has been developed and refined by CEEW in close consultation and coordination with DoE (Department of Environment, (GNCTD)). This approach entails identifying, mapping, and addressing hyperlocal dispersed sources of pollution comprehensively. The report aims to provide a template for other cities to emulate. Hence, the report exclusively focuses on the scientific approach and methodology and does not include any primary data generated during the study. With a dedicated field team and geographic information system (GIS) tools, we have created a system to catalogue dispersed pollution sources at the ward level. Our interactions with ULBs and SPCBs, in addition to inputs from the Fifteenth Finance Commission guidelines, suggest that all the 131 non-attainment cities are currently working towards identifying pollution hotspots and developing plans for managing them. As a part of our approach to identifying causes of pollution in a city, we have also developed a custom indicator called the Composite Ward Score (CWS) that can help cities identify pollution hotspots for prioritising action. Further, we illustrate how this approach can be applied to any city independent of the population.

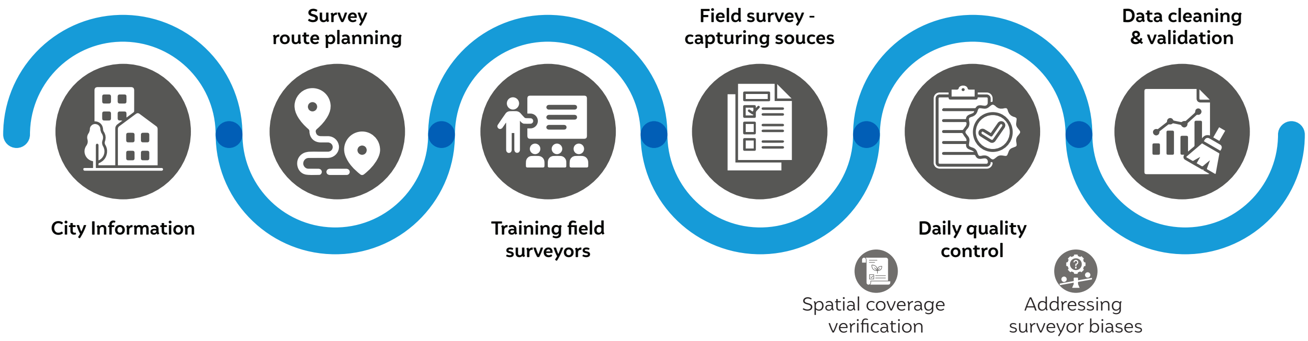
A. Method: How to generate hyperlocal insights on air pollution in a city?

A field reconnaissance survey involves a team of field surveyors going around the city to digitise dispersed sources of air pollution at the neighbourhood level. The operational process of the field survey includes sequential steps like survey route planning, training of field surveyors, field survey, and data management.

Step 1: Ward-level route planning. Each ward's target roads (primary roads, secondary roads, and key tertiary/ quaternary roads) are pre-marked to guide the field surveyor during the field reconnaissance. The field surveyors are trained to use the route plans on Google Maps during the field survey exercise.

Step 2: Ward-level survey protocol design. A simple, quick, easy-to-implement tool to collect user-friendly information on hyperlocal emission sources was designed. The emission sources chosen are comparable to those recommended by the Central Pollution Control Board (CPCB) in its prescribed method for conducting emission inventories and source apportionment studies. However, our method also focuses on the less studied sources for which emission factors are unavailable at the national level. We have attempted to capture 17 different sources, including fugitive emission sources such as burning garbage, construction areas, road dust, diesel generator (DG) sets, and construction and demolition (C & D) waste dumps.

Figure ES 1 Steps to conducting a Field Reconnaissance Survey



Source: Authors' compilation

Step 3: Open Data Kit (ODK) app to digitise dispersed source details: The next step would be to train field surveyors to use the ODK app to collect details such as date and time, source image, global positioning system (GPS) coordinates, and source-specific description for each source. For most sources, we compiled a point GPS location. However, for road dust, unpaved roads, and construction areas, multiple GPS locations of the same source must be collected in order to demarcate the precise boundary. Source-specific descriptions include details like phase of construction, building size, and type of construction (residential/commercial/road construction) for construction sources.

Step 4: Data repository and usage: The subsequent step is to input the gathered data into a cloud-based database with programmatic access. Programmatic access facilitates integration with servers of grievance redressal portals such as Sameer app (developed by the Central Pollution Control Board) and other integrated grievance redressal portals. Additionally, programmatic access facilitates various real-time applications like tracking resolution of the air pollution sources through an interactive dashboard, dynamically updating city-level insights on top polluting air pollution sources and most polluted wards/hotspots.

B. Quality control protocols

We developed a quality assurance protocol to ensure that the data collected during the survey is representative of the area covered by the field surveyor. This protocol can be customised to aid implementing agencies in remote monitoring. Automating data collection and real-time reporting can improve the efficiency of inspection teams. The following components were included for quality assurance and control:

- Spatial coverage of the planned route
- Accuracy of the location of the source
- Addressing the surveyor biases for sources within a ward

Spatial coverage verification

In order to ensure optimum coverage of the wards, data managers monitor the regions of insufficient coverage by overlaying the actual route traversed by field surveyors over the pre-set ward route plan that covers all the primary, secondary, and tertiary roads in each ward. This check is done daily for each ward. Field surveyors are asked to re-cover the ward if the coverage is unsatisfactory.

To ensure objectivity, we have developed a 'spatial coverage metric', a proxy to assess the quality of spatial coverage by field surveyor.

$$\text{Spatial coverage metric (SCM)} = \frac{\text{(Number of control points captured within a ward)}}{\text{(Number of control points preset on ward route plan)}} \times 100$$

In order to develop this metric, we pre-marked an evenly placed set of reference control points that the field surveyors are mandated to capture on the ward route plan. The field surveyors are instructed by the data managers to re-do the ward, if the SCM for that ward has dropped below 75 per cent. This two-step quality assurance/quality control (QA/QC) method ensures a thorough, high-quality survey covering almost every locality within a city.

> **The quality control protocols can be customised to aid implementation agencies in remote monitoring of field inspection teams.**

Validating accuracy of the location data captured by overlaying with Google satellite imagery

The ODK survey form interface must be conditionally coded to not collect or accept any GPS coordinate with a location deviation more than 10 metres.[1] This needs to be supported by validation of the captured location data by overlaying them on Google satellite imagery. At times, some rectification of the captured location data would be needed, especially for area sources, where minor location errors add up to create displaced polygons in location data.

Addressing surveyor observational biases and feedback discussions

As a final step in ensuring quality, there should be day-to-day feedback discussions with the field surveyors. The discussions should be centred on reducing the observational biases in capturing sources to the field surveyors that facilitate course correction and continuous improvement of the survey quality.

C. Identifying local pollution hotspots within cities

Identification of pollution hotspots is crucial so as to focus mitigation efforts on areas that disproportionately contribute to the city's total polluting sources. Hotspot management is also identified as one of the components under the implementation of NCAP. This is mainly required to offset the resource crunch faced by ULBs. Furthermore, competing insights from different factors often perplex ULBs while taking an actionable decision.

To address these issues, we have developed a Composite Ward Score (CWS), which is a spatial prioritisation matrix used for ranking the wards, to prioritise action.

$$C_j = \sum_{i=1}^{n} R_i$$

where C_j is the composite rank value of the *j*th ward and R_i is the rank of an individual factor.

CWS is calculated by combining the individual ranks of four priority factors. The four priority factors considered for calculating CWS are as follows:

- Population density of each ward
- Areal source density in a ward, that is, frequency of sources per sq. km. area
- Total number of top three sources in a ward
- Average $PM_{2.5}$ concentration from satellite measurements

Wards can be ranked in order of priority of action using the CWS. Actions could be prioritised in the ward with the greatest CWS first, while the ward with the lowest CWS would be considered last.

D. Recommendations

Our report provides simple protocols that can be used by implementation agencies in non-attainment cities to generate a comprehensive database of hyperlocal emission sources. It generates actionable insights faster than the more resource-intensive source apportionment studies. Additionally, the Composite Ward Score, developed by us, enables ULBs to prioritise localities/wards that need immediate attention. The score also helps identify locations where abatement measures will bring maximum air quality improvement.

Additionally, our findings emphasise the importance of hyperlocal sources, which when considered in aggregate, contribute significantly to worsening air quality. As a result, these should be prioritised for abatement, involving broad participation from both industries and the general public. The data analysis shows that the distribution of sources is not uniform across the city.

Based on our analysis, we propose the following recommendations for various entities involved in controlling air pollution:

- The quality assurance/quality control protocol developed for the reconnaissance survey can be customised to enhance the capacity of implementing agencies for remotely monitoring the efficiency of inspection teams through automation of data collection and real-time reporting.

> **Composite ward score enables the ULBs to identify and prioritise localities where abatement measures will bring maximum air quality improvement.**

1 10 m deviation is taken after multiple trial runs to ensure the optimum satellite coverage.

- Implementation agencies and urban local bodies can utilise the reconnaissance data to regulate the informal sources of pollution that do not find a place in any of the emission inventories/source apportionment studies.
- The research institutions involved in conducting source apportionment/emission inventory can leverage this data to develop source-specific emission factors. This will help enhance the accuracy of emission estimations.
- The Composite Ward Score (CWS) approach will aid the policymakers in prioritising the wards/localities based on their CWS ranking to set tenable targets with defined outcomes.
- Regulatory bodies can employ the findings of our analysis in identifying hotspots where regular monitoring is required. The database will be helpful in the site selection for new monitors and to assess the appropriateness of the existing monitor's location.
- The insights from the ward-wise database can be employed to initiate customised public information, education and communication (IEC) campaigns that are more relatable to the local residents, thus enhancing the awareness level of hyperlocal air pollution issues. Such stakeholder-specific awareness campaigns will create favourable policy impact and drive behaviour change. Results from a periodic field survey can make a forecast decision support system fully actionable by providing the specific pollution sources and prioritised areas that need immediate action.

1. Introduction

Air pollution is detrimental to all living things. It remains much of an invisible problem having repercussions on the economy and people. The study from World Health Organization (WHO) shows that almost all of the global population (99 per cent) breathes air that exceeds WHO guideline limits and contains high levels of pollutants, with low- and middle-income countries suffering from the highest exposures (WHO 2022). Rapid urbanisation and exploding population in urban areas have exposed a sizeable urban population to the negative consequences of air pollution, making cities the focal point for addressing air pollution-related concerns. As a concrete step towards pollution control, the Government of India launched the National Clean Air Programme (NCAP; MoEF&CC 2019) in 2019 to tackle air pollution in cities that have failed to satisfy air quality criteria for five consecutive years (these cities were called non-attainment cities).

As part of NCAP, 131 cities throughout the country have been classified as non-attainment cities. The NCAP is envisioned as a collaborative, multi-stakeholder, and cross-sectoral programme to address all causes of air pollution. The State Pollution Control Boards (SPCBs) have developed city-specific interventions and action plans under the NCAP. To further its commitment to reducing air pollution, the Government of India earmarked a total of INR 12,139 crore as budgetary allocation under the Million-plus Challenge Fund for million-plus cities based on the Fifteenth Finance Commission's recommendations (Prana Portal, n.d.)

Information on the type and source of emissions is a crucial requirement for understanding air pollution and monitoring city action plans. Currently, most city action plans have been developed without gathering information on source-specific emissions. Even the few action plans that have included the source-related information fail to effectively integrate the insights into actionable data (Ganguly, Selvaraj, and Guttikunda 2020). Even as the lack of actionable information continues to remain a challenge in most cities, with the introduction of the NCAP, the knowledge sharing between technical institutions that work in the air quality space, the SPCBs, and urban local bodies has increased. A 2020 assessment by CEEW finds that only 25 per cent of city clean air plans contained information on the relative contribution from the sources of pollution. As of December 2022, only 30 per cent of the 131 non-attainment cities had completed a source apportionment/emission inventory study.

Source apportionment studies have been recognised as a vital component for formulating and improving city-based clean air plans by both NCAP and the National Green Tribunal (NGT) (NGT OA 681 /2018). It is, however, a resource and time-intensive, highly specialised technical exercise for which competence is confined to select institutions and organisations identified through the national knowledge network. While a comprehensive source apportionment research offers contributions from sectoral sources, in the absence of gridded emission inventories and spatially resolved source contribution maps, cities do not have access to precise data on local pollution causative sources and activities.

> **As of December 2022, only 30% of the 131 non-attainment cities had completed a source apportionment/ emission inventory study.**

Creating an emission inventory is the first step in understanding the sources of pollution and their magnitude. It is a less resource-intensive exercise than source apportionment and provides a comprehensive accounting of emissions emanating from all emission sources; nonetheless, it is usually executed as a subcomponent of a source apportionment analysis. While emission inventory data is appropriate for long-established, registered or regulated sources such as industries and thermal power plants, the data reliability becomes questionable for ever-changing sources such as road dust, solid waste, infrastructure activities and construction, and waste burning, which cause fugitive emissions. Furthermore, emission inventories frequently overlook the hyperlocal dispersed sources of pollution that, when added together, might contribute significantly to pollution (Karagulian et al. 2015).

While the credibility of both the methods (apportionment and emission inventory) for generating pollution-related information is well established and both are crucial to gain an understanding pollution sources, their resource-intensive nature, time taken for completion, and the dearth of required expertise make it difficult for cities to use these methods to get updated information on pollution sources periodically. While cities can continue their efforts in getting the city-specific emission inventories and source apportionment studies done, this should not be a reason to delay action on the ground. Therefore, cities need to explore ways that can help them take action by generating high-resolution pollution source information periodically and quickly. In this study, we attempt to answer the following questions to propose an alternative method to generate hyperlocal information on a city's pollution sources and accordingly prioritise local actions:

- How can we generate up-to-date, cost-effective local intelligence on what is polluting a city?
- How can we prioritise areas and sectors that need immediate attention?

2. Collecting field evidence: step-by-step approach to prioritising local action in cities

In this chapter, we elaborate the process that we followed to collect information on local pollution sources. This includes the survey methodology and the quality control protocols adopted during the survey. We also highlight the limitations of this exercise and opportunities for improvement. We illustrate the steps involved in this process by imagining activity levels and ward distribution in a typical tier-2 Indian city.

The entire activity is classified into six phases:

- Understanding the city
- Planning the reconnaissance survey
- Executing the survey
- Analysing survey results
- Calculation of ward-wise pollution scores
- Identification of priority wards

Each phase is further broken down into multiple inter-related steps. The phase-wise details are provided below.

2.1 Understanding the city

Obtaining background information about the city is crucial to planning and developing the survey, as well as calculating the human resource and budgetary requirements. The background information of the city includes the following:

- The latest ward-level map (shapefile), which demarcates the administrative boundaries of an urban local body
- Information on the distribution of wards into administrative zones: To assess how pollution sources are distributed across the city
- Population and area of each ward: To understand the distribution of vulnerable populations across the city
- The city's infrastructure, especially the condition of roads, determines the time taken to cover each ward
- Ambient air quality network in the city: To assess the land use conditions and activity levels around the existing monitoring stations
- Pollution levels across the city: To understand the spatial distribution of pollution levels in the city.

The background information for establishing knowledge of the city is done through desktop research and primary site visits. The sources of information that we used in our study are summarised in Table 1.

> **Updating pollution source information in cities is challenging due to constraints in resource, expertise, and time for source apportionment and emission inventory studies.**

2.2 Collecting information on local polluting sources

We collected primary data on the nature and distribution of hyperlocal pollution sources through a field reconnaissance survey. A field reconnaissance survey involves a team of field surveyors going around the city to digitise dispersed sources of air pollution at the neighbourhood level. The operational process includes the following sequential steps like survey route planning, training of field surveyors, field survey, and data management.

Survey route planning

As this method focuses on hyperlocal dispersed sources of pollution, the reconnaissance survey is aimed at covering all the areas falling only within the municipal ward limits of the city. To ensure thorough spatial coverage, a ward-level route planning is undertaken, where each municipal ward is treated as an individual unit of planning. The ward-level route planning was done to ensure maximum coverage of primary, secondary, tertiary roads, and critical quaternary roads across all wards. Ward-level planning also facilitates internal administrative work allotment to sanitary inspectors and other ward-level staff within the urban local body (ULB).

Each ward's target roads (that are to be covered) are pre-marked using Google's My Maps tool before the field reconnaissance. These pre-marked roads (shown in red) in Figure 1 guide the field surveyors in navigating the ward during the field reconnaissance route plan.

Survey form design and data collection

One of the essential components of our method was to design and set the survey's objectives. The survey's primary purpose was to generate actionable information for air pollution mitigation by ULBs. Our idea was to generate intelligence that can be readily used by ULBs to plan, prioritise, and roll-out mitigation measures in near real-time basis.

The key aspects considered while designing the survey were the following:

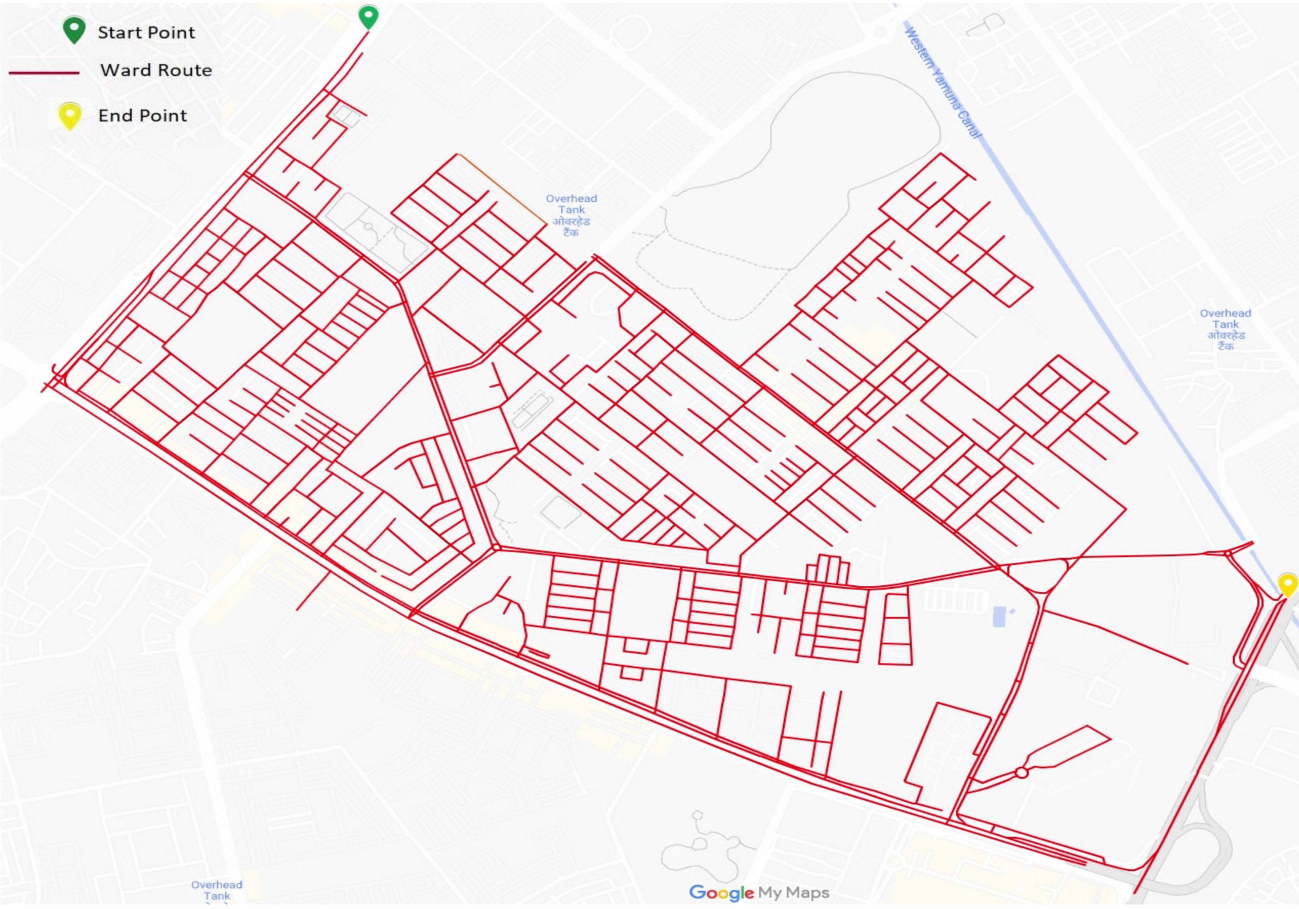
- **Scope:** The purpose of this activity is to gather evidence of hyperlocal pollution by gathering necessary information on pollution sources that can be handled at the ULB level. Our review of city clean air plans formulated under the NCAP suggest that the primary responsibility of implementing an action plan lies with the ULBs. Therefore, ward-level information on pollution sources will assist these agencies to prioritise the action on the ground. In addition to this, it will also help them to assess the impact of actions on the ground. The emission sources chosen are comparable to those recommended by the CPCB for developing emission inventories except that our method focuses on the less studied sectors, that is construction and demolition (C&D), road dust, and C&D waste for which emission factors (EF) have not been developed yet, and EF from the United States Environmental Protection Agency (USEPA) is still used (Emission and Reports 2022).

Table 1 Gaining Insight into the City through gathering background Information

Data	Source
Land use (Ward-level shapefile)	Nagar Nigam of the study city
Population (2011)	Primary Census Abstract
Satellite-derived $PM_{2.5}$ data	IIT Delhi
Pollution estimates	Urban emissions
Air quality data	Central Pollution Control Board

Source: Authors' analysis

Figure 1 A comprehensive route plan for field reconnaissance covering primary, secondary and tertiary roads with start and end point



Source: Authors' compilation

All these sectors are identified as key sectors in the city action plans. By using the data collected from the reconnaissance surveys, we can fill in any gaps and update the missing information in the existing inventories. At the same time, the reconnaissance data may be used to assess the impact of the ULBs' actions on the city's air quality and track the progress of the city action plan. The details of sources included in the survey and the type of emission sources are provided in Annexure 1.

- **Ease of implementation:** A simple, quick, and easy-to-implement survey procedure was designed so that implementation agencies can understand and execute it regularly. To accomplish this task, the survey is automated using the Open Data Kit (ODK) mobile app to collect details about each air pollution source, as elaborated in Annexure 1. The field surveyors are trained to use the Open Data Kit (ODK) ("ODK—Collect Data Anywhere" 2022) mobile app to collect details about each air pollution source, as elaborated in Annexure 2. Details compiled in the survey include images, location details, and source characteristics. For the ease of understanding of surveyors, the survey form and other related documents are translated into the local language.

- **Resource efficiency:** One of the most crucial factors to consider while developing the survey is how to make it resource and time-efficient. Resource efficiency in this protocol is achieved through proper route planning and systemising the procedure with the help of automation.

A cloud computing server is employed to collect responses from the ODK mobile app installed on the mobile phones of field surveyors. Cloud server enables programmatic access (application programming interface (API)) of the survey data and also facilitates integration with servers of other grievance redressal apps and portals like Sameer app and Green Delhi app. Following the successful pilot study conducted using the ODK tool, we embarked on an extensive and comprehensive hyper-local source mapping by utilising DPCC's Green Delhi App, facilitating our data collection efforts. The exercise went beyond data collection, evolving into a holistic grievance redressal system. Within the framework, various agencies from different departments, including Junior Environmental Engineers and other officers, were actively conducting inspections and promptly addressing pollution sources periodically.

Programmatic access (API) also opens up myriad real-time applications like tracking resolution of the air pollution sources through an interactive dashboard, dynamically updating city-level insights on top polluting air pollution sources and most polluted wards/hotspots.

Figure 2 **CEEW expert guiding enumerators on how to find and record 17 distinct dispersed pollution sources using ODK app**

Image: Adeel Khan/CEEW

Table 2 **Survey specs: stages in survey design, preparation, and execution**

Resources	Tasks
3 Researchers	**Research design** • Research focus **Mapping of dispersed air pollution sources** • Questionnaire design **5 minutes long**
1 Field Manager 2 Supervisors	**Survey preparation** • Vendor selection • Ward-level survey route planning • Pilot study • Questionnaire coding **Open Data Kit**
4 Enumerators	**Survey execution** • Enumerator training • Data collection • Data monitoring and cleaning

Source: Authors' analysis

Resources and economics of the field survey

A field survey crew and a data management team are among the human resources necessary for the field survey. The field survey crew includes four surveyors and one on-site supervisor. Two data managers constitute the data management team. Data managers are responsible for checking each field surveyor's route coverage regularly throughout the field survey.

Furthermore, at the end of each survey day, data managers conduct quality control checks on accurate geographical coverage of each ward and construct quality assurance metrics, as detailed in section 2.3. Data managers also guide field surveyors to navigate unfavourable field situations such as inaccessibility and global positioning system (GPS) coverage. During the survey period, a team of four individuals could survey 12 wards, each of which spans an approximate area of 1 sq.km in a single day.

Total survey cost majorly consists of one-time personnel compensation, fuel, and transport costs. Costs of cloud server deployed (to collect survey responses and API) was the only recurrent expenditure borne. Detailed cost breakup of each expenditure head has been tabulated in Annexure 3.

As previously mentioned, the method will be most successful when used on a periodic basis. One of the primary components indicated for improving city air quality in non-attainment cities, prescribed under NCAP as well as the prerequisite for the release of the first instalment of Fifteenth Finance Commission grants, is enhancing and updating information about emission sources and pollutants. This method may also serve as one of the most cost-effective and time-efficient ways to gather information on polluting sources so as to close the knowledge gap. Given the workforce and financial resources required, ULBs may want to consider including this approach as one of the components for financing under the air pollution grants.

2.3 Quality control of field reconnaissance survey

We developed a quality assurance protocol to ensure that the data collected during the survey is appropriate and representative of the area covered by the field surveyor. The same protocol, after due customisation, can enhance the capacity of implementing agencies for remote monitoring including tracking spot checks and enforcement teams. For instance, to monitor and supervise Graded Response Action Plan (GRAP) implementation, the enforcement task force constituted by the Commission on Air Quality Management (CAQM) deploys inspection teams or flying squads to inspect the compliance with air quality norms. Given the resource scarcity and manual reporting, it is not easy to ascertain whether the deployed inspection teams have covered all the areas. This is where our quality control protocols could particularly prove very useful.

The following components were included for quality assurance and control:

- Spatial coverage of the planned route
- Accuracy of the location of the source
- Addressing the surveyor biases for sources within a ward

All three components of the quality control protocol are further detailed in the sections below.

Spatial coverage verification of planned route

As a first step, spatial coverage is ensured by verification of surveyor route vis-à-vis pre-planned ward route plan as described in section 2.2. Google timeline is enabled on mobile devices to capture the actual path traversed by each field assistant during the field survey.

The actual route (covered by a surveyor on the field) is overlaid on the pre-set ward route plan to thoroughly evaluate spatial coverage at the end of each survey day. Within each ward, data managers cross-check for patches of insufficient coverage. Field surveyors re-do these sections of poor coverage the immediate next day. Figure 3 shows inadequate coverage and Figure 4 shows the ward being fully covered after sending the field surveyor back on the reserve day.

Nevertheless, it is not practical to cover each ward in as much detail as set out in the ward plan because of access issues and other logistical challenges. So, data managers take a call on deviation from the ward plan on a case-to-case basis for each ward. Therefore, we have developed a spatial coverage metric to restrict data manager's subjectivity in decision-making.

> **For quality assurance and control, components such as spatial coverage, accuracy in source location, and addressing surveyor biases were incorporated.**

We have pre-placed a set of reference control points (numbered/starred points) on the ward route plan at crucial intersections in all ward directions for developing the above metric. Field surveyors are instructed to capture GPS coordinates of these control points during the field survey.

Figure 3 **Insufficient spatial coverage in ward's pollution source recording: qa/qc reveals spatial coverage metric below 75% by one field staff**

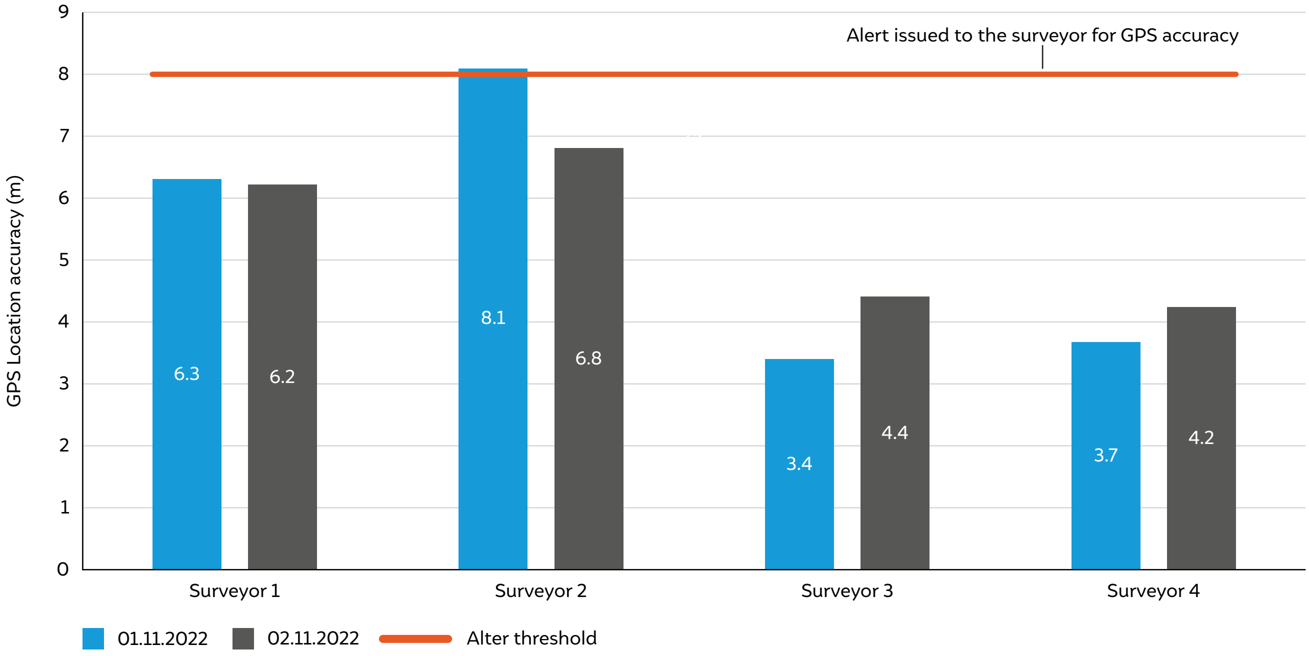
Figure 4 **High spatial coverage achieved by one field staff while capturing pollution sources in a ward, meeting QA/QC standards with over 85% coverage metric**

Source: Authors' compilation

Figure 5 **Route plan of the ward marked with numbered (black) and starred (blue) points for efficient navigation**

Source: Authors' compilation; representation of a ward

Figure 6 **Maintaining field surveyor gps location accuracy within 8 metres through qa/qc protocol under two consecutive days**



Source: Authors' compilation

The percentage of control points (numbered and star points) captured within the ward are calculated after the completion of each ward. It is recommended to ensure that if the spatial coverage metric falls below 75 per cent, data managers send the field surveyors back to re-work the patches of insufficient coverage within a given ward.

Ensuring location accuracy and validating with Google satellite imagery

Location accuracy in GPS coordinates captured is crucial to relocate the source (for resolution) and spatial analysis of air pollution. Keeping this in view, the ODK form interface is conditionally coded in such a way that it does not collect/store any GPS coordinate with a deviation of more than 10 metres. Further, it is recommended that data managers calculate the location accuracy of all GPS coordinates collected for each field surveyor at the end of each survey day. Field surveyors are immediately alerted if their locations' deviations averaged around eight metres provided the network connectivity is good inside and within urban limits where the survey has been carried out. If we carry out the exercise in town or any other tier-2 or tier-3 cities and based on a few trials, the accuracy can be determined accordingly.

Despite the above measures, minor deviations in GPS locations disproportionately affected geo-polygons (in the case of construction areas) and line shapes (for start and end of unpaved road, road dust). To clean the data for these deviations, GPS coordinates, polygons, and line shapes of the sources are overlaid on the Google satellite imagery to validate and correct the shape boundaries.

Figure 7 Using Google satellite imagery to rectify a construction source's misplaced polygon mapped by field staff while recording the source

Before—Displaced polygon shape

After validation—Precise construction area

Source: Authors' compilation

Addressing surveyor biases to ensure a representative survey exercise

Surveyor or observational bias is the most common pitfall in any survey exercise. Observational bias in this survey manifests in the field surveyors' undue focus on capturing a few air pollution sources while neglecting or omitting the collection of other source types. It is important to note here that not all surveyor biases can be addressed, and measurement errors are likely to occur. But, with a thorough review of data being generated on a day-to-day basis, instances of surveyor biases can be significantly reduced.

Figure 8 depicts one such incident where a field surveyor collected four construction material dumps and zero potholes and unpaved road stretches. The on-field observations recorded in adjacent wards in the same zone suggested that poor maintenance of roads was a challenge throughout the zone. These observations and feedback were communicated to the surveyors, who were then sent back to capture polluting instances in the same ward.

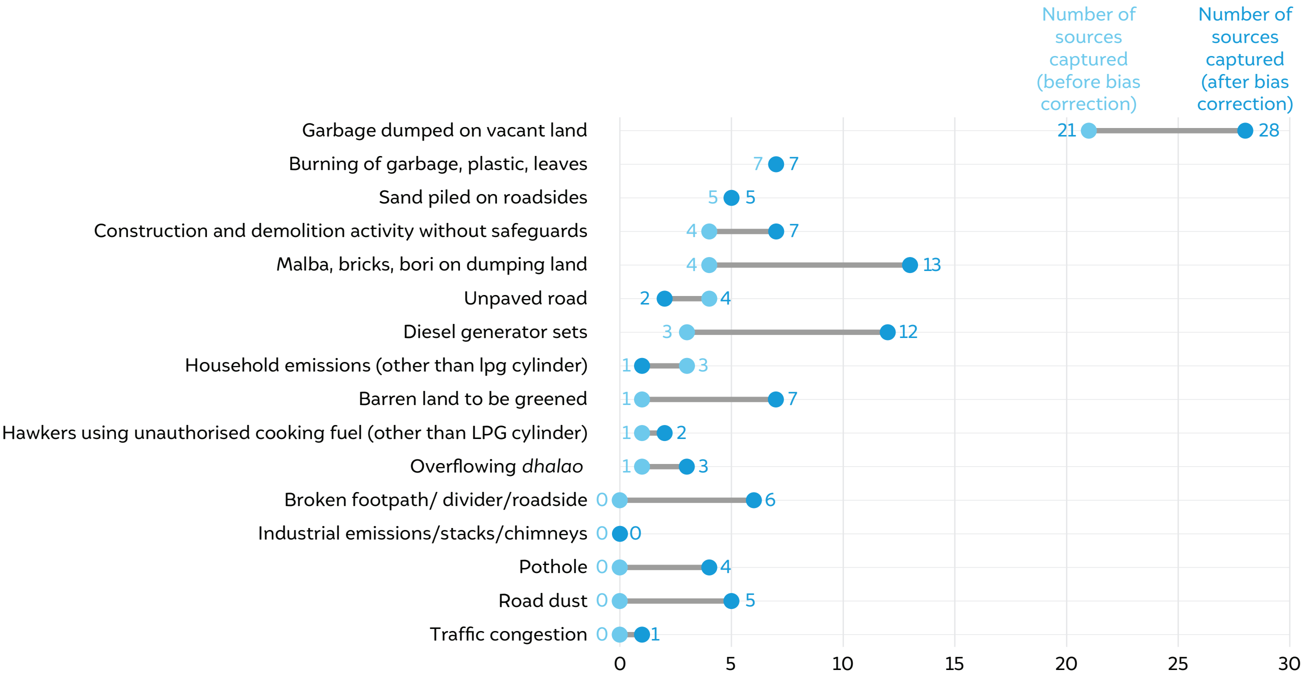
As illustrated in Figure 8, the representation of sources in a ward changed once the surveyor bias was addressed. It is important to note here that not all surveyor biases can be addressed, and measurement errors are likely to occur. But, with a thorough review of data being generated on a day-to-day basis, instances of surveyor biases can be significantly reduced.

2.4 Identifying pollution hotspots using survey results

As discussed earlier, ULBs often face a scarcity of workforce and resources to tackle all polluting sources of the city at once (Deshmukh n.d.). In such a scenario, ULBs would prefer to plan mitigation efforts focused on wards that disproportionately contribute to the city's total polluting sources. Furthermore, competing insights from spatial and statistical analysis considering individual factors discussed above might confuse personnel of ULBs while taking an actionable decision.

With a view to help ULBs identify pollution hotspots using survey data and prioritise action, we have developed a metric called the Composite Ward Score (CWS). The CWS is a ranking method based on a simple normalisation technique used for multivariate data with different units of measurement. It is not affected by the outliers and allows the performance of wards to be followed over time in terms of relative positions (rankings). The same method has been used by many governments across the globe including India for policy decision-making. Some examples that use ranking include the Information and Communications Technology Index (Fagerberg 2001) and the Medicare Study on Healthcare Performance across the United States (Jencks et al. 2003).

Figure 8 Recognising and addressing observational bias in capturing the pollution sources to minimise obeservational bias



Source: Authors' compilation; The sources count is from a specific ward

For assigning CWS for air pollution in a ward, we combine the individual ranks of four priority factors:

- **Population density** of each ward: The direct impact of the air pollution from dispersed sources is on the people living in the vicinity of these sources; therefore, we have included population density as one of the variables for calculating CWS. Considering population density as a metric to prioritise wards will ensure that areas where people are more likely to get exposed to pollution are addressed first. We have considered the Census 2011 for determining population density.
- **Areal sources density** of each ward: We observed that the frequency of polluting sources varies significantly from one ward to another; thus, we estimated the areal density of polluting sources in the ward to depict geographical distribution better. The spatial approach to gauging the number of polluting sources per square kilometre ward area is known as areal density and is calculated using the following equation:

$$\text{Ward's areal density of polluting sources} = \frac{\text{Number of polluting sources captured in ward}}{\text{Ward area}}$$

  This metric helps in determining how pollution sources are spread over across wards. However, it is only a quantitative measure, independent of the strength and size of the pollution source. it would be imperative to prioritise action in wards where a higher proportion of the city's local pollution sources are concentrated.

- **Total number of top three polluting sources** in the ward: As mentioned earlier, not all sources can be tackled at once by ULB; therefore, to maximise the impact we have considered the presence of the top three city-level pollution sources as another variable for calculating CWS.
- **Particulate matter ($PM_{2.5}$) concentration** of each ward: The main objective of this exercise is to reduce pollution in the city. For assessing the impact, it is necessary to have information on the baseline trends of pollution. We employed $PM_{2.5}$ concentrations derived from satellite-based aerosol pptical depth (AOD) observations as one of the variables to determine the most polluted ward due to the limited strength of the ambient air quality monitoring network to predict pollution levels across the city. However, this can very well be substituted by the pollutant concentration values as observed by the ambient air quality monitors in case the monitoring coverage is optimum covering the whole city.

> Considering population density as a metric to prioritise wards will ensure that areas where people are more likely to get exposed to pollution are addressed first.

Composite Ward Score is calculated using the following formula:

$$C_j = \sum_{i=1}^{n} R_i$$

where C_j is the composite rank value of the *j*th ward and R_i is the rank of an individual factor.

The ranks for each factor are calculated by assigning the highest rank to the wards with the lowest value of the individual factor. For example, a ward with the lowest population density will be assigned rank one for population density, and a ward with the lowest $PM_{2.5}$ concentration will be assigned rank one for $PM_{2.5}$ concentration score. The composite score will be the sum of all the individual rankings. Wards can be rated in order of priority of action using the CWS. For priority, the ward with the greatest CWS score will be ranked first, while the ward with the lowest CWS score will be considered last. The ward names are not mentioned due to administrative reasons.

If there is a tie for the CWS, the ward with the larger areal density of pollution sources will be ranked higher. The population exposed to pollution sources in the ward would be the second priority for a tie-breaker. This would be established by comparing the population density ranks. Here, we have prioritised top 10 wards based on the ranking coefficient for 36 wards as part of our pilot study, which can emulated to all wards of any city.

2.5 Limitations of the methodology

While the methods described above are certainly a time- and resource-efficient way to obtain information on local pollution sources and prioritise action, it is important to note that the field survey is a work in progress and continuous refinements will be made as additional quality data becomes available. The most important limitation is the time of the survey for capturing and documenting air pollution sources. The survey was carried out from 9 a.m. to 6 p.m. and did not record any sources after sunset or at night because it is difficult to capture sources in the dark. In addition, access to certain areas in cities is also limited owing to army restrictions, forested areas, apartments, or shopping complexes and regulatory permissions are needed to enter these areas.

Table 3 Ranking the top 10 wards based on their Composite Ward Score - Prioritisation for immediate action[2]

Name of the ward	Population density	Rank 1	Pollution sources density	Rank 2	SAANS data	Rank 3	Top 3 city level pollution sources	Rank 4	Combined score (Ranking Coefficient)
Ward 1	58816	24	140.82	35	181.35	27	55	15	100
Ward 2	56866	21	115.26	10	181.50	23	18	17	84
Ward 3	33205	12	89.24	23	181.38	26	51	22	83
Ward 4	72399	27	84.99	7	181.69	18	21	10	62
Ward 5	25727	7	89.14	15	181.91	28	22	10	61
Ward 6	36323	16	54.81	11	181.78	28	27	10	51
Ward 7	28371	30	52.39	10	190.11	3	14	4	47
Ward 8	77452	10	96.77	16	181.87	5	12	15	46
Ward 9	56619	28	78.36	10	181.87	6	14	18	43
Ward 10	20698	5	71.43	8	181.59	25	45	3	43

Source: Authors' compilation

Composite ward score

50 75 100

2 Ward numbers correspond to their ranks; for example, Ward 1 denotes the ward with the highest CWS score and rank 1.

3. Recommendations

Given the sources captured in the field survey are dynamic in nature, it is crucial to periodically capture these sources to prioritise action as well as assess the impact of interventions to address these sources. Based on our observations and survey data analysis, we offer the following strategies to strengthen local action on pollution.

3.1 Regulating the informal sectors through periodic field surveys

Identifying all informal and illegal pollution sources whose contributions remain unaccounted for in all the city's emission databases has been one of the city administration's many difficult tasks. According to our findings, these dispersed sources may not have a substantial impact on pollution individually; yet, when they are combined, they lead to a considerable rise in hyperlocal pollution, which may be short-lived but extremely detrimental to the individuals who reside in and around these sources. Implementing agencies might employ hyperlocal data to control all informal entities in non-conforming locations, including non-compliant diesel generator (DG) sets and unregistered industrial micro-units. Furthermore, research institutions and regulatory authorities can use this data to update emission inventories and source apportionment studies, which frequently lack information on these hyperlocally distributed sources.

3.2 Using CWS to prioritise action while comprehensive pollution assessment studies are underway

Higher pollution has negative health effects on residents, necessitating the implementation of suitable mitigation measures. A CWS strategy might allow the administration to select the top polluting sources across each ward. This will not only improve the overall air quality of the city but will also provide a precedent for further research into the impact of these measures on the health of the people who live in these locations.

> ULBs may organise ward-specific IEC programmes on air pollution with targeted messaging using insights from the survey.

3.3 Drive behavioural change with public contribution and partnership

Road dust, dust arising from construction and demolition, and waste (garbage dump, burning of garbage) are the most significant pollutants affecting any city in India. The high content of particulate matter in the dust in air pollution affects the health of people. Most of the cities have already deployed dust-absorbing and water-spraying machines on roads to reduce the pollution due to dust. Further, ULBs should think about innovative solutions for the disposal of collected dust by converting it into bricks rather than dumping it.

3.4 Conducting customised information, education and communication (IEC) campaigns based on the insights from the survey

Our findings show that the majority of these pollution sources may be effectively tackled through public engagement and behavioural change. The ULBs must ensure that all relevant stakeholders are informed of the deleterious effects of air pollution. To inform, ULBs should launch city and ward-level information, education, and communication (IEC) programmes that reach diverse stakeholders with appropriate messaging, which raises their knowledge of the issue of air pollution and motivates them to help reduce emissions. For example, construction companies should be sensitised towards illegally dumping construction waste in open areas. IEC activities should encourage citizens to increase green cover by tree plantation exercises on roadsides and other uncovered barren land areas. Awareness campaigns and incentivisation for people to segregate household waste at the source as dry and wet waste and encourage composting of wet waste will create a favourable policy impact and nudge behavioural change.

3.5 Strengthening the efforts of Task Force deployed for implementation of Graded Action Response Plan (GRAP)

At the onset of the winter season and especially during the episodes of very poor and severe air quality, the regulatory bodies intensify their efforts to reduce pollution by implementing GRAP in Delhi NCR. To monitor and supervise GRAP implementation, the

Enforcement Task Force constituted by the Commission on Air Quality Management (CAQM) (Commission for Air Quality Management 2022) deploys inspection teams or flying squads to inspect the compliance of air quality norms. Given the resource scarcity and manual reporting, it is not easy to ascertain whether the deployed inspection teams have covered all the areas. The survey protocol developed during this study can enhance the capacity of implementing agencies for remotely monitoring the efficiency of inspection teams through automation of data collection and real-time reporting.

4. Conclusion

A dynamic real-time emission inventory is not only crucial for planning the city-level interventions, but it is also equally beneficial to assess the city's efforts to mitigate air pollution.

A periodic field reconnaissance survey conducted at least once a quarter would help the ULBs understand the seasonal variation of dispersed pollution sources. Understanding seasonal variation of polluting sources will aid ULBs to be better prepared to manage air quality in the succeeding years. For instance, peri-urban wards in the vicinity of brick kilns are most polluted during the operational season of brick kilns. Temporal analysis of sources data from periodic surveys will uncover spatial hotspots of polluting sources. Further analysis of these legacy hotspots may help ULBs identify city-level-causal air pollution activities, which were hitherto unknown, establishing causality at the ward-level so that efficient regulation and better civic awareness of air pollution can be done.

Periodic field reconnaissance surveys can potentially plug the gaps and address the uncertainties in emission inventories. **The protocol has been carefully designed to incorporate sources that are dynamic in character and change often over time. For example, many industries/factory workshops within the municipal areas of the cities, which may have been missed to be mentioned in government reports, can be identified using this survey and the data can be updated in the emission inventory.** Similar is the case of road dust, and infrastructure activity-related emissions, where the length of road and area under construction can be captured using the

> **Our findings suggest that although insignificant individually, dispersed sources collectively contribute significantly to hyperlocal urban air pollution.**

survey and updated in the emission inventory. The data on unpaved roads and broken footpaths from our results supplemented by official records will provide the ULBs with an updated list of roads that need intervention to address the road dust emissions in a city. The updated data will also aid air quality management researchers in addressing the uncertainties in estimating road dust emissions.

The geo-tagged data on construction and demolition (C&D) activities and C&D waste dumping will aid ULBs in adopting a targeted approach for enforcement of C&D waste management rules and guidelines by the project owners. A similar approach can be taken to address solid waste dumping and burning. An up-to-date and simplified listing of hyperlocal pollution sources will facilitate ULBs, State Pollution Control Boards, and line departments responsible for implementing the NCAP to chalk out better and pragmatic solutions for improving air quality.

During our study, we set out to identify and analyse the share and spatial distribution of air pollution sources that are distributed across the city. Our findings imply that, while these sources may not be substantial when considered individually, such sources collectively can account for a major portion of hyperlocal urban air pollution. The repository of such pollution sources will also help the city officials quantify the targets and allocate the resources optimally towards air pollution control.

Currently, two funding sources are available solely for air pollution: NCAP funds and Fifteenth Finance Commission grants. Both fundings are heavily tied to the improvement of the city's air quality, besides other requirements such as the development of the monitoring network and source identification/apportionment studies. The key problem is appropriately utilising such grants, as evident in the existing state of fund usage across all million-plus cities as well as other non-attainment cities. In addition, there are several more government programmes that address concerns indirectly related to air quality. However, due to a lack of understanding of the underlying challenges, many such schemes remain underutilised.

A reconnaissance survey exercise undertaken every three months will offer a fuller view of the city's pollution sources. **The reconnaissance database can also be used by implementation agencies to create targeted short- and long-term mitigation solutions. These methods will involve issue prioritising based on a feasibility study of solutions in terms of funding available, time to solve the problem, and human resource availability.** Indian cities incur a huge health and cost burden due to air pollution. Air pollution was responsible for almost 18 per cent of deaths in India in 2019 incurring an economic loss of INR 4,500 crore (CAF, CII, and Dalberg 2021). While ULBs will need a dedicated budget to carry out and sustain this activity, the predicted impact on the health of the exposed population in terms of morbidity and mortality loss would be significant. Furthermore, due to its resource-efficient nature, the budget consequences will be offset by the indirect cost saved from the city's gross domestic product (GDP) loss.

Implementation of solutions based on the database generated through these reconnaissance surveys will assist the ULBs in achieving the air quality improvement target of 15 per cent in terms of reductions in particulate matter (PM_{10}) and an increase in the number of good days, a metric used for the assessment of performance for the release of funding for the succeeding year. **The Composite Ward Score will be helpful in prioritising actions and systematic allocation of available funds to attain the maximum impact.**

Furthermore, the necessity of getting the consistent year-on-year particulate matter (PM) data has been highlighted in the Fifteenth Finance Commission report. It is imperative to note that while strengthening of monitoring network plays a pivotal role in addressing this requirement, the data can only be helpful for the implementation agencies when the emission source is attributed at the local scale. **In a collaborative pilot initiative, Department of Environment (GNCTD) and Council on Energy, Environment and Water (CEEW) jointly implemented this methodology to identify the key sources of hyperlocal air pollution in the identified hotspots under the purview of winter action plan.** As source apportionment/emission inventory studies are resource-intensive, require technical expertise, and take longer to complete, the implementation agencies can leverage the data generated from the reconnaissance survey so that the undue delay in taking actions could be avoided due to the slow progress of source apportionment and emission inventory studies.

All of these advantages come with the caveat that ULBs may face some difficulties at the beginning due to factors such as data capture, network issues, the QA/QC process, human resource management, and real-time feedback, among others. The majority of these challenges can be resolved by automation and capacity building of the survey team. However, once these concerns are rectified, ULBs will be able to maximise the benefits of the reconnaissance exercise by identifying, prioritising, and establishing targeted actions to improve air quality.

Annexures

Annexure 1: List of information collected in the survey

Table A1 **Detailed outline of the survey questions and description**

Survey field	Description
Date–time	Timestamp at the start of capturing the source
Image(s) of the source	One/multiple picture(s) of the air pollution source
Air pollution source	17 distinct air pollution sources are captured
Source duration	Intermittent or Continuous source
Source details	Air pollution source-specific details
Location coordinates	The point, line (start and end points), polygon (four or more points) depending upon the type of source. Refer to Annexure 2
Landmark (nearby)	Famous place in the vicinity of source for easy re-identification/verification

Source: Authors' compilation

Annexure 2: Information on dispersed air pollution sources, details, and spatial data type collected for each source

Table A2 **Detailed information on the dispersed pollution sources**

Source	Source details	Location coordinates
Garbage dumped on vacant land	• Composition of waste—plastic/biodegradable waste • Dry or wet waste: old/new waste • Size/amount of waste (small, medium, large)	Point (latitude, longitude)
Burning of garbage, plastic, leaves, and branches	• Size of the burning area	Point (latitude, longitude)
Construction and demolition activity without safeguards	• Phase of construction • Size of construction • Type of construction, for example, residential/ commercial/metro/road construction etc.	Polygon (indicating area of the construction site)
Sand piled on roadsides	• Sand piled due to active construction activity • Sand piled when there is no active construction • Dried drain silt/sewage	Point (latitude, longitude)
Malba, bricks, and bori on the dumping land	• Size of dump	Point (latitude, longitude)
Road dust	• Nature of road (primary/secondary/tertiary) • Name of the road/start and endpoint of the road	Line start, endpoint
Unpaved road	• Start and end point landmark for unpaved road	Line (start, endpoint)
Broken footpath/divider/roadside	• Size of the broken footpath	Point (latitude, longitude)
Pothole	• Start and endpoint in case of multiple potholes	Point (latitude, longitude)
Barren land to be greened	• Size of the land	Point (latitude, longitude)
Overflowing dhalao	• Type of infrastructure	Point (latitude, longitude)

Source	Source details	Location coordinates
Industrial emissions/stacks/ chimneys	• Nature of smoke • Name and type of industry • Hours of operation	Point (latitude, longitude)
Brick kilns	• Nature of smoke • Whether running or closed • Hours of operation	Point (latitude, longitude)
Household emissions (chula, firewood burning, etc.; other than LPG cylinder)	• Type of dwelling/area with no. of households etc.	Point (latitude, longitude)
Diesel generator sets	• Type of establishment • Diesel generator capacity	Point (latitude, longitude)
Hawkers using unauthorised cooking fuel (other than LPG cylinder)	• Number of hawkers (estimated)	Point (latitude, longitude)
Traffic congestion	• Nature of roads (primary/secondary and tertiary)	Point (latitude, longitude)

Source: Authors' compilation

Annexure 3: Detailed cost breakup of field reconnaissance survey

Table A3 Expenditure range for City > 100 and < 200 sq.km area

Description	Expenses
Field team (4 Surveyors + 1 Supervisor) compensation	INR 55000 to 1,75,000
Data management personnel compensation	INR 10,000 to 25,000
Travel expenses	INR 20,000 to 55,000
Total	**INR 85,000 to 2,55,000**

Source: Authors' compilation

Table A4 Expenditure range for City > 200 and < 300 sq.km area

Description	Expense
Field team (4 Surveyors + 1 Supervisor) compensation	INR 85,000 to 3,00,000
Data management personnel compensation	INR 15,000 to 50,000
Travel expenses	INR 35,000 to 1,00,000
Total	**INR 1,35,000 to 4,50,000**

Source: Authors' compilation

Table A5 Common expenditure*

Type of expenditure	Description	Expense
One-time	Training of Field team and data managers	INR 36,000
Recurrent	Cloud server maintenance	INR 1,200/month

**Common expenditure denotes a final amount incurred for any number of cities combined*
Source: Authors' compilation

Acronyms

AOD	aerosol optical depth
C&D	construction and demolition
CAQM	Commission on Air Quality Management
CPCB	Central Pollution Control Board
CWS	Composite Ward Score
DG	diesel generator
EF	emission factors
GDP	gross domestic product
GIS	geographic information system
GNCTD	Government of the National Capital Territory of Delhi
GPS	global positioning system
GRAP	graded response action plan
IEC	information, education and communication
NAC	non-attainment cities
NCAP	National Clean Air Programme
ODK	Open Data Kit
SCM	spatial coverage metric
PM	particulate matter
SPCB	State Pollution Control Board
ULB	urban local bodies
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

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Member Secretary with DPCC who has demonstrated history of working in natural resource management like forests, wildlife, wetlands, urban greenery and prevention of environmental pollution emphasing on air quality management. Highly skilled in environmental public policy, sustainable development, project management and capacity building. Strong managerial, administrative and professional capabilities with interest in helping design, evolve, implement and monitor public environmental programs who has been instrumental in launch of Green Delhi App.

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