REGULATING AIR QUALITY AT AN AIRSHED LEVEL IN INDIA

August 2023

SHIBANI GHOSH | BHARGAV KRISHNA | ABINAYA SEKAR

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About CPR-ICEE

This Paper is produced by the Initiative on Climate, Energy and Environment at the Centre for Policy Research (CPR-ICEE). CPR-ICEE aims to stimulate an informed debate on the laws, policies and institutions shaping climate, energy and environmental governance in India. Our research focuses on improved understanding of climate, development and environmental challenges and pathways to improved outcomes, in three key areas: climate policy and institutions, the political economy of electricity in India, and air quality governance.

About the authors

Shibani Ghosh is an environmental lawyer and formerly Fellow at the Initiative on Climate, Energy and Environment at the Centre for Policy Research (CPR-ICEE). Bhargav Krishna is Fellow and Abinaya Sekar is Senior Research Associate at CPR-ICEE.

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Indian laws and policies, as well as regulatory institutions, are designed to primarily regulate air pollution levels in cities and they consider state-level agencies to be appropriate forums for planning and implementation. Regulatory approval processes focus on the source of the pollution, and that too mostly point sources. The area affected by the pollution or the population likely to be exposed to the pollution are not taken into account. This is a critical flaw in the regulatory framework as it fails to recognize that air pollution is not contained within administrative boundaries.

Air pollutants disperse across regions. These regions – or airsheds – are defined by many factors including wind direction and speed, topographical elements like vegetation, mountains and river basins, altitude, precipitation, temperature variations, and proximity to the sea. Emerging scientific literature provides substantial evidence that demonstrates the limitations of city-centric strategies to mitigate air pollution [1], [2]. Thus, for regulation to be effective in mitigating or controlling air pollution, it must be designed to account for the transport of pollutants and the impacts of this pollution across regions, and the boundaries of such regions need to be scientifically identified.

With a few notable exceptions, there has been little official acknowledgement of the significance of air quality governance at the airshed or regional level in India. The National Clean Air Programme (NCAP) launched by the Ministry of Environment, Forest and Climate Change (MoEF&CC) in January 2019 was the first national policy focussed on air quality [3]. It set a tentative national target of 20-30% reduction of ambient particulate matter ($PM_{2.5}$ and PM_{10}) concentration by 2024, keeping 2017 as the base year, and suggested various institutional arrangements to better regulate air pollution in the country. This target has subsequently been revised to a reduction in ambient particulate matter concentration of 40% by 2026 [4]. The NCAP largely adopts a city-centric approach to pollution mitigation. In some places it refers to the regional impacts of air pollution, particularly in the Indo-Gangetic Plains (IGP) but does not provide guidance on how to tackle this issue at a regional level. The Environment Pollution (Prevention and Control) Authority (EPCA), the primary agency dealing with air quality management in Delhi for more than twenty years, looked beyond Delhi's borders as well. But its focus remained urban-centric. The EPCA was replaced by the Commission for Air Quality Management in National Capital Region and Adjoining Areas (CAQM) in 2020. The law setting up the Commission acknowledges the regional nature of air pollution and creates a different (and additional) regulatory framework for air pollution in Delhi and its surrounding areas – its geographic jurisdiction being defined more broadly than that of the EPCA.

However, apart from the NCAP and the CAQM Act, the needle on airshed level air quality regulation has moved incrementally, mostly in the form of few state-level initiatives like the Uttar Pradesh Clean Air Management Project (UP-CAMP) [5]. Reportedly, the Union Environment Minister at a meeting in March 2023 of the National Apex Committee under the NCAP spoke about the significance of the airshed level approach in the IGP and the need for regional cooperation to combat air pollution [6]. Given the scale and nature of the air pollution crisis in India, urgent systemic reforms that adopt an airshed level approach and facilitate inter-state regional cooperation are essential. These reforms are likely to take time to operationalize and yield visible result, but the groundwork for them must be laid now. What would a regulatory architecture that appropriately responds to the pollution crisis at the airshed level look like? How would it address the crisis at multiples scales – spatial (micro, zonal, city, regional), temporal, and institutional? Is there precedent in Indian regulation where natural resource governance has not followed the conventional administrative boundaries? In this Paper, we unpack some of these key questions relating to air quality governance at the level of airsheds.

Q1: What is the current regulatory framework for air quality governance in India?

The primary regulatory tools for preventing and controlling air pollution in India are the Air (Prevention and Control) of Pollution Act 1981 [the Air Act], the Environment (Protection) Act 1986 [the EP Act], the CAQM Act 2021, and the Rules and directions issued under these legislations [7]. Vehicular emissions are regulated under the Motor Vehicles Rules 1989 [MV Rules].

Presently, rulemaking, standard setting, and policymaking powers relating to emissions under the Air Act, the EP Act,

the CAQM Act and the MV Rules lie across several agencies in the Union Government, the State Governments, and the Central and State Pollution Control Boards (CPCB and SPCBs). The primary tasks of implementation and enforcement are with the SPCBs and the urban local bodies (ULBs).

India's current regulatory framework is designed in a way that the jurisdictional mandate of regulatory bodies aligns with state or city boundaries. When they discharge their functions, they initiate regulatory actions which impact sources emanating from within their jurisdiction. The SPCBs as well as city-level agencies (such as municipal corporations) are empowered to regulate sources within their jurisdictions. Thus, SPCBs implement rules relevant to polluting sources situated within their states on consents processes, inspections, enforcement actions, and other regulatory processes. Rules framed under the EP Act regulate particular sources of pollution like solid waste and construction sites [8], [9] and prescribe emission standards for specific sources [10].

With the exception of the CAQM (which has jurisdiction over the National Capital Region (NCR) and adjoining areas), regulators currently cannot take action against polluters that impact the air quality within their jurisdiction unless the polluters are also situated within their jurisdictional boundaries. For example, if residents of an area are affected by fumes from a landfill located across the state boundary, the SPCB of the state in which the residents reside does not have jurisdiction over the landfill. The SPCB of the state in which the landfill is located, along with other agencies liked the concerned ULB, is empowered to take the necessary measures.

Q 2: What is an airshed, and how can it be delineated?

An airshed is a geographical area which due to reasons of climate, topography and/or meteorology shares a common and discrete air mass. Technically, it refers to the volume of the atmosphere, typically within the planetary boundary layer where air circulation occurs. Airshed delineation is the process of establishing the boundaries of an airshed. The lower boundary of the airshed is the surface of the earth, while the lateral boundaries are determined by several factors such as wind direction and speed, topographical elements like vegetation, mountains and river basins, altitude, precipitation, temperature, and proximity to sea, among others. The upper boundaries can be established by the topography and atmospheric conditions [11].

The process of delineating an airshed can be broadly divided into three stages:

First, preparation of an emissions inventory (EI). An EI is a comprehensive listing of pollutants from all the sources within a geographical area during a defined period of time [12]. The steps involved in developing an accurate EI include determining the types of sources, the pollutants emitted from these sources, their number, size, and emission factors, activity rate, and the available emission reduction technologies [12]. An EI is a prerequisite for air quality models to understand the spatial and temporal distribution of pollutants [13].

Second, monitoring of air quality and meteorology. Air quality monitoring refers to the measurement and

The process of airshed delineation must blend science with administrative efficiency.

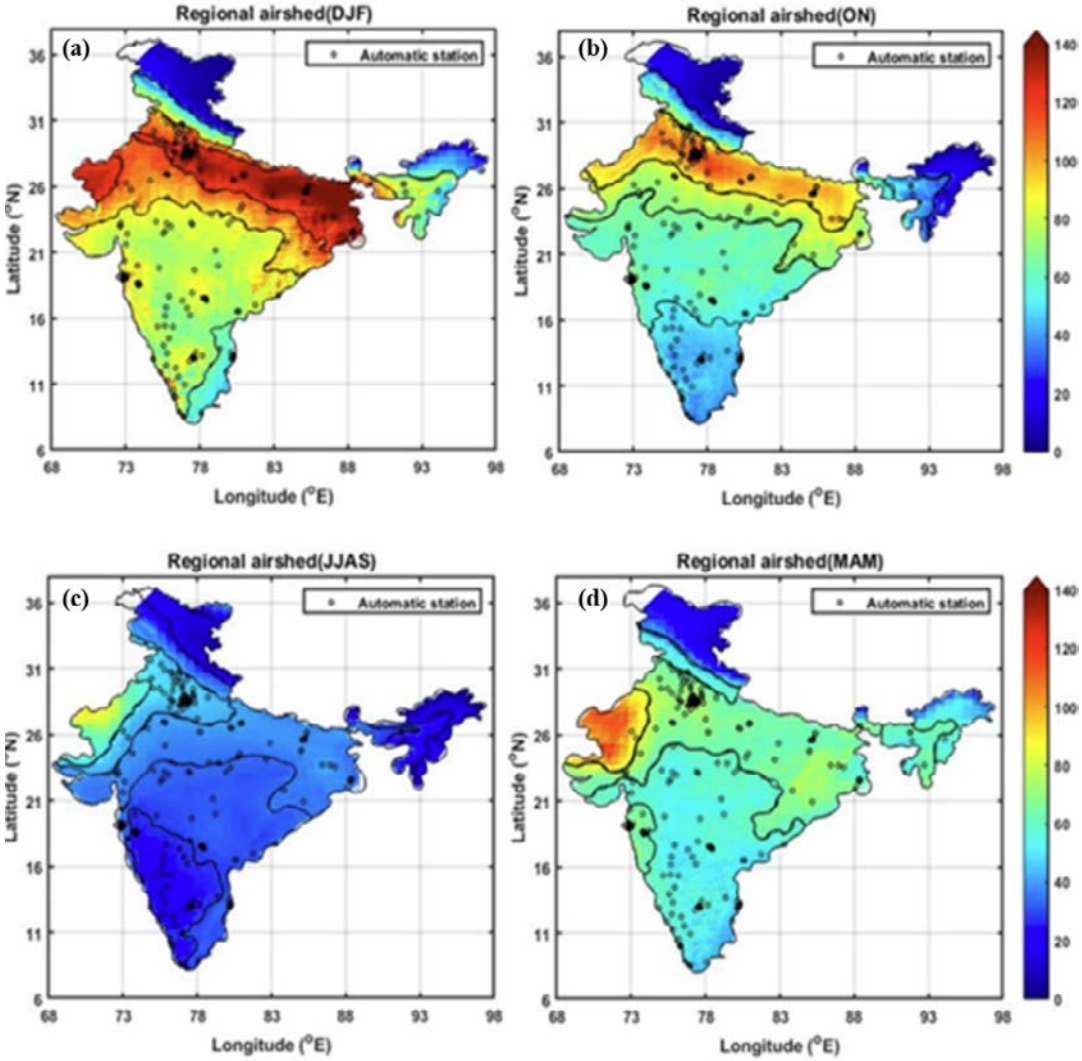

Figure 1: Seasonal-based regional airsheds as per IIT Delhi

Fig. 1(a)- DJF indicates December, January, and February; **Fig. 1(b)-** ON indicates October and November; **Fig 1 (c)-** JJAS indicates June, July, August and September; **Fig 1 (d)-** MAM indicates March, April, and May

Source: IIT Delhi, 2023 [15]

collection of data on ambient air pollution levels at various spatial and temporal scales through the use of fixed or mobile monitors. Air pollution and meteorology have to be monitored at the national, regional and local levels to understand the variation. The meteorological parameters include temperature, wind speed and direction, relative humidity, atmospheric pressure, precipitation, mixing layer heights, surface threshold velocities, stability parameters, dew point, cloud layers, among others [14].

Third, air quality modelling. In addition to the air quality data obtained through monitoring, an air quality dispersion model can predict ground-level concentrations of pollutants at fine spatial and temporal scales. The models can also estimate the dispersion, transportation, and transformation of pollutants using source emissions, topographical and meteorological data.

It is important to note that dispersion models are complex and different from statistical models. Statistical models are widely used especially in the case of health studies as they can establish the relationship between observed air quality and factors like emissions, meteorology, and other parameters. They can be used to predict the pollutant concentration in the future or at the locations where the monitoring data is not available. However,

they do not capture the dynamic nature of physical and chemical process involved in pollutant transport and transformation.

Several studies have identified airsheds in India through different methodologies:

- IIT Delhi under the project "Satellite-based monitoring of ambient $PM_{2.5}$ at national scale for air quality management" has delineated seasonal-based regional airsheds and local airsheds [15]. The study identified regional airsheds (Figure 1) based on the similarities in the 20-year satellite $PM_{2.5}$ data sets and other environmental factors. The study employed the k-means clustering method to group together regions exhibiting similar air pollution patterns. The data was partitioned seasonally to investigate the variations in airsheds over different seasons, and unallocated data points were included in broader regions using criteria such as land elevation and seasonal wind patterns [15]. While delineating the local airsheds it was evident that airsheds are wider and overlap between the cities [15].
- Guttikunda et al. (2023) suggest 104 micro airsheds that encompass 164 cities. The demarcation of a representative airshed for each city was based on urban-rural classifications, land-use information, and known emission sources within and immediately outside the city limits. The size of the airshed was determined by beginning with the administrative boundary of the main city and expanding to include satellite cities as well as any adjacent high-density diffuse and point sources that have impact on the air quality [16].
- An analysis by the World Bank identifies 6 key airsheds in South Asia (Figure 2) based on climate, terrain and where air quality is highly spatially interdependent [17]:
  - **(1) West/Central Indo-Gangetic Plain:** Punjab (Pakistan), Punjab (India), Haryana, part of Rajasthan, Chandigarh, Delhi, Uttar Pradesh;
  - **(2) Central/Eastern Indo-Gangetic Plain:** Bihar, West Bengal, Jharkhand, Bangladesh;
  - **(3) Middle India:** Odisha/Chhattisgarh;

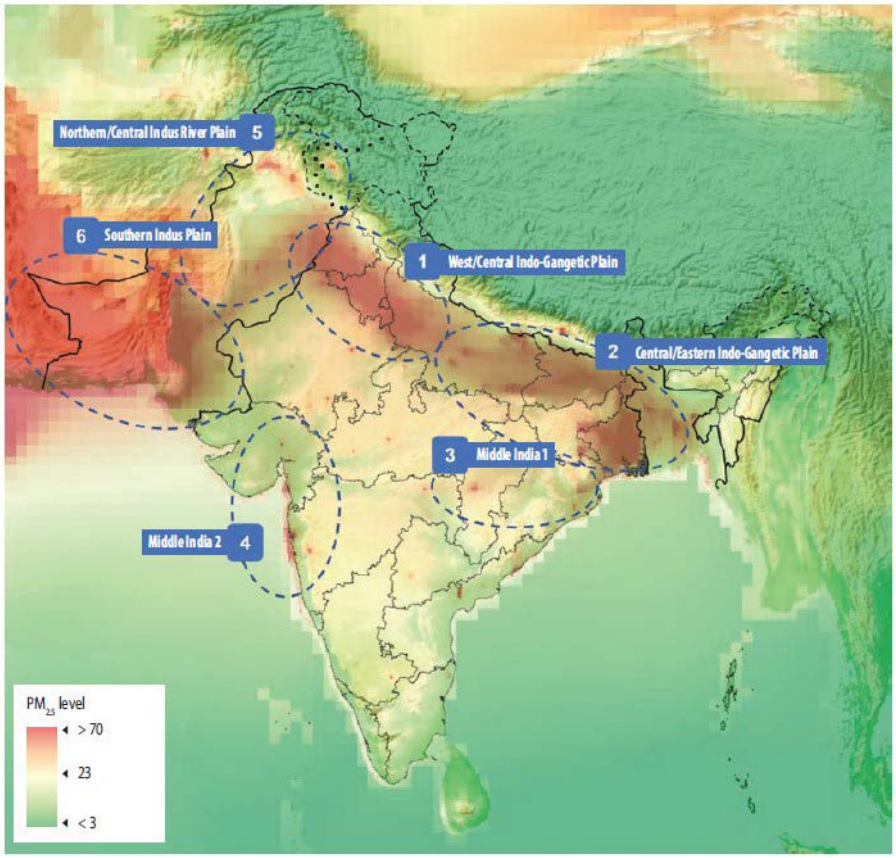

Figure 2:
Six major airsheds in South Asia as per the World Bank.

Source: The World Bank, 2022 [17]

- **(4) Middle India:** Eastern Gujarat/Western Maharashtra;
- **(5) Northern/Central Indus River Plain:** Pakistan, part of Afghanistan; and
- **(6) Southern Indus Plain and further west:** South Pakistan, Western Afghanistan extending into Eastern Iran.

It is critical that India transitions to air quality governance at a regional level, where the region is not defined by administrative boundaries of a state or city. Airsheds identified in the literature cited above and elsewhere could be useful starting points as India considers this transition.

It is important to include a note of caution here regarding airshed delineation. Ideally a region should be one composite, scientifically determined airshed. However, given the shifting nature of seasonal airshed boundaries, this may not always be possible, and it could lead to various problems in planning and administration. Administrative efficiency and ease of planning and implementing regulations also need to be considered while delineating an airshed. For instance, the IIT Delhi work shows us that for most part of the year, the IGP comprising states from Punjab in the west to West Bengal in the east function largely as a unified airshed, but not during the monsoon period. However, these states should be brought under the ambit of a single airshed level regulator with similar considerations applied across geographies, notwithstanding certain variations during the monsoon period. Airshed delineation has to blend science with administrative efficiency.

Q3: What is an airshed level approach to air quality governance? Why is it a recommended policy tool for India?

As an airshed shares a common air mass, with pollution generated in one part of the airshed most likely affecting other parts of the airshed as well. Therefore, an airshed level approach to air quality governance requires identifying and regulating all sources of emissions within an airshed. It also requires policy makers and regulators to consider the exposure of the entire population likely to be affected by the pollution. There are four main reasons that provide salience for a transition towards an airshed level approach to air quality governance in India.

First, air pollution is a pan-India problem. It affects rural and peri-urban areas as much as the urban areas. The air quality data presently available is almost exclusively for urban areas as the ambient air quality monitoring network in India has few monitors outside large cities [18], [19]. But studies relying on satellite data and modelling estimate that average rural and urban exposure to $PM_{2.5}$ are similar [20]. According to these estimates, 77% of the population of India is exposed to air quality poorer than the national ambient air quality standards (NAAQS) [21]. Significantly, about 41% of nitrogen-dioxide (NO_2) pollution in India is emitted by rural sources [22]. Some studies reveal that rural areas are worse off than urban areas. For instance, elevated levels of ozone (O_3) have been observed in the rural regions when compared with the urban regions [23], [24]. Adverse health effects attributable to $PM_{2.5}$ and O_3 in rural areas are as severe or more severe than in urban areas of India [25], [26].

Mitigation efforts that are city-centric do not yield the desired results as air quality in cities is affected by sources in the wider airshed, not just those situated in cities.

Second, air pollution mitigation efforts are currently focused within city limits. Mitigation efforts are focused on pollution sources within cities. However, such efforts do not yield the desired results as air quality in cities is affected by sources in the wider airshed, not just those situated in cities. Studies show that in cities with very high pollution levels, a significant proportion of the pollution is caused by sources located outside the city limits or even outside the state in which it is located. For example, the contribution of $PM_{2.5}$ from NCR, upwind NCR states, and upwind regions outside India to Delhi's air quality was 24%, 17%, and 33%, respectively from April 2016 to February 2017 [27]. This indicates that significant amounts of $PM_{2.5}$ in Delhi's air originates from outside of Delhi. Another example is the impact of stubble burning in north India. Smoke from farm fires in Punjab and Haryana move in the southeast direction to other parts of northern India. The wind direction, lower mixing heights and weaker wind speeds experienced particularly during winter increase the accumulation of $PM_{2.5}$ in the lower troposphere. This contributes up to 50% increase in daily average $PM_{2.5}$ levels during the pre-winter season in Delhi [28].

A study titled *Air pollution knowledge assessments (APnA)* conducted for 20 Indian cities, apart from Delhi, estimated that tier-2 cities receive approximately 30 to 40% of the $PM_{2.5}$ from sources originating outside the city boundaries. For example, 36% and 32.5% of $PM_{2.5}$ in Agra and Coimbatore, respectively, originates outside the urban airsheds of the two cities [29]. Apart from particulate matter, studies have shown substantial NO_x pollution in Delhi comes from outside the city limits with the higher contribution from the transport sector [30]. Therefore, mitigation efforts must go beyond city limits, and be broad-based at an airshed level.

As noted already, rural air pollution is a large and neglected crisis. Just as rural sources contribute to urban air pollution, urban sources result in increased pollution in rural areas leading to adverse consequences on health as well as crop yields. Expanding monitoring networks significantly in rural areas while considering mitigation efforts beyond city boundaries will improve our understanding of the nature and extent of the problem and likely increase the efficacy of solutions [16].

Third, there is a need for uniform and consistent regulatory practices for the same type of polluters. As sources of pollution affect not only the area and population in close proximity, but the regional air quality, they should be regulated in a consistent manner across the airshed or region irrespective of administrative boundaries. Therefore, statutory processes like consent granting and renewal, inspections, siting criteria, standard setting, enforcing emission standards and monitoring the proper installation and functioning of air pollution control devices, etc., must be uniform and consistently undertaken for the same type of sources in a single airshed.

Fourth, scarce regulatory resources can be shared through well-coordinated measures. Resources for regulating pollution are finite, and at present, inadequate. Coordinated efforts across a region including sharing of knowledge, monitoring technology and enforcement capabilities could result in a common and improved understanding of the issues that affect the region, and enhance India's ability to achieve increased air quality gains.

As discussed above, there are several reasons for India to adopt an airshed level approach. However, it is important to keep in mind that the feasibility of regulating airsheds significantly depends on pragmatic considerations such as regulatory capacity. As research has shown, regulatory capacity for pollution prevention and control in India is weak and present regulators face systemic problems which cripple their ability to function [31],[32]. Effectively implementing airshed-level regulation will require well-financed state level environmental regulators with the requisite technical expertise and manpower. Enhancing the capacity of current regulators to effectively deliver on their mandate by augmenting their poor technical capacity, providing guaranteed untied financing from State Governments, and appointing capable leadership that can ensure the SPCBs' functional autonomy is vital.

Q4: What do we need to facilitate air quality regulation at the airshed level?

An airshed level approach requires us to plan beyond the existing jurisdictional boundaries of states and cities, consider all pollution sources, and the population exposed to these sources in a region or airshed. The first

The proposed institution will undertake rulemaking, policymaking, and standard setting for the region. SPCBs, ULBs, etc. will continue with implementation and enforcement tasks.

task is therefore demarcation or delineation of airsheds. As stated earlier, this is a complex process and involves the interplay of several factors and modelling exercises. However, even a less-than-perfect airshed demarcation would yield significant air quality gains in India.

▸ NOTIFYING PARTS OF AN AIRSHED AS AIR POLLUTION CONTROL AREAS UNDER AIR ACT

While various studies have suggested airsheds or regions that may be demarcated and considered as units for regulation, and similar other studies are underway, airsheds are yet to be statutorily notified in India. Without resorting to legislative amendment, one statutory mechanism that already exists and that could be used for notifying airsheds is the declaration of 'air pollution control areas' by State Governments under Section 19 of the Air Act 1981. Once an airshed is appropriately delineated by the Union Government, State Governments with jurisdiction over parts of such an inter-state airshed or region can declare those parts as an air pollution control area, and notify the same in the official Gazette. Contiguous air pollution control areas notified across states can together form a composite region for regulation. This allows the State Governments to then coordinate while prescribing emission and control technology standards in consultation with the Union Government and the CPCB, thereby ensuring that they are consistent and appropriately strict across the entire airshed.

▸ REFORMING THE INSTITUTIONAL FRAMEWORK

From a governance point of view, regulating at a regional or airshed level raises several important concerns particularly around the governing institutional structure. If an airshed has to be regulated as a single unit, there needs to be an institutional mechanism in place that allows coordinated regulatory efforts across states situated in the same airshed. The duties and powers of the institutional mechanism will have to be clearly identified to ensure that it can function effectively and without jurisdictional conflicts.

Reforming the institutional architecture so that it responds to the requirements of airshed level governance raises key issues which we unpack below with our suggestions:

1. Form and composition of new institution

How can the institutional reform be executed and what form would it take? There could be three routes for introducing institutional reform:

- Setting up a new statutory authority under a new law passed by Parliament or through an amendment to an existing law.
- Enhancing the powers of an existing agency (such as the CPCB or the CAQM) through an amendment to the law under which it has been set up.

- Setting up an empowered committee or commission with multi-stakeholder membership/ representation through notification by the Union Government while exercising its executive powers such as those under the EP Act.

Without resorting to new legislative processes or enhancing the powers of current regulators that are either overburdened and under-resourced, or whose effectiveness and capabilities are yet to be fully ascertained, we suggest taking the third route. A committee or a commission may be established through notification by the Union Government while exercising its powers under Section 3(3) of the EP Act. The notification would list the composition, powers, and functions of the newly constituted body (Figure 3). Each airshed or region in the country would have a different committee or commission regulating its air quality. The membership would include:

- *senior bureaucrats from the Union Government,*
- *chief secretaries of states in the region,*
- *senior bureaucrats of relevant state departments* (particularly environment, health, transport, rural and urban development, and industry),
- *heads of ULBs* (as all ULBs cannot be represented on the committee, at least those from the major non-attainment cities in the region must be represented on a rotational basis),
- *persons with expertise in the science, regulation, and health impacts of air pollution* (they will occupy their positions in part-time capacity, and the notification will mandatorily require their appointments to be completed by the Union Government in a time-bound manner).

The new institution will have full-time staff including technically qualified persons competent to understand various aspects of air quality, and who are able to assist and advise the members of the institution.

2. Powers and functions of new institution

What kind of powers should such an institution possess to ensure air pollution is addressed at a regional level effectively? A new multi-stakeholder body is likely to find it difficult to take over all air quality governance functions. The current institutional architecture has been in place for decades and is extremely complex. Activities across the economy contribute to air pollution, and a variety of stakeholders are affected by air quality regulation. It is therefore suggested that the new institution takes over the tasks of rulemaking, policymaking, and standard setting for the region. Implementation and enforcement would continue to remain with the SPCBs, ULBs and other agencies.

This division of powers would allow the new institution to take a region-wide perspective of the air pollution crisis, and at the same time not have significant resource demands for implementation and enforcement. It will guide knowledge generation and sharing, set goals for pollution mitigation in consultation with stakeholders in the region (including sectoral goals), and coordinate implementation actions across states. As a supra-state institution, it would be the first port of call to resolve any issue of jurisdiction, regulatory overlap or any other form of dispute relating to planning or regulation relating to air quality in the region. However, it will not initiate enforcement action or act as an appellate body against enforcement measures taken by the SPCB or any other body.

Air quality monitoring data will be routinely shared with this institution for analysis, review and used for future planning. As it will be notified under Section 3(3) of the EP Act, the new institution will have the powers to issue directions akin to those of the Union Government under the EP Act. It can issue directions to various entities to execute its region-wide plans, adopt its region-specific emission standards and implement its policies.

As one of its key functions, we recommend that the new institution frame area or region-specific air quality targets that are more stringent than the NAAQS. Due to variations in topography, meteorology, and pollution sources, different parts of the country experience different levels of pollution and exposure to pollution. The ability of these parts to achieve air quality standards also varies. For instance, highly urbanized areas like Chennai in southern India benefit from their proximity to the ocean, relatively flat terrain, and fewer geographical obstacles, all of which aid in the dispersion of pollutants. Conversely, regions located in the IGP are landlocked, presenting challenges for pollutant dispersion. Region-specific standards can account for these variations and address the unique challenges faced by each region. At the same time, region-specific standards can also encourage regions to achieve

Formation	Composition	Powers/roles	Outside its jurisdiction
Through notification by the Union Government under Section 3(3), EP Act	1. Senior bureaucrats from the Union Government 2. Chief secretaries of the states in the airshed 3. Senior bureaucrats of relevant departments 4. Heads of (select) ULBs 5. Persons with relevant expertise in air pollution and its impacts	**Rule Making and Planning for the airshed** 1. Policy-making 2. Standard setting for emitters 3. Goal setting for pollution mitigation in consultation with stakeholders **Monitoring and implementation** 1. Coordinating implementation actions across states 2. Resolving any issue of jurisdiction and regulatory overlap 3. Issuing directions 4. Referring non-compliance or default to the Union Government **Knowledge and data** 1. Guiding knowledge generation and sharing 2. Reviewing air quality data	1. Does not have enforcement powers 2. Not an appellate body against action taken by SPCBs or any other body

Figure 3: Functions, composition, and powers of the proposed institution

air quality levels that are below the NAAQS which are a national baseline for acceptable levels of exposure.

▸ ENSURING ACCOUNTABILITY

The new approach will also have to address crucial concerns relating to accountability. Violations of emissions norms, technology standards or any other regulatory requirement would then be offences against the entire population in the airshed, and therefore any person living in the airshed should be able to hold a polluting entity and/or non-performing government agency accountable.

How will non-compliant state actors and polluters be held accountable for their actions within the region? To begin with, as the membership of the institution will include chief secretaries of states and the institution will engage in thorough stakeholder consultation, it is hoped that there will be high degree of compliance with directions and guidance issued by it. But holding defaulting actors accountable for their actions remains a particularly difficult concern as the proposed institution is designed to be a focal point for guidance, planning and knowledge generation, not for 'hard regulation'. At the same time, unless all (or a majority of) actors in the region follow its directions, regional level regulation will fail. Therefore, some powers and processes need to be envisaged. We propose two accountability mechanisms.

First, the institution refers the non-compliance or default to the Union Government for further adjudication. The Union Government has extensive powers to issue directions under Section 5 of the EP Act to any person, officer or authority, and such person, officer or authority is bound to comply with such directions. The directions could be directions for closure of any polluting industry, stoppage of utilities to such polluting industry, payment of compensation for environmental damage, etc. The

Union Government could also issue directions to regulatory authorities or government agencies in the airshed to take appropriate time-bound action against polluting or non-complying entities, take appropriate regulatory time-bound measures like setting standards, inspection protocols, etc. At the same time, it can also use its offices to facilitate or coordinate actions that incentivize and promote compliance with the directions. For instance, if there is a direction to switch fuels in a particular type of industry, and the State Governments are unable to enforce such a switch, the Union Government through the concerned ministry can initiate a scheme to make the switch smoother by providing financing mechanisms for affected industries.

Second, the institution moves the National Green Tribunal under the provisions of the NGT Act 2010. An application can be filed under Section 14 of the Act as it would relate to the implementation of the EP Act or the Air Act (or both). The cause of action in such cases would be non-compliance with the institution's directions. Under the NGT Act, the institution can be considered an aggrieved person, and the NGT has extensive powers to enforce statutory obligations. However, this route has not been a preferred mechanism for other regulators like the SPCBs and the CAQM to challenge non-compliance of their directions, and thus there is not much by way of precedence to refer to.

Q5: Are there other examples of zones or areas in India that have been demarcated for monitoring, data collection or regulation that do not adopt the conventional administrative boundaries?

While airsheds have not been notified in India, there have been other instances of environmental regulation in which regulated areas have been demarcated based on a shared natural resource or regional impacts of environmental degradation. These instances of regulation could provide useful learnings for the proposed regulatory framework for airshed or regional level air quality governance.

1. THE TAJ TRAPEZIUM ZONE (TTZ) AND THE TTZ AUTHORITY

Legislative basis and jurisdiction: The Taj Trapezium Zone (TTZ), initially identified by the CPCB in 1983, is spread across Agra Division in Uttar Pradesh and Bharatpur Division in Rajasthan. According to the CPCB's website, the boundary of the TTZ was demarcated "on the basis of the weighted mean wind speed in twelve directions from Agra to Mathura and Bharatpur", and "keeping in mind the effect of any pollution source in this zone on the critical receptor-The Taj Mahal" [33]. In 1999, through a notification issued by the Union Government under the EP Act, the TTZ Pollution (Prevention and Control) Authority was set up with jurisdiction over the Agra Division of the TTZ. The notification has subsequently been amended on several occasions, most significantly in 2003, when its jurisdiction was expanded to the Bharatpur Division of Rajasthan.

Composition: Chaired by the Commissioner of the Agra Division, the Authority's membership includes three civil society representatives, officials from both State Governments, ULBs as well as representatives of the Union Government. The Authority is under the overall supervision and control of the Union Government, and exercises powers under Section 5 and 19 of the EP Act.

Functioning: The Authority's functions include monitoring the progress of various schemes for the protection of the Taj Mahal and the TTZ, to ensure compliance of vehicular emissions and fuel quality standards, and deal with any other environmental issue referred to it.

Air pollution in the TTZ remains a serious cause for concern [34], and the Supreme Court through various orders in a case filed in 1984 continues to oversee some of the issues arising from it [35]. There is no information on the functioning of the TTZ Authority on its website. From a perusal of recent orders of the Supreme Court it appears that the Authority exercises some implementation functions. A 2015 report of the Parliamentary Standing Committee on the "Effects of Pollution on the Taj" made a damning observation about the Authority -

> *"...aghast to note that no administrative setup has been constituted for TTZ Authority and as such no mechanism is available to implement the decisions of the TTZ Authority. As admitted by TTZ Authority, for all practical purposes TTZ Authority is not functioning optimally as it consists of only members with no supporting staff. Further, no budget is allocated for proper functioning of TTZ Authority." [36]*

We were unable to locate any analysis of the present working conditions of the Authority, and whether the Parliamentary Standing Committee's recommendation to the MoEF&CC to "provide the necessary financial support, manpower and infrastructure to the TTZ Authority without any further delay" was acted upon [36]. The Report, however, does strike a cautionary note on how statutory authorities constituted to focus on specific issues can be severely handicapped due to institutional constraints.

2. ENVIRONMENTAL POLLUTION (PREVENTION AND CONTROL) AUTHORITY

Legislative basis and jurisdiction: The EPCA was constituted by the Union Government in 1998 under the EP Act to protect and improve the environmental quality in the NCR [37]. The NCR includes the National Capital Territory of Delhi and certain districts in Haryana, Rajasthan, and Uttar Pradesh.

Composition: Initially composed of five members, the EPCA was subsequently reconstituted on few occasions, notably expanding its membership to include bureaucrats from the ULBs of Delhi and other departments of Delhi Government, and civil society representation [38], [39]. It was chaired by a retired bureaucrat who held the post the entire time that the EPCA was in existence. Interestingly, EPCA's membership did not include persons or departments from the three other states in the NCR. The Authority was delegated powers under Sections 5 and 19 of the EP Act and was under the supervision and control of the Union Government.

Functioning: The EPCA was established with a comprehensive mandate to protect the environment in the NCR and was given significant powers including powers to issue directions and take cognizance of offenses under the EP Act. One of its primary functions was to provide recommendations to the Supreme Court of India through reports, and monitor compliance of the Court's orders. Its recommendations contributed to some key policy measures including the adoption and incentivisation of cleaner fuel, transitioning to higher vehicular emission standards, the Graded Response Action Plan, and the Comprehensive Action Plan for the NCR [40]–[42].

However, the Authority came under criticism for not fully utilising its powers and inadequately addressing concerns relating to air quality in the NCR [43]. Its chairperson and all its members held their positions in part-time or ex-officio capacity, and some of its members represented interests or departments which were either responsible for the pollution or for neglecting to control it. Thus, leading to a reasonable doubt about it being a fully independent body [43].

3. THE RIVER GANGA (REJUVENATION, PROTECTION AND MANAGEMENT) AUTHORITIES ORDER, 2016

Legislative basis and jurisdiction: The River Ganga (Rejuvenation, Protection and Management) Authorities Order, 2016 issued by the Union Government under the EP Act constitutes an institutional framework for the

Institutional structures that have previously been set-up to regulate shared natural resources, and the factors that have influenced their functioning, provide valuable guidance for the design of airshed level governance.

protection of the Ganga River Basin. It replaced earlier notifications issued for the protection of the Ganga, and dissolved the National Ganga River Basin Authority set-up in 2009. It enjoys primary and exclusive jurisdiction over decision-making relating to the Ganga as it is "overall responsible for the superintendence, direction, development and control of River Ganga and the entire River Basin (including financial and administrative matters) for the protection, prevention, control and abatement of environmental pollution in River Ganga and its rejuvenation to its natural and pristine condition and to ensure continuous adequate flow of water in the River Ganga and for matters connected therewith."[44]

Composition: The prescribes a five-tiered national, state, and district-level institutional structure headed by the National Ganga Council. The Council is chaired by the Prime Minister, and its members include Chief Ministers of five Ganga states and several Union Ministers. The National Mission for Clean Ganga serves as the implementing arm of the Council and is led by a Director General who is also an Additional Secretary at the MoWR.

Functioning: One of the key features of the Order is that it requires the Ganga, which (along with its tributaries) flows through ten states and the National Capital Territory of Delhi, to be managed as 'a single system'. The Order lists principles that would govern the management of the Ganga.

Apart from the 2016 Order, the government has taken other policy steps for the protection of the Ganga including the Namami Gange program, and there has been significant budget allocation for the protection of the Ganga.

Ganga and its tributaries continue to suffer from toxic pollution in several stretches, wastewater treatment infrastructure remains inadequate, and effective enforcement mechanisms are lacking. There is insufficient coordination among stakeholders, inadequate funding, several projects that have been allocated funds have not been implemented, and public participation is limited [45]–[48]. The CAG in its 2017 report on the Namami Gange program pointed to several of these flaws [49].

We were unable to access any assessment of the functioning of the 2016 Order's institutional mechanisms, and given the state of the Ganga presently, there is certainly need to analyse why these mechanisms are failing to provide effective protection to the river and its ecology. The complex institutional structure set-up by the Order with central and state government representation, the powers and functions of the various institutional mechanisms, and the principles prescribed in the Order are indicative – at the least – of the Union Government's acknowledgement that the present state of the Ganga requires strong and urgent interventions. The 2016 Order's treatment of the Ganga as a single system and its emphasis on maintaining minimum ecological flow in the river can be considered as a policy precedent for considering airsheds as composite systems requiring coordinated treatment.

Two other instances of Indian environmental regulation that treated a natural resource shared across state boundaries as a single unit may also be referred to here. As very little information is available on the functioning of these two regulatory mechanisms is available, we are unable to elaborate on them much. First is the Aravalli range notification issued by the Union Government in 1992 under the EP Act. The Notification put in place a regulatory mechanism for in the Aravallis situated in the Alwar district of Rajasthan and the Gurgaon district of Haryana. It required an approval from the Union Government for undertaking certain activities in the Aravallis based on an environmental impact statement and environment management plan [50]. However, the Notification was amended in 1999 and powers of the Union Government were delegated to the respective State governments [51].

Second was the setting up of the National Tri-State Chambal Sanctuary Management and Coordination Committee in 2011 by the Union Government [52]. The Committee was set up to ensure coordination across the three states of Madhya Pradesh, Rajasthan, and Uttar Pradesh in which the National Chambal Sanctuary, situated along the river Chambal. The committee was composed of representatives from forest departments of the three states, representatives from other government departments, experts and stakeholders from NGOs, research institutions and local communities. A tri-state management plan for the Chambal was prepared by the Committee in 2014.

All instances of environmental regulation discussed in this section provide instructive precedent on the forms of institutional structures that have previously been put in place by the government to regulate shared natural resources, and the factors that have been instrumental in their effective or ineffective functioning. Importantly, they provide valuable guidance for how inter-state coordination can be carried out while governing at the airshed/regional level.

Q6: What kind of measurement and monitoring systems need to be in place to support airshed level regulation?

A well-designed monitoring network for airshed level regulation should provide data for assessing the air quality to ensure compliance, identify sources and transport of pollutants, determine trends (long and short-term), evaluate regulatory effectiveness, and serve as an early warning system. To meet this array of requirements, the monitoring devices in such networks are used to measure the concentration of pollutants, meteorological variables, and other relevant data.

The common monitoring devices that can be used for airshed level monitoring are ambient air quality monitors, meteorological sensors, emission monitors, low-cost sensors, mobile monitoring devices, remote sensing devices, supersite monitors, data loggers and telemetry systems, and equipment for quality assurance/quality control [53].

Air quality monitors are already in use widely and have either been set up by the Union or State Governments. While the density of the monitoring network has grown in recent years, concerns remain regarding the adequacy, reliability, and integration of the monitors at different spatial scales nationwide. There are currently 438 Continuous Ambient Air Quality Monitoring Stations (CAAQMS), far fewer than are required in most cities to meet the CPCB's minimum requirement based on the population of the cities that these monitors are located in [16]. A recent report by the Centre for Science and Environment also reveals that only 12% of Indian cities have air quality monitoring systems, and rural areas are largely uncovered. This leaves a large swathe of the Indian population uncovered by the monitoring grid [54]. Ensuring the harmonization of existing monitors, strategic placement of new monitors, and their integration into a nested network is vital for effective airshed monitoring.

The proposed nested monitoring system would integrate different techniques and technologies for monitoring at five different spatial scales – ranging from micro to national. The system can be linked to a technical decision-making platform which can assist the new institution in its decision making.

In addition to the regulatory grade monitors, higher resolution ***supersite monitors*** to identify the pollution sources are currently in place in Delhi [55]. ***Low-cost sensor*** (LCS) networks have been piloted in several states in partnership with academic, private sector, and civil society organizations [56]–[59], demonstrating reasonably accurate results [60].

The CPCB has mandated the installation of ***Continuous Emissions Monitoring Systems*** (CEMS) in polluting industries, with efforts to encourage their use for both more effective monitoring by the SPCBs as well as for self-regulation [61]. They are currently inadequate in

their scale of implementation, however, and integrating emissions monitors with air quality monitoring networks is challenging due to their distinct purposes and measurement parameters.

Satellite data provides wide spatial coverage, offering a comprehensive view of air quality on a regional or global scale in both urban and rural areas. ***Air quality models*** based on these satellite data utilize complex algorithms to simulate and predict pollutant concentrations. These models substantially enhance monitoring capabilities by providing valuable insights into pollutant distribution, sources, and trends. Currently, the System of Air and Weather Forecasting and Research (SAFAR) [62] and the Delhi Air Quality Early Warning System [63], leverage various data sources to forecast air quality levels and inform policy measures in selected cities [64]. An important caveat on air quality models is that sufficient ground monitoring stations are essential for validating and calibrating satellite-derived air quality data, ensuring their accuracy and reliability. These stations provide ground-truthed measurements that help improve the precision of satellite data interpretation and enhance the overall quality of air quality predictions.

The diversity of data available from these different monitoring approaches present both a challenge and an opportunity. While the challenge is centred around the differential purposes for which they were originally established, there is potential under an airshed management regime to integrate closely many of these sources under a hybrid monitoring approach that can provide spatially and temporally relevant air quality data at various scales

Table 1: Proposed nested hybrid monitoring network

Scale	Description	Monitoring approaches	Use case	Agencies
Micro	Concentration within an area ranging from <1 square kilometre to a few square kilometres.	Low-cost sensors (LCS), temperature and humidity sensors.	To identify the hotspots of pollution. Hyperlocal information on temperature can also be used for relevant heat wave policy development.	Resident welfare associations, panchayats, industrial associations, ULBs and SPCBs.
Zones and wards	Concentrations within a large, uniformly populated/ land-use area of the city with dimensions between a few square kilometres to tens of square kilometres.	LCS, mobile monitors, temperature and humidity sensors.	To generate spatially disaggregated data and identify potential localised sources for action.	ULBs, and SPCBs
Urban	Conditions that apply to the entire city, ranging from tens to hundreds of square kilometres.	LCS, mobile monitors, manual monitors, CAAQMS and temperature and humidity sensors.	These measures could be used to evaluate urban and peri-urban air quality trends and, in turn, the efficacy of air pollution action plans.	SPCBs
Regional/ Airshed	The topography is largely uniform over distances of hundreds to thousands of square kilometres.	LCS, mobile monitors, manual monitors, CAAQMS, supersites, satellite data and meteorological sensors (temperature, humidity, wind speed, wind direction, precipitation and others).	The data can be better used for conducting source apportionment, understanding the background levels, and regional transport of pollutants.	SPCBs, CPCB, and proposed new institution.
National	Concentrations that characterize the country.	LCS, Mobile monitors, manual monitors, CAAQMS, Supersites and satellite data.	To provide representative snapshot of air quality conditions at the national level.	CPCB

within an airshed [65]. Such a network would combine the use of reference grade and well-calibrated low-cost air quality monitors, meteorology sensors, and satellite data to ensure that data on the levels and transport of pollutants are available at a high spatial resolution including in areas under-served by traditional monitoring [16].

Our proposal for a hybrid monitoring network that would function at the level of an airshed is laid out in Table 1 above. In principle, this nested monitoring system would integrate different techniques and technologies for monitoring at different spatial scales, with the data generated from each of these scales having a particular use case. We propose the monitoring occur at five different spatial scales ranging from micro to national. Owing to the complexity of integrating CEMS, we have excluded them from this nested network.

This nested monitoring system, operating at different spatial scales, can be linked to a technical decision-making platform, such as a control room or an information centre. The platform can assist and inform the new institution while it designs and adopts suitable air quality management policies to complement and guide regulation at the airshed level.

Conclusion

Air pollution is a pan-India problem, and whether viewed in terms of pollution sources or exposure, there is no reason to continue an urban-focus in air pollution mitigation measures. It is imperative for air quality governance in India to transition from a city-centric approach to an airshed approach. As resources to address the pollution crisis are scarce, a coordinated effort across a region, that supports consistent and uniform measures against similar pollution sources, is likely to lead to greater gains in terms of air quality.

In this Paper, we unpack some of the key issues relating to airshed-level governance and what is required to make that transition in India. The current regulatory set-up is designed to primarily focus on point sources, and the jurisdictional mandate of regulatory bodies aligns with state or city boundaries. To effectively regulate pollution and reduce pollution exposure, changes need to be introduced to this regulatory architecture, making it adopt an airshed-level approach. To begin with, airsheds have to be demarcated based on several criteria. However, there is sufficient literature available to initiate necessary reform measures, and the transition to an airshed or regional approach is not contingent on perfect airshed demarcation.

We propose that airsheds be notified under the Air Act by the State Governments as 'air pollution control areas', and the Union Government may constitute, through notification, multi-stakeholder institutions for each airshed under the EP Act. We have outlined the composition of such an institution, its powers, roles, and responsibilities. It will be a focal point for standard setting, policy guidance, planning and knowledge generation for the airshed, while not being involved in enforcement. A key ingredient for successful airshed-level governance is effective accountability mechanisms that ensure compliance by actors across the region. We envisage a role for the Union Government under the EP Act as well as for the National Green Tribunal in this regard.

Valuable lessons can be learned from other legal instruments that have been issued by the government to regulate shared natural resources such as the Taj Trapezium Zone notification, the EPCA notification and the Ganga River Authorities Order 2016. We provide an overview of these instruments as an analysis of the institutional mechanisms set-up under them will provide instructive precedent for airshed-level institutions.

Regarding air quality monitoring, there is a need for optimizing the use of existing monitors while strategically installing new ones to achieve improved temporal and spatial resolution. The suggested approach advocates for a hybrid monitoring network that combines regulatory monitors with calibrated sensors, enhancing the accuracy and comprehensiveness of air quality data.

The need for a regional approach has been acknowledged by the NCAP for the IGP and by the passing of the CAQM Act. We hope this Paper will serve as food for thought for policymakers, researchers, and regulatory agencies, urging them to consider regulatory reforms that take an airshed or regional approach across the country. By adopting a regional perspective and introducing regulatory reforms such as the proposed airshed-level institution and nested hybrid monitoring networks, India is much better positioned to address the complex challenges posed by air pollution and work towards safeguarding public health and the environment.

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CENTRE FOR POLICY RESEARCH
DHARAM MARG, CHANAKYAPURI, NEW DELHI-110021, INDIA

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