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National Clean Air Programme (NCAP) for Indian cities: Review and outlook of clean air action plans

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ABSTRACT

National Clean Air Programme (NCAP), launched in 2019, is India's flagship program for better air quality in 122 cities. This review evaluates the scientific, legislative, financial, and institutional framework of the 102 publicly available clean air action plans submitted under NCAP. We assessed the robustness of the plans using the background information on pollution sources and their contribution; legal backing for the clean air action plan; cost of measures; and existing institutional accountability regime. We used the tally chart method for estimating city-specific and sector-specific mitigation measures, the number of actions under the purview of various implementation agencies, and the number of institutional, physical, and promotional interventions in the plans. Transport and road dust together cover 50% of action points, followed by interventions for the industries. Domestic cooking and heating is mentioned as a source only in 42 plans for a total of 2% of the action points. Institutional nature of the interventions was observed in 74% of the action points, using the language "overseeing, planning, proposing, preparing, investigating, identifying, ensuring, strengthening, training, studying, and engaging". We also identified the plans that contained information on source contributions, an outline of financial requirements for executing the plans and measures for mitigating pollution from regional sources. Only 25% of the plans integrated information on the relative source contributions to formulate control strategies. Even fewer plans outlined the financial requirements for executing the plans. The institutional and administrative arrangements for ensuring inter-departmental and regional alignment in air pollution mitigation strategies are absent. We close the review with recommendations which include mandating regular updates for emission and pollution loads, granting greater fiscal autonomy for Urban Local Bodies to maintain the infrastructure necessary for sustaining air quality benefits, and moving from city-centric to airshed-centric air quality management.

1. Introduction

A clean air plan is a collection of regulations, policies, and programmes, which aims to improve air quality and public health by identifying cost-effective measures to reduce emissions from all the known sources. Evolution of air pollution regulations and control planning in India is presented in Table 1. Health impact estimates associated with different polluting sources establish the need for a prioritized cost-effective emission mitigation strategy by sector (Venkataraman et al., 2018). Residential biomass combustion contributed to an estimated 268,000 deaths; coal combustion in thermal power plants and industries contributed to 169,000; anthropogenic dust contributed to 100,000; agricultural burning contributed to 66,000; and road transport, non-road diesel, and brick kilns contributed to over 65,000 (GBD-MAPS, 2018; Balakrishnan et al., 2019). A proposal was prepared by the Ministry of Health and Family Welfare (MoHFW), for an exposure-centric management approach for integrating the health impacts of air pollution into the policy dialogue in India (Sagar et al., 2016). In January 2019, the Ministry of Environment, Forest and Climate Change (MoEFCC) launched the National Clean Air Programme (NCAP) to prepare clean air action plans with an objective to reduce PM_{2.5} pollution by 20–30% by 2024 as compared to 2017, in 122 cities (NCAP, 2019). This paper presents a review of the approved clean air action plans, review of key elements in case studies from global clean air action plans, and recommendations to strengthen the plans.

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Table 1

A timeline of clean air planning in India.

Year	Action
1974	Central Pollution Control Board (CPCB) established under the
	water (prevention and control act)
1981	CPCB entrusted with the powers and functions under the Air
	(Prevention and Control of Pollution)
1986	CPCB adds provisions for environment (protection) act
April 1994	National ambient air quality standards were introduced
1997	MoEFCC prepared an action plan for controlling pollution in Delhi
January 1998	Environment Pollution (Prevention & Control) Authority (EPCA)
	established to address air pollution in the national capital region of
Ostaber 1000	Delhi National ambient air quality standarda years revised
00000er 1998	National ambient air quanty standards were revised
2003	Abmedabad Kanpur, Sholapur, Lucknow, Bangalore, Chennai
	and Hyderahad to reduce RSPM levels
2009	CPCB introduced the Comprehensive Environmental Pollution
2009	Index as a tool for environmental assessment on industrial clusters
November	National ambient air quality standards were revised and PM2.5
2009	added to the list
January 2014	National air quality index (AQI) methodology was established
2015	CPCB issued directives under Air Act, 1981, for the
	implementation of 42 action points that includes control and
	mitigation measures in the major cities including Delhi and the
	National Capital Region (NCR)
April 2016	$PM_{2.5}$ is included for all manual stations under the national
D	ambient monitoring programme (NAMP)
December	Graded Response Action Plan (GRAP) established to address air
2010 April 2018	MoEECC circulated a draft concept note of National Clean Air
Mp111 2010	Programme (NCAP) with multiple time bound strategies to reduce
	air pollution
July 2018	102 non-attainment cities were announced under NCAP
October 2018	National Green Tribunal (NGT) directed the states and union
	territories with non-attainment cities under NCAP to prepare
	action plan
	EPCA reconstituted with new members from the government,
	academia, and civil society
January 2019	NCAP - a time-bound national level strategy to tackle increasing
	air pollution, was launched by MoEFCC
	Examination and approval of clean air plans by 3-member central
August 2010	Addition of 20 new non attainment cities after NGT's intervention
2019 2024	NCAD target to reduce PM ₂ - pollution in 122 non attainment
2027	cities by 20–30%, compared to 2017 levels

2. Material and methods

2.1. NCAP and clean air action plans

NCAP designated 122 cities as non-attainment (Table 2) from 21 states and 2 union territories (Chandigarh and Delhi) based on the ambient monitoring data from the network operated by CPCB. Maharashtra has the most cities (18) followed by Uttar Pradesh (15). NCAP in its first round of activities aims to increase the capacity of CPCB and State Pollution Control Board (SPCB)'s to measure, evaluate and manage air pollution. Some specific activities include (a) preparation of an information baseline for emissions and pollution loads and an assessment of source contributions in the non-attainment cities (b) an air information cell to maintain and disseminate information generated under NCAP (c) a technology assessment cell to support bilateral and multilateral agreements undertaken by the boards (d) a network of technical institutions to provide support for policies and programmes of the Government of India on air pollution (e) a three-tier mechanism at the pollution control boards to review assessment and inspection guidelines for implementation of standards (f) an awareness, training, and capacity building drive at the boards (g) a committee to review the ambient and emission standards and (h) a framework to establish international cooperation to share best practices on air pollution.

The non-attainment cities were further advised to prepare action plans detailing how to build internal capacity and achieve clean air. In Atmospheric Environment: X 8 (2020) 100096

Table 2

State/Union Territory	No. of cities	City's with a source apportionment study
Andhra Pradesh	13	Anantapur, Chitoor, Eluru, Guntur, Kadapa,
		Kurnool, Nellore, Ongole, Rajahmundry,
		Srikakulam, Vijayawada, Vishakhapatnam,
		Vizianagaram
Assam	5	Guwahati, Nagaon, Nalbari, Sibsagar, Silchar
Bihar	3	Gaya, Muzaffarpur, Patna
Chandigarh	1	Chandigarh
Chhattisgarh	3	Bhilai, Korba, Raipur
Delhi	1	Delhi
Gujarat	3	Ahmedabad, Surat, Vadodara
Himachal	7	Baddi, Damtal, Kala Amb, Nalagarh, Paonta Sahib,
Pradesh		Parwanoo, Sunder Nagar
Jammu &	2	Jammu, Srinagar
Kashmir		
Jharkhand	1	Dhanbad
Karnataka	4	Bengaluru, Devanagere, Gulburga, Hubli-Dharwad
Madhya	6	Bhopal, Dewas, Gwalior, Indore, Sagar, Ujjain
Pradesh		
Maharashtra	18	Akola, Amravati, Aurangabad, Badlapur,
		Chandrapur, Jalgaon, Jalna, Kolhapur, Latur,
		Mumbai, Nagpur, Nashik, Navi Mumbai, Pune,
		Sangli, Solapur, Thane, Ulhasnagar
Meghalaya	1	Byrnihat
Nagaland	2	Dimapur, Kohima
Odisha	7	Angul, Balasore, Bhubneshwar, Cuttack, Kalinga
		Nagar, Rourkela, Talcher
Punjab	9	Amritsar, Dera Bassi, Gobindgarh, Jalandhar,
		Khanna, Ludhiana, Naya Nangal, Pathankot/Dera
		Baba, Patiala
Rajasthan	5	Alwar, Jaipur, Jodhpur, Kota, Udaipur
Tamil Nadu	2	Trichy, Tuticorin
Telangana	4	Hyderabad, Nalgonda, Patencheru, Sangareddy
Uttar Pradesh	15	Agra, Allahabad, Anpara, Bareily, Firozabad,
		Gajraula, Ghaziabad, Jhansi, Kanpur, Khurja,
		Lucknow, Moradabad, Noida, Raebareli, Varanasi
Uttarakhand	3	Dehradun, Kashipur, Rishikesh
West Bengal	7	Asansol, Barrackpore, Durgapur, Haldia, Howrah,
-		Kolkata, Ranigunj

2018, the National Green Tribunal (NGT) directed a state-level sixmember committee called the Air Quality Monitoring Committee, comprising of Directors of Environment, Transport, Industries, Urban Development, Agriculture and the Member Secretary of Pollution Control Boards, for the purpose of preparing the city clean air action plans. The 2017 comprehensive action plan to control air pollution in the National Capital Region (NCR) of Delhi, prepared by the Environmental Pollution (Prevention and Control) Authority (EPCA) and approved by the Supreme Court of India, acted as the template for preparing city specific plans. A central committee, comprising of Dr Prashant Gargava (Member Secretary, CPCB), Dr Mukesh Khare (Professor, IIT Delhi) and Dr Mukesh Sharma (Professor, IIT Kanpur) reviewed the plans and the Chairman, CPCB approved 102 action plans, as of May 2020. Another eight plans were approved in August 2020, which are not included in this review. The internal guidelines for approving an action plan are not public.

The approved 102 NCAP clean air action plans list sector-specific interventions with predetermined timelines and an agency responsible for execution. Some plans also include interim milestones and financial requirements for some action points. While these plans are meant to evolve with scientific information on emission and pollution loads in the cities, they are currently a representation of the scale of ambition of Indian cities to manage air quality.

2.2. Review tally

We reviewed the approved plans for (a) sector-specific mitigation measures (b) the number of action points under the purview of every implementation agency (c) the number of institutional, physical, and promotional interventions in the plans (d) information on source contributions and (e) financial requirements for executing the plans (Table 3). The review was limited to counting the action points and did not delve into quantifying the strengths of the action points. The later requires in-depth information and analysis at the sectoral level, which is mostly missing in the clean air plans.

3. Results and discussion

3.1. Sector-specific interventions

Broad interventions that all the cities want to implement under NCAP are (a) augment public transport (b) eradicate road and construction dust (c) abolish open waste burning (d) promote clean cooking (e) enforce compliance with industrial emission standards (f) increase ambient monitoring capacity and (g) raise public awareness. A consolidated list of activities under these categories is presented in Table 4 and a count of the action points by category and by state is presented in Fig. 1.

Odisha with six non-attainment cities with an average of 118 action points per city has the longest list and Karnataka with four cities with an average of 29 action points per city has the shortest list. Transport sector dominates all the clean air plans, followed by industries. Across the 102 action plans, 38% of the action points discussed transportation activities including road, rail, aviation, and shipping. With road dust, this share is closer to 50%. Multiple source apportionment studies estimated contribution of transport sector to Delhi's air pollution at under 20% and yet this sector gets the most attention in the clean air plans (CPCB, 1997, 2011; Dubash and Guttikunda, 2018). Domestic cooking and heating is 2% and mentioned only in less than half of the clean air plans, in spite of an estimated average contribution of 30–50% across India's urban and rural areas (Balakrishnan et al., 2019; Chowdhury et al., 2019).

NCAP explicitly proposed to enhance the ambient air quality and emissions monitoring capacity in India. As of May 2020, CPCB operates and maintains 230 continuous ambient air quality monitoring stations (CAAQMS) covering all the criteria pollutants and meteorological parameters and 750 manual monitoring stations reporting PM_{2.5}, PM₁₀, SO₂, and NO₂. Monitoring guidelines estimate a need for at least 4000 CAAQMS to spatially and temporally represent India's air quality - 2800 in the urban areas and 1200 in the rural areas (CPCB, 2003; Brauer et al., 2019). The NCAP programme by 2024 aims to (a) increase the CAAQMS to 1000 stations (b) expand the monitoring network to 50 rural areas with at least one station (c) revise the 2003 guidelines for ambient monitoring to enable alternative methods like low-cost sensors and emerging research grade monitoring equipment including a new certification system (d) establish a 10-city super monitoring network (Venkataraman et al., 2020) (e) promote programs on indoor air pollution

Table 3

Definition of phrases used in this evaluation.

Phrase	Definition
Action points	Each of the interventions to control air pollution discussed in the respective action plans
Sector-specific	Interventions were clubbed into transport (all road,
interventions	railway, aviation, and shipping), industry (all
	manufacturing activities), waste management, domestic
	(all cooking, lighting, and heating), construction activities
	(including debris management), road dust, ambient
	monitoring and public awareness, and others
Institutional	All interventions mentioned as overseeing, planning,
	proposing, preparing, investigating, identifying, ensuring,
	strengthening, training, studying, and engaging
Physical	All interventions mentioned as buying, installing,
	retrofitting, and cleaning
Promotional	All interventions mentioned as incentivizing and
	promoting

Table 4

Summary of the action points mentioned in the NCAP clean air plans.

Sector	Action Points
Transport	1. Plying of electric vehicles for public transport and establishment
	of charging stations for all vehicles
	2. Construction of expressways/bypasses/peripheral roads
	3. Arrangement of multi-level parking facilities
	4. Development of cycle zone
	5. Retrofitting of particulate filters in diesel vehicles
	6. Use of bio-ethanol
	7. Widening of Roads
	8. Remote sensor-based PUC system
Industry	 Adoption of zig-zag technology in brick kilns
	2. Monitoring of Industrial emissions through Online Continuous
	Emission Monitoring System (OCEMS)
	Shifting of air pollution industries to conforming zones
	Installation of web cams and OCEMS in gross polluting
	industries
Waste	1. Extensive drive against open burning
burning	2. Proper collection of horticultural waste
	3. Door to door collection of segregated waste
	4. Establishment of compost pits
Construction	1. Control measure for fugitive emissions
	2. All construction areas must be covered to avoid dispersion of
	particulate matter
	 ensure carriage of construction material in closed/covered vessels.
Residential	1. Engage with concerned authorities on continual basis for
	maximizing coverage of LPG/PNG for domestic and commercial
	cooking with target of 100 per cent coverage
Dust	1. Maintenance of 33 per cent forest cover
	2. Creation of green buffers
	3. Maintain potholes free roads
	4. Introduce water fountains
	5. Wall to Wall pavement
	6. Blacktopping of metallic roads

monitoring with special focus on managing household fuel combustion and (f) establish an air information centre. The awareness programs include dissemination of the monitoring data and short-term air quality forecasts.

3.2. Category-specific interventions

All the action points were also binned into three categories to evaluate the commitment of the cities to address their air pollution problem – institutional, physical, and promotional (Table 3). A total of 74% of the action points were categorized as "institutional" which used the language of "overseeing, planning, proposing, preparing, investigating, identifying, ensuring, strengthening, training, studying, and engaging". These activities are often part of the capacity building activities and not expected to yield any tangible benefits for air quality, but will result in building the computational, technical and institutional capacities of CPCB and SPCB's.

3.3. City- and state-specific action plans

The absence of source information has resulted in plans being replicated for the cities within a state. Nine states with multiple non-attainment cities have used the same set of action points and timelines across all cities. For example, Uttar Pradesh has 15 non-attainment cities, which is the second highest number after Maharashtra (18), and except for Anpara, all have identical plans, each with the same 56 action points. Only 48 cities in eight states have prepared clean air plans with distinct actions and interim targets (Table 5).

Delhi's air quality is the most media covered and the most studied in India (CPCb, 1997; Bell et al., 2004; Guttikunda and Calori, 2013; Kumar et al., 2017; Patel, 2019). Two cities from Uttar Pradesh – Ghaziabad and Noida in Delhi's airshed are also NCAP's non-attainment cities. Other commercially and industrially active satellite cities in the



Transport Industry Waste burning Residential Construction Road dust Monitoring/Awareness Others

Fig. 1. Average count of action points by sector mentioned in the NCAP clean air plans by state.

airshed include Faridabad, Gurugram, and Rohtak in the state of Haryana and some smaller cities in Rajasthan and Uttar Pradesh, collectively referred as the National Capital Region (NCR) of Delhi. Since 1997, multiple action plans were introduced to address Delhi's air quality and often judicial intervention was necessary to implement some of the action points (Bell et al., 2004), such as converting the bus and para-transit vehicles to operate on compressed natural gas (DTE, 2002), relocation of the brick kilns and smaller industrial clusters to the outskirts, introduction of the cleaner Bharat-VI fuel two years earlier than the rest the nation, approval of the graded responsibility action plan (GRAP) in case of severe episodes (WIRE, 2017), and piloting the odd-even scheme during the winter months (Kumar et al., 2017). Delhi's NCAP action plan is the only plan approved by the Supreme Court and the National Green Tribunal. Irrespective of the source contribution information from the official and academic apportionment studies (Dubash and Guttikunda, 2018), of the 92 action points in the plan – 55% address vehicle exhaust and road dust; 24% address industries; 2% address waste management; 3% address domestic cooking and heating; and the rest address others including ambient monitoring and public awareness. Several of the 102 NCAP action plans cite Delhi's GRAP program as an example for local replication.

Rajasthan has five non-attainment cities - Alwar, Jaipur, Jodhpur,

Table 5

Categorization of states based on the nature of clean air plans – distinct or similar.

States with multiple cities and similar plans	States with multiple cities and distinct plans	States with only one city or one approved plan
Andhra Pradesh Assam Himachal Pradesh Jammu & Kashmir Nagaland Odisha Rajasthan Uttar Pradesh Uttarakhand	Bihar Chhattisgarh Gujarat Jharkhand Karnataka Madhya Pradesh Maharashtra Meghalaya Punjab Telangana	Chandigarh Delhi Tamil Nadu West Bengal

Kota and Udaipur, all with the same 44 action points and the same timeline for implementation. 38% of these actions address vehicle exhaust regardless of the extent to which the sector contributes in the five cities. Further, the same 33 actions in all the plans are listed as short-to-medium term measures with less than 12 months for implementation. This points to the absence of prioritization of action points specific to the cities. None of the five plans outline financial requirements nor mention the institutional arrangement required for managing regional influences.

Chandigarh's action plan contains 31 points with 50% of them addressing vehicle exhaust and dust and with responsibility of implementing them distributed across 14 agencies. 35% of the actions also warrant inter-departmental coordination. Chandigarh is in the unique position of being a union territory that serves as the capital for the states of Haryana (on the east) and Punjab (on the north, west and south), which adds to the administrative burden of implementing interventions. During the winter months, a majority share of the pollution originates outside the administrative boundary and on an annual basis 50% of $PM_{2.5}$ pollution can be attributed to sources outside the boundary (Guttikunda et al., 2019b). However, Chandigarh's NCAP plan does not account for this regional influence and does not contain any institutional arrangements needed for regional coordination and alignment.

Jharkhand and Meghalaya have one non-attainment city each. The plan for Dhanbad particularly stands out because it identifies locationspecific sources. For instance, the plan lists specific locations within the city where emissions from brick kilns is the primary concern. The plan for Meghalaya's Byrnihat has 36 action points. 90% of the action points have a timeline of less than 180 days for implementation.

Three action plans from the state of Bihar for Patna, Gaya, and Muzaffarpur present 135 action points with near equal weights between vehicle exhaust (32%), industries (13%), waste management and household cooking (20%), road dust and construction debris management (19%), ambient monitoring and awareness (11%), and others (5%). A comprehensive assessment of the action plan prepared by the Bihar State Pollution Control Board also outlined the institutional and financial requirements for implementing the interventions (BSPCB, 2019).

Seven action plans from the state of Himachal Pradesh are identical. Outdoor and indoor air pollution levels are severe during the winter months and most of the space heating needs are met using biomass and coal (Balakrishnan et al., 2011; Chowdhury et al., 2019). Despite this recurring need, the seven plans do not address fuel combustion for household cooking and heating.

West Bengal's seven NCAP cities can be clubbed into two airsheds (a) Kolkata, Howrah, Haldia, and Barrackpore and (b) Asansol, Durgapur, and Ranigunj, given the proximity of these areas, feeding each other commercially, industrially, and economically (UEinfo, 2019). In Kolkata's action plan, 50% of the points addressed vehicle exhaust and road dust. While the source apportionment studies estimate 30% PM_{2.5} pollution coming from industrial sources, the plan includes only 9

measures to address these sources. The 59 action points are distributed across 19 agencies and 60% of them needing inter-departmental coordination.

Maharashtra submitted 17 distinct city clean air plans. Seven plans for Amravati, Badlapur, Mumbai, Nagpur, Nashik, Pune, Sangli and Solapur also outlined the financial requirements. While plans for Chandrapur, Amravati, Aurangabad and Kolhapur contained emission load estimates, Mumbai's plan contained results of source apportionment studies. As observed in the case of Rajasthan, none of Maharashtra's action plans allude to the need for institutional and administrative arrangements for tackling regional influences.

Mumbai plays a central role in India's economy and accounts for 25% of industrial output, 70% of maritime trade, and 70% of capital transactions of the country and along with Delhi, is one of the most studied cities in India, due to the presence of the Indian Institute of Technology, which anchored the first batch of source apportionment program by CPCB (CPCB, 2011; Gargava and Rajagopalan, 2016; Police et al., 2018). While land-sea breeze allows for some dilution, transport and industrial emissions are the growing influence on the local air quality. The Greater Mumbai's airshed includes the satellite cities Thane and Navi Mumbai, also part of the NCAP program. Due to constant commercial and personnel movement between these three areas, it is difficult to delineate the plans and responsibilities for these municipalities to manage air quality.

Tuticorin, Tamil Nadu, despite being home to several power plants, smelters and fertilizer units which contribute to a majority share of $PM_{2.5}$ in the city, only 14% of the actions address these emissions. 50 action points address vehicular and dust emissions. Chennai and Coimbatore are the largest commercial and industrial hubs in the state but are not part of the NCAP.

Bengaluru's clean air plan contains 44 action points that are distributed across 11 agencies - the Karnataka State Pollution Control Board is responsible for only 7% of the points and the municipal authority is responsible for 36%. The sectoral split of actions in Bengaluru's plan aligns with the relative source contributions – 70% to vehicular exhaust (20–35%), waste burning (11–20%) and dust (10–30%) (Guttikunda et al., 2019a). Since the approval of the action plan, 90% of the activities are either mentioned as on-going/continuous activities or to be implemented in 2020.

3.4. Implementation plans

For effective implementation of a clean air action plan means (a) designating an area as non-attainment (b) setting permissible pollution load targets based on the ambient air quality measurements (c) setting tracking procedures to ensure effective and timely implementation of the controls by sector and (d) outline the role of implementing agencies.

Section 16, Clause 2(a) of the Air Act, 1981 lists the planning and execution of a nationwide programme for the prevention and control of air pollution as one of the CPCB's main functions (Table 1). Similarly, Section 17, Clause 1(a) lists planning a comprehensive programme for the prevention and control of air pollution and securing its execution as a SPCB function. Despite these provisions, NCAP is the first instance when SPCBs across the country attempted to draft plans. Apart from Delhi's clean air plan, which the Supreme Court notified for implementation in January 2018, no other clean air plan has binding obligations for implementation.

By contrast, in the United States, state implementation plans (SIPs) are considered the backbone of efforts to attain better air quality (Mathias, 2007). The United States Clean Air Act requires a general plan for all areas of the country and specific plans for all non-attainment areas. Similarly, the EU Ambient Air Quality Directives oblige EU member states to divide their territories into zones and agglomerations for the purposes of air quality assessment and management (Kuklinska et al., 2015). Both the directives demonstrate that non-attainment regions are legally mandated to frame a clean air plan for regions that

exceed local standards. Without mandated targets and timelines, there is no room to question failures in preparing and executing the clean air plans (Lele et al., 2010; USEPA, 2015; Acosta, 2018).

3.5. Institutional accountability

Air quality issues span widely across sectors and a variety of stakeholders have an interest in, or may be affected by, these issues. Studies have often cited the lack of coordination and integration in planning across concerned departments as the reason for failure of state and central governments introduced schemes (AIGGPS, 2015). In our tally of the action points, 24% were allotted to the pollution control boards and 60% to the urban local bodies (ULBs), including municipal corporations, development authorities, transport department, and traffic police (Fig. 2). The remaining 16% percent lies with miscellaneous agencies (Table 6).

In half of the cities, less than 37% of the responsibilities lie with the ULBs. This disproportionate allocation of activities to ULBs is problematic due to India's underdeveloped municipal finances (Ahluwalia et al., 2019). The 74th Amendment Act that formally recognized ULBs as the third tier of the government and vests the responsibility of identifying potential revenue sources entirely with the state government. Thereby leaving the ULBs with limited fiscal autonomy.

The NCAP lays down the institutional framework for implementation in the form of a state-level review and monitoring committee under the

Table 6List of miscellaneous responsible agencies.

0

10

11

12

S. No	Responsible agency
1	National Highway Authority of India (NHAI)
2	Public Works Department (PWD)
3	Vehicle manufacturing companies
4	Ministry of Road Transport and Highways (MoRTH)
5	Food and civil supply
6	Oil companies
7	Forest department
8	Irrigation department

chief secretary of the state, a district-level committee under the district collector, and a city-level review committee under the municipal commissioner; however, the composition of the committees and their strengths are not elaborated, making it difficult to assess the enforcement powers of these committees.

Agriculture department

District Industries Centre

Housing companies

Urban development department

In case of the industrial pollution management, PCBs play both monitoring and auditing roles, with only the power to request compliance, but cannot levy penalties in the event of non-compliance. Only criminal courts can levy penalties and this significantly limits PCB's power to enforce regulations in the absence of compliance (Ghosh,



Fig. 2. Share of mitigation activities allotted to pollution control boards (PCB), urban local bodies (ULB), transport department (TR) and others.

2015). Environmental protection agencies could have the legal authority to penalise and prosecute violators. For instance, the USEPA has a dedicated enforcement and compliance cell that can choose to take non-judicial or judicial action against violators as it deems fit (USEPA, 2018). While judicial action involves formal lawsuits, non-judicial action can take the form of a notice of violation or an order that involves penalties for non-compliance.

3.6. Regional coordination

While most city plans include the recommended measures, there are no clear guidelines on establishing regional coordination. For example, Delhi's action plan lists three action points for mitigating pollution from the states of Punjab and Haryana (a) measures to reduce the regional influence from the crop residue burning (b) measures to enforce the ban on crop residue burning by increasing the subsidies for technological solutions and (c) enforcing the judicial directives on the ban and facilitating its reuse and recycle. In addition, Delhi's plan also contains measures that warrant inter-state coordination, such as banning the use of dirty fuels like furnace oil and pet coke across NCR and implementation of an electric mobility policy for three-wheelers in the NCR states (Delhi, Punjab, Haryana, and Uttar Pradesh, and Rajasthan). For NCR, EPCA was established to coordinate between the states, however with no clear guidelines delineating responsibilities between SPCB's or select departments led to lapses in pollution management.

Outside Delhi, in the Indo-Gangetic plain, there is limited distinction between the urban and rural areas, with differences coming only from the composition of the sources (GBD-MAPS, 2018; Purohit et al., 2019). Here the contribution of sources outside the city administrative boundary is also substantial. Table 7 presents a summary of estimated source and boundary contributions using a combination of emission inventory, meteorology, and chemical transport models (UEinfo, 2019). For cities like Amritsar, Ludhiana, Patiala and Chandigarh, contribution from outside their respective airsheds is more than 50%. For a city like Chennai this share is 15% because of the land-sea breeze and the dominance of agricultural activities outside the city boundary. The air

Table 7

Summary of estimated source contributions including the contribution of sources outside the city airsheds. A = all transport (road, rail, aviation, and shipping); B = residential; C = industries (without brick kilns); D = all dust (construction and resuspension due to vehicle movement); E = open waste burning; F = diesel generator sets; G = brick manufacturing; H = sea salt; and I = outside/regional contribution (Guttikunda et al., 2019b; UEinfo, 2020).

	City	A	В	С	D	Е	F	G	Н	I	Study year
1	Agartala	17.5%	14.9%	4.3%	15.3%	8.3%	2.7%	2.1%		34.9%	2019
2	Ahmedabad-Gandhi Nagar	14.9%	6.6%	12.4%	17.7%	8.4%	6.5%	0.7%		32.8%	2019
3	Allahabad	18.6%	12.5%	6.2%	14.9%	4.0%	4.1%	3.2%		36.6%	2019
4	Asansol-Durgapur	12.5%	7.1%	8.5%	16.2%	4.9%	4.2%	13.9%		32.7%	2019
5	Aurangabad	10.8%	4.3%	18.7%	10.7%	12.0%	6.7%	1.9%		34.9%	2019
6	Dharwad-Hubli	21.6%	5.6%	9.2%	14.7%	8.5%	1.7%	0.7%		38.0%	2019
7	Dhanbad-Bokaro	12.2%	4.1%	12.5%	29.2%	2.6%	3.0%	4.3%		32.2%	2019
8	Gaya	23.1%	10.0%	0.9%	17.3%	3.6%	4.4%	4.7%		36.1%	2019
9	Guwahati-Dispur	36.5%	6.8%	5.2%	27.0%	6.8%	1.7%	0.8%		15.1%	2019
10	Gwalior	12.7%	9.3%	12.2%	12.9%	4.8%	2.5%	4.2%		41.4%	2019
11	Hyderabad	16.5%	4.8%	14.8%	18.6%	12.9%	6.8%	0.2%		25.3%	2019
12	Jamshedpur	19.5%	6.6%	25.8%	15.0%	3.0%	3.7%	2.2%		24.1%	2019
13	Jodhpur	19.9%	6.1%	6.6%	25.5%	3.8%	2.1%	0.0%		36.0%	2019
14	Kolkata-Howarh	13.5%	8.6%	17.6%	12.5%	12.8%	9.4%	6.7%		19.0%	2019
15	Kota	16.7%	8.0%	19.5%	12.5%	4.7%	1.4%	0.5%		36.6%	2019
16	Lucknow	13.0%	24.3%	4.3%	13.9%	7.5%	3.3%	3.5%		30.1%	2019
17	Madurai	23.4%	3.5%	13.6%	19.0%	15.0%	3.6%	0.0%		22.0%	2019
18	Mumbai	16.4%	3.2%	15.0%	12.6%	3.8%	1.9%	2.3%	12.1%	32.6%	2019
19	Nashik	12.1%	6.6%	15.8%	13.2%	8.7%	3.6%	0.9%		39.1%	2019
20	Panjim-Vasco-Margao	22.6%	0.6%	4.5%	12.6%	2.8%	2.6%	0.0%	17.0%	37.3%	2019
21	Puducherry-Cuddalore	9.7%	1.2%	27.8%	6.7%	8.9%	7.8%	0.6%	7.3%	30.0%	2019
22	Rajkot	19.0%	5.1%	20.9%	16.4%	6.9%	2.2%	0.0%		29.6%	2019
23	Shimla	17.4%	11.8%	0.2%	11.8%	5.5%	1.0%	0.0%		52.2%	2019
24	Srinagar	9.8%	41.3%	0.8%	8.2%	6.4%	7.4%	1.8%		24.4%	2019
25	Surat	16.4%	1.7%	31.4%	10.3%	9.8%	3.3%	0.3%	5.6%	21.2%	2019
26	Thiruvananthapuram	37.0%	5.5%	9.4%	17.4%	6.6%	5.4%	0.0%	3.2%	15.4%	2019
27	Tiruchirapalli	19.0%	3.9%	28.2%	16.2%	7.9%	4.4%	0.0%		20.5%	2019
28	Vadodara	20.8%	4.7%	8.0%	17.2%	7.6%	5.8%	0.6%		35.4%	2019
29	Vijayawada-Guntur-Tenali	22.7%	3.5%	11.7%	19.7%	9.3%	5.9%	1.4%		25.8%	2019
30	Visakhapatnam	19.3%	3.3%	23.5%	10.9%	8.1%	2.3%	0.0%	4.8%	27.8%	2019
31	Agra	13.9%	23.8%	0.2%	10.7%	12.4%	2.7%	0%		35.9%	2017
32	Amritsar-Tarn Taran	10.5%	10.6%	7.3%	7.1%	6.1%	3.1%	2.1%		52.7%	2017
33	Bengaluru	26.5%	9.8%	2.1%	23.0%	16.1%	4.0%	2.5%		15.6%	2017
34	Bhopal	14.1%	10.2%	2.8%	17.1%	8.7%	4.9%	0.0%		41.8%	2017
35	Bhubaneswar	17.0%	15.9%	0.6%	20.8%	5.7%	3.6%	4.0%		32.0%	2017
36	Chandigarh-Patiala-Ambala	10.6%	11.4%	1.3%	12.6%	8.9%	2.6%	1.3%		50.8%	2017
37	Chennai	24.5%	3.6%	12.8%	23.5%	15.5%	1.6%	3.1%	1.8%	13.3%	2017
38	Coimbatore	18.3%	6.4%	11.1%	13.7%	14.1%	2.4%	1.0%		32.5%	2017
39	Dehradun	14.2%	14.3%	1.3%	4.4%	19.6%	3.8%	0.4%		41.7%	2017
40	Indore	26.9%	8.1%	2.4%	22.7%	7.8%	2.0%	2.0%		27.8%	2017
41	Jaipur	24.1%	13.4%	2.4%	17.5%	8.4%	2.2%	1.7%		29.9%	2017
42	Kanpur	13.7%	33.8%	6.5%	8.9%	8.8%	4.1%	1.2%		22.5%	2017
43	Kochi	20.2%	9.5%	4.1%	16.3%	3.8%	4.5%	3.8%	16.5%	20.9%	2017
44	Ludhiana-Phillaur	16.3%	7.8%	7.9%	12.3%	9.2%	2.6%	2.8%		40.7%	2017
45	Nagpur	17.2%	6.8%	26.7%	10.9%	11.6%	1.8%	3.2%		21.4%	2017
46	Patna	14.8%	14.6%	11.2%	12.1%	12.9%	5.4%	9.3%		19.2%	2017
47	Pune-Pimpri Chinchwad	24.0%	5.8%	9.8%	23.4%	6.4%	2.8%	2.6%		24.7%	2017
48	Raipur-Durg-Bhillai	17.2%	11.8%	22.8%	11.5%	6.2%	2.8%	1.4%		25.8%	2017
49	Ranchi	21.1%	18.0%	1.1%	14.1%	12.2%	1.3%	3.2%		28.5%	2017
50	Varanasi	13.5%	20.9%	0.2%	8.2%	16.2%	3.3%	6.1%		31.2%	2017

pollution's cross-sectoral and cross-regional nature calls for cross-state and cross-departmental participation and coordination.

The first stage of NCAP's clean air planning focused only on city-level interventions. Summary of boundary contribution for 50 airsheds averaged 30% of the observed PM_{2.5} pollution (Table 7), which needs more regional collaboration for cleaner air. Chennai, Delhi, and Mumbai are examples of big cities with many satellite settlements. While Chennai and Mumbai have the luxury of most of its influential regions in their own states, Delhi requires a strong regional coordination with the states of Haryana, Punjab, Uttar Pradesh, and Rajasthan. With limited coordination mechanism between the sectoral ministries at the national and city level and overlapping states in the city airsheds, delineating accountability thus becomes essential for ensuring timely and effective implementation of the plans and to achieve the overall target 20–30% reduction in $PM_{2.5}$ levels in all the cities.

Outside India, China's State Council supported the establishment of the mechanism for coordinated prevention and control of air pollution in Beijing–Tianjin–Hebei (BTH) tri-cities and surrounding areas to ensure regional coordination and achieve alignment among the boards (UNEP, 2019). The government also set up a coordination group, which was chaired by the vice premier and joined by members of key central government agencies and the seven provincial governments (ADB, 2019). Through coordinated planning, common emission standards, and information sharing, the average annual PM_{2.5} concentrations in BTH have decreased by 25% during 2013–2017 (Xue et al., 2019).

3.7. Source identification

A quantitative understanding of sources is critical for planning emission control interventions. Source information is available via emission inventories and chemical analysis studies (Watson et al., 2002; CPCB, 2011; Johnson et al., 2011; Guttikunda et al., 2019b). These source apportionment studies, whether conducted using activity data to estimate emission and pollution loads or via ambient sampling and chemical analysis, provides the policymakers and the involved stakeholders a scientific basis for formulating strategies and prioritising actions towards improving air quality. In varying proportions, vehicle exhaust, coal and fuel combustion at the industries (including power plants and brick kilns), coal and biomass combustion for cooking and heating, open waste burning, dust from resuspension on roads and construction activities, and seasonal seasalt, dust storms, and open fires, are considered the main sources of air pollution across Indian cities.

All the 122 non-attainment cities under NCAP are required to plan and execute a source apportionment study to identify sources and estimate contributions. Only 25 clean air plans contained information on sources and 56 contained measures expressing intent to conduct source apportionment studies (Table 8). In case of the 25 cities with information, studies were discussed, but failed to effectively integrate the scientific insights in their plans. Consequently, the plans turn out to be a mere compilation of activities without specific emission reduction targets.

A clear understanding of sources will eliminate the tendency to overor under-emphasise certain sectors or conversely ignore others. For instance (Chowdhury et al., 2019), identified that addressing residential biomass burning across India's urban and rural areas for cooking, water heating, and space heating during the winters, will help reach the national ambient air quality standard. Despite various government schemes, studies have demonstrated that the number of households across six Indian states that use LPG as a primary fuel is still low at 37% in 2018 (Jain et al., 2018). In spite of this, most action plans have targeted LPG coverage while neglecting the wider adoption of LPG as a primary fuel (Kar et al., 2020). All the plans combined, only 2% of the action points in 44 plans even mention residential cooking and heating as a sector to address air pollution.

In the United States and the European Union, the states are required

Table 8

Planned and proposed source apportionment studies planned under NCAP and their status as of August 2020 (Source: Central Pollution Control Board, New Delhi, India).

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

(continued on next page)

Table 8 (continued)

State	No. of cities	Non-attainment cities	Institutions conducting the study	Remarks
Maharashtra	18	Mumbai, Pune	NEERI and IIT-	Completed
		Akola, Amravati, Auranagbad, Badlapur, Chandrapur, Jalgaon, Jalna, Kolhapur, Lathur, Nagpur, Nashik, Navi Mumbai, Sangli, Solapur, Thane, Ulhasnaear	Bombay NEERI and IIT- Bombay	Study initiated
Meghalaya	1	Byrnihat		Not initiated
Nagaland Odisha	2 7	Dimapur, Kohima Angul, Talcher, Rourkela, Cuttack, Balasore, Bhubneshwar, Kalinga Nagar		Not initiated Proposal stage
Punjab	10	Amritsar, Ludhiana	Punjab State Council for Science and Technology (PSCST) +TERI	Study initiated
		Dera Bassi, Dera Baba Nanak, Jalandhar, Khanna, Mandi, Gobindgarh, Naya Nangal, Patiala	IIT-Delhi	MoU signed
Rajasthan	5	Jaipur Jodhpur, Kota, Udaipur, Alwar	IIT-Kanpur	Completed Not initiated
Tamil Nadu	2	Tirchy, Thootukuddi		Proposal stage
Telangana	4	Hyderabad	NEERI + Environment Protection Training and Research Institute (EPTRI)	Study initiated
		Nalgonda,	. ,	Not initiated
Uttar Pradesh	15	Sangareddy Ghaziabad	IIT-Delhi	Study initiated
		Agra, Allahabad, Kanpur, Lucknow.	IIT-Kanpur	Study initiated
		Varanasi Anpara, Bareily, Firozabad, Gajraula, Jhansi, Khurja, Moradabad,		Not initiated
Uttarakhand	3	Noida, Raebareli Rishikesh, Kashipur,		Proposal stage
West Bengal	7	Dehradun Kolkata Asansol, Barrackpore, Durgapur, Haldia, Howrah, Ranigunj	NEERI	Study initiated Not initiated

to set emission ceilings to achieve air quality targets (Kuklinska et al., 2015). The USEPA has mandated that states keep the inventory up to date by submitting periodic emission inventories every three years (USEPA, 2017). In India, number of source apportionment and emission inventory studies are limited and majority of them concentrated in the Tier 1 and Tier 2 cities. The lack of a national emission inventory coupled with the absence of a standard protocol for air pollution emission reduction targets. SPCBs can use the existing global and regional emissions and pollution information resources as a starting point to identify and target high-priority sources (UEinfo, 2020).

3.8. Cost of measures

Evaluating the cost-effectiveness of the control measures is critical for an effective CAP with prioritized actions to reach the clean air targets. Estimating measures' cost can also help cities and states determine their required air pollution prevention and control expenditure. Only ten cities (seven cities in Maharashtra, two cities in Nagaland, and one city in Telangana) listed budgetary requirements for executing their plans and the cost of execution ranged from INR 89 crore (~USD 12.7 million) in Dimapur, which is the least densely populated city to INR 16,780 crore (~USD 2400 million) in Mumbai, which is the most densely populated city. In case of Dimpur, INR 77 crore is for core infrastructural activities like improving flexible pavement and repairing roads and drains. This reinforces our finding that the effective air quality management is contingent upon active participation of ULBs in ensuring core infrastructural facilities.

In 2019, MoEFCC announced INR 460 crore for all the activities proposed by the non-attainment cities. 28 cities with population of one million plus and PM_{10} concentration greater than 90 µg/m³ will receive INR 10 crore for various components, including installing and commissioning CAAQMS; creating green buffer zones along roads; acquiring mechanical street sweepers, mobile enforcement units, and water sprinklers; and funding public awareness and capacity building activities. The remaining non-attainment cities will receive INR 10 or 20 lakh per city with population less than 500,000 or between 500,001 and 1,000,000, respectively. While NCAP proposes to enhance the CAAQMS network from 230 stations (in May 2020) to 1000 stations in 2024, budgetary allocations are not enough, given the capital cost of a CAAQMS is approximately INR 1.5 crore (Brauer et al., 2019; Pant et al., 2019).

Availability of the central funds implementing the proposed action points by individual non-attainment cities is also inadequate. In February 2020, the Union Budget of India announced INR 4400 crore (~USD 630 million) for air quality improvements in million-plus cities in accordance with the recommendations made by the Interim Report of India' Fifteenth Finance Commission (Finance-Commission, 2019). Of the 42 million-plus cities in India, only 34 are part of the 122 designated non-attainment cities, which will have access to these funds.

In the absence of central assistance, state governments and municipalities will need to identify clear revenue streams to fully implement the plans. Bihar State Pollution Control Board (BSPCB) revised their action plan for the city of Patna that differs from the one that is available on the CPCB-NCAP portal (BSPCB, 2019). This plan compared execution costs for three scenarios, namely high-pollution reduction (for a reduction of 69% in PM_{2.5} concentrations), medium-pollution reduction of 30%). The estimated cost ranged from INR 2600 to 3800 crore (~USD 370 to 540 million) over eleven years (2019–2030). In all three scenarios, Patna's currently inefficient public infrastructure, interventions in the transport sector account for the expenses that plans will incur since some actions call for core infrastructural developments and the purchase of state assets like mechanical street sweepers and CAAQMS.

4. Policy recommendations

NCAP is a milestone effort by MoEFCC to lead the air pollution mitigation efforts under one umbrella. The approved 102 clean air plans represent a beginning in consolidating the available information at the city level and creating a collective understanding of the scientific, legal, and institutional needs for better air quality. Based on our assessment of the plans, we recommend the following strategies to strengthen cities' pollution control planning process.

Provision for regular updates: Section 17, Clause 1(a) of the Air Act empowers SPCB's to plan and execute a comprehensive programme for the prevention, control, and abatement of pollution. An extension of this clause is development of emission baselines and establishing technical capacity at SPCB's to maintain and regularly update these baselines. MoEFCC could mandate preparation and maintenance of such information databases, which currently happens on a need per basis, like NCAP. This will automatically help address the information gaps to support planning, tracking progress, and evaluating impacts of interventions. The baselines could include establishing protocols and laboratories for continuous measurements and building monthly and annual emission inventories.

An airshed management approach: In the densely populated areas, NCAP could consider moving from city-centric design to an airshed approach, to compliment city's efforts with the regional efforts. This approach requires inter-state coordination mechanism, which can be facilitated by setting up regional airshed management authorities that enjoy cross-state jurisdiction. For instance, (a) broadly, the six zones created by the India's climatology community are unique in their landuse and annual precipitation profiles: mountainous north covering the Himalayan ranges, humid subtropical covering most of the Indo-Gangetic plain and the northeast, tropical wet and dry which is most of the Central and East India covering the Deccan plateau, tropical wet which is most of the regions west of the Ghats, arid regions covering the desert and semi-arid regions between the Ghats and plateau (b) The fifteen agro-climatic zones created by the Planning Commission to regionalise agricultural planning, which overlap with the river basins across the country (c) the most interesting and useful approach comes from the India Meteorological Department, with 36 sub-divisions drawn along the district boundaries with similar temperature, precipitation, and landcover classification. The daily reports for each of these sub-divisions include short-term (1-2 days) dust, thunder, lightning, and storm alerts and long-term (10 days to a month) meteorological predictions to help the local farmers. This can be extended to include air pollution information and management, under which the regional airshed authorities can independently address the non-compliant sources outside the city boundaries like the power plants.

Financial commitments: A baseline assessment of the financial requirements could be included in all the action plans. Municipal corporations and SPCBs could also identify potential revenue streams associated with potential action points. Since 37% of the responsibility lies with ULBs, they could be granted greater fiscal autonomy for maintaining the infrastructure necessary for sustaining any air quality gains.

Tracking progress: The clean air plans could report interim milestones and sectoral emission reduction targets and the responsible agencies could identify key indicators to track progress. For example: Pradhan Mantri Ujjwala Yojana (PMUY) scheme's progress is tracked as the number of new LPG connections at the district level. A similar tracking mechanism is needed across sectors wherein the ULBs maintain a dashboard of the ward-wise number of households that segregate waste or use public transport or use renewable energy for household amenities. In addition, the PCBs could maintain a dashboard of the number of inspections carried out per industry as well as improvements discerned through subsequent inspections.

Delineating responsibilities: In the interest of eliminating responsibility overlap, the existing plans' single column of identifying a responsible agency should be split into four so that, for each recommended measure, agencies can be identified per necessary duty, i.e., planning, implementing, enforcing, or monitoring.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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