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Evolution of air pollution management policies and related research in India

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ABSTRACT

Air pollution has been a matter of grave concern since time immemorial but was brought to the attention of stakeholders only in the last few decades. The adverse repercussions of air pollution are still being observed, which have indicated uncertainties and gaps in existing management policies and control strategies. Hence, to reduce the detrimental consequences of air pollution, a more stringent and impeccable set of decisions that could govern the issue coupled with technological advancements is the need of the hour. The prerequisite for effective and efficient air quality management is to understand research gaps so far. The article attempts to provide information about the evolution of air quality management policies in India by collating data from the past studies compiled in a virtual repository called **Ind**ian **A**ir Quality Studies **I**nteractive **R**epository (IndAIR). The study also highlights the research gaps in the past studies and spatial distribution over the country map using the Geographical Information Systems (GIS). The gap analysis indicates that air pollution has been well studied in Indo-Gangetic Plains (IGPs), and metro cities. In contrast, Eastern, Southern, and the Central States are the least researched regions of the country. Further, the spatial distribution of $PM_{2.5}$ and NO_x concentrations are analyzed and found that highly polluted cities are studied more and vice versa. One of the least studied areas of various air quality domains is the socioeconomic effects of air pollution. Therefore, these regions and domains should be explored more closely to understand location-specific problems to tackle air pollution. The present review revealed several gaps, classified into three categories: research, policies, and economics.

1. Introduction

Air pollution is almost a century-old challenge in India. However, the last few decades have been severe, the primary cause of which can be attributed to rapid population growth, unplanned urbanization, and industrialization (Kapoor, 2017; Udara, 2016). India is the second-most populous country in the world, which accounts for 17.7% of the global population (Census, 2011). Many Indian cities are ranked as the top polluted cities globally (IQAir, 2020). As per the World Health Organization (WHO) database from 2008 to 2013, India was among the most polluted countries (WHO, 2014). In 2019, air pollution surpassed the effects of other commonly known chronic diseases, such as obesity (high BMI), high cholesterol, and malnutrition, to become the fourth leading cause of death worldwide (IHME, 2020). According to the global burden of disease study, 2019 estimates, ambient air pollution accounts for 17.8% of the country's total deaths (Lancet, 2020), however, these data are yet to be verified from hospital records. The majority of these deaths were exacerbated by ambient particulate matter (PM) and household air pollution. The study also reported that India's goal of becoming a $5 trillion economy by 2024 might be hampered by the high burden of death and disease caused by air pollution (Abbafati et al., 2019). Outdoor air pollution has been classified as a group I carcinogen by the International Agency for Research on Cancer (IARC) (IARC, 2015). The assessment of air quality and its management depends on the legislative framework, adequate monitoring network, and emission source identification and its load estimation.

India has witnessed the most intense and extensive events during the past two decades, making air pollution an utmost concern for the regulatory bodies. The IGPs is subjected to severe pollution episodes, mainly during the post-monsoon season. For a week during early November 2017, Delhi $PM_{2.5}$ particle levels surpassed WHO norms by 25 times (11 times by Indian standards), resulting in an environmental health emergency (Vito et al., 2018; Beig et al., 2019, 2020). Additionally, in 2021, the World Health Organization (WHO) modified its previous air quality guidelines of 2005 and set revised annual and 24-hour standards for six classic pollutants (WHO, 2021) with an intermediate target. For example, the annual average standard of PM_{10} and $PM_{2.5}$ has

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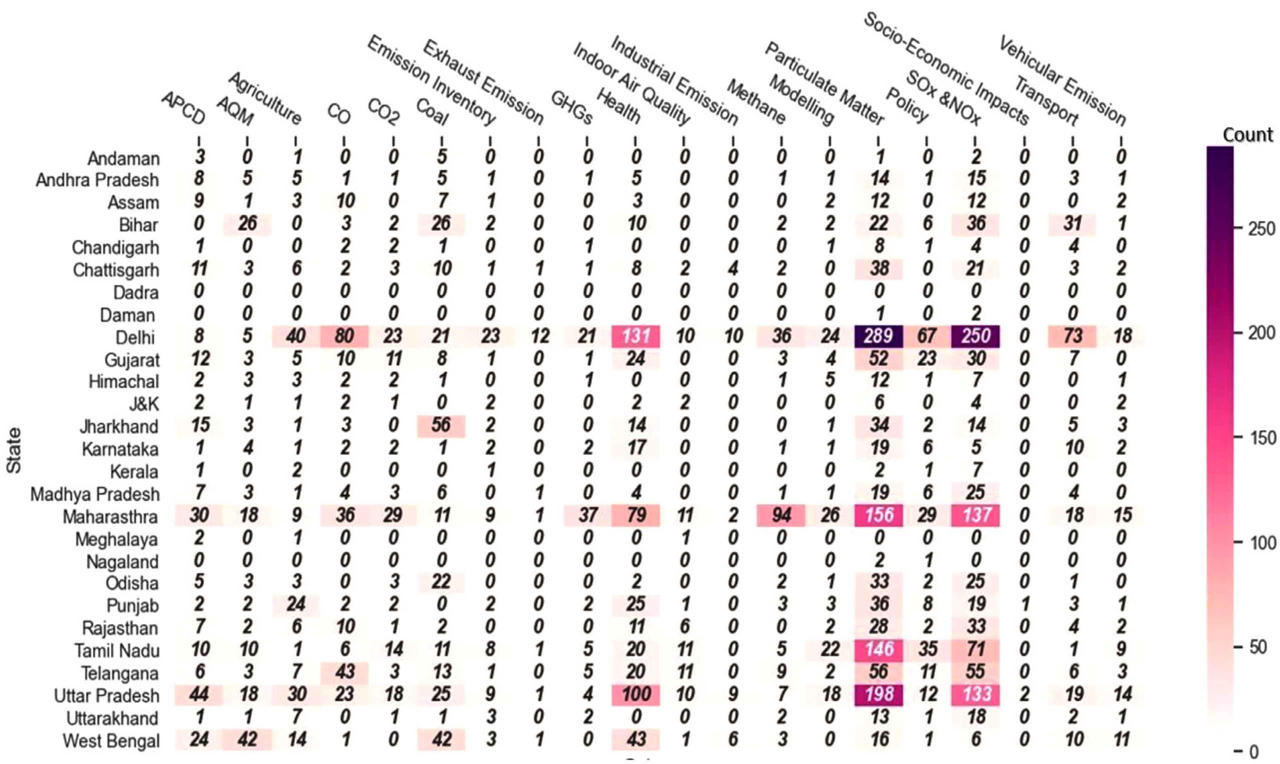

Fig. 1. Air quality domains specific studies and respective geographical distribution based on the IndAIR database.

been revised from 20 μg/m^3 to 15 μg/m^3 and 10 μg/m^3 to 5 μg/m^3 respectively. Although with the advent of novel technologies and various government initiatives, there have been improvements in air quality (Gulia et al., 2018; Khilnani and Tiwari, 2018; Gurjar et al., 2018). According to the Central Pollution Control Board (CPCB), SO_2 concentrations have decreased over time, whereas PM_{10} concentrations have shown a fluctuating trend and $PM_{2.5}$ concentrations have shown a stable trend (CPCB, 2020).

The present article summarizes the research on air pollution and related aspects in India since the pre-internet era. The paper discusses the evolution of research on air quality in India along with legislation. The studies on different critical components of air pollution are spatially plotted on the Indian map and summarized to understand the geographical gap and spotlight potential areas for future action. The present work is based on a project which focuses on the compilation of studies on air pollution in India conducted by Indian researchers. The studies are compiled on a virtual platform (https://indair-neeri.res.in/) called **Ind**ian **A**ir Quality Studies **I**nteractive **R**epository (IndAIR).

IndAIR is an unprecedented air pollution research repository. It provides access to research and studies in air quality management since pre-Internet times. At the time of analysis (February 2020), the repository was composed of approximately 1670 research papers, 30 reports and case studies, 66 court trials, and over 7 statutes, compiled with data from 1950 to February 2020. Fig. 1 depicts various air quality domains studies concerning the study location based on the IndAIR database. It is inferred that the National Capital Territory, Delhi, Maharashtra and Uttar Pradesh with 1144, 747 and 694 number of studies, respectively, are more researched regions in the country. However, most of the studies are limited to major cities only, which usually own a high density of pollution sources. The least number of studies were conducted in Dadra (0), Daman (3), and Nagaland (3). Since PM emission causes most ambient air pollution in India, there are approximately 1213 studies on PM, which is the most significant number of studies among other air pollution research areas. Delhi, Telangana, and Maharashtra were identified as having the highest number of studies on the air quality health impact. It is observed that socioeconomic impact of air pollution is least studied domain in the country (Maharajan et al., 2010). Indoor air quality is also least studied in India, which is a critical component for society's well-being as people are exposed to ~90% of the time in the indoor environment.

It can be observed that majorly studies are being carried out either in prominent metropolises or in the cities, which become known due to episodic air pollution events. To narrow down the assessment, a finer analysis of the states of Maharashtra, Uttar Pradesh, and Tamil Nadu are being presented. Maharashtra is the second-most populous state in the country wherein out of 36 districts in the state, there were only 18 districts included in the analysis. In all the domains, Mumbai and Pune in Maharashtra and Agra and Kanpur in Uttar Pradesh were the most studied cities. In the case of health impact, there were 31 and 12 studies conducted over Mumbai and Pune respectively.

Uttar Pradesh, on the other hand is a state of IGPs comprising maximum districts amongst any other state of the country. In the case of Uttar Pradesh also, only 15 out of 75 districts of the state were included in the analysis wherein Agra, Kanpur and Lucknow were the only cities which were extensively studied. For instance, Agra is thoroughly studied in all the domains due to impact of air polluting activities on the Taj Trapezium Zone (TTZ) airshed which included 63 studies on PM and 57 studies on pollutants other than PM.

With respect to air pollution events, the southern India's coastal states are in much better condition when compared with other regions. For example, there were a total 386 studies on analyzed domains of air quality in Tamil Nadu wherein in accordance with the IndAIR database, there were 8 emission inventories in Chennai and only a one in Coimbatore. While in case of air pollution health impact Tuticorin and Trichy has 3 studies each.

2. Evolution of air quality management in india

This section examines various legislation and conventional air quality management components, which serve as a foundation for national enforcement of air quality mitigation efforts and the reinforcement of air pollution management plans.

2.1. Air pollution legislation and regulation

To combat air pollution, various legislations have been introduced in India since pre-independence. The first law aimed at reducing air pollution in India was introduced in Bengal. It later was introduced in Bombay (currently Mumbai). The Bengal Smoke Nuisance Act, 1905 seeks to eliminate nuisances caused by smoke from furnaces or fireplaces in towns and suburbs of Kolkata and Howrah. Likewise, Bombay Smoke Nuisance Act, 1912 was curated to tackle similar concerns in state of Maharashtra (Santhi and Radha, 2019). Subsequently, the Motor Vehicles Act was enacted in 1939, including provisions for regulating vehicular pollution (Bhave and Kulkarni, 2015). The latest amended Motor Vehicles (Amendment) Bill, 2019, empowers the government to recall vehicles if a defect has been found to cause damage to the environment or other road users. The manufacturer of the recalled vehicle will be required to either (i) refund the customer for the total cost of the vehicle or (ii) replace the defective vehicle with one that meets the same or better requirements (CPCB, 2017; Sankar, 1998; Ministry of Law and Justice, 2019). Subsequently, the Factory Act, 1947 was enacted, which encompassed all of these industrial problems. It was a national act that included the management of activities involving dust and fumes from industrial complexes (Bhave and Kulkarni, 2015). Later in 1963, Gujarat Smoke Nuisance Act was introduced in Gujarat (Aggarwal and Karia, 1988).

After the United Nations Conference on the Human Environment in Stockholm in June 1972, India witnessed a pivotal moment addressing environmental problems. To monitor and prevent water pollution, the CPCB was established in 1974 under Section 3 of the Water (Prevention and Control of Pollution) Act of 1974. However, later control and prevention of air pollution were added to the Board's power. As a result, the Air (Prevention and Control of Air Pollution) Act (Air Act, 1981) was passed in 1981 to regulate and reduce air pollution. Further, the Air Act, 1981 was amended in 1987, giving the central and state pollution control boards the authority to deal with severe air pollution emergencies (GOI, 1981; Bhave and Kulkarni, 2015).

In 1986, The Environment (Protection) Act (EPA) was enacted as an umbrella act for environmental protection and prevention. Many other rules and laws were included in this act. EPA, 1986 enhances and improves the regulation and implementation of national prevention, control and abatement program. The Central Government can make rules in these areas by publishing them in the Official Gazette.

The United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992 was another international call to protect the environment. The conference urged governments to enact national legislation regarding pollution accountability and compensation for victims of environmental damage. This resulted in the creation of the National Environment Tribunal (through the National Environment Tribunal Act (NETA), 1995) with the task of establishing strict liability for damage caused by accidents involving hazardous substance handling. In 1997, the National Environment Appellate Authority (NEAA) Act was legislated to create a NEAA to deal with complaints involving environmental clearances within restricted areas. Later, under Article 21 of the Indian Constitution, the National Green Tribunal (NGT) Act, 2010, clarifies the right to live in a clean and safe environment, effectively repealing the above two acts. The NGT Act established the Tribunal to expedite the resolution of environmental petitions (National Green Tribunal Act, 2010; Khandare, 2016).

Under the different provisions of these legislations, various rules and notifications were also passed for effective management of air quality and sustainable growth of the economy, such as Environmental Impact Assessment Notification of 1994, Environment Pollution (Prevention & Control) Authority, 1998, Graded Response Action Plan, 2017 and National Clean Air Programme 2019, etc. In Delhi, EPCA is now replaced by the Commission for Air Quality Management (CAQM) in the National Capital Region and Adjoining Areas vide Parliamentarian Ordinance 2020, which received the presidential assent in August 2021. **Fig. 2** depicts a history of legislation and regulation in India starting from 1905 to 2020.

2.2. Evolution of national ambient air quality standards (NAAQS)

The setting up of air quality standards is a crucial step of any Air Quality Management Practices/Action Plan (AQMP) towards reduction of health impact and making compliance monitoring an essential component. In 1982, CPCB, under the Air Act, 1981, introduced the first Ambient Air Quality Standards. The CPCB amended the air quality standards in 1994. Initially, NAAQS was devised for only three pollutants, SO_2, NO_2, and SPM. Later in 1994, four new pollutants were added to the list, i.e., RSPM, Pb, NH_3, and CO (CPCB, 2000) which was amended in year 2009 as depicted in **Fig. 3** (CPCB, 2009).

In addition to NAAQS, the National Air Quality Index (NAQI) concept was introduced, aiming at intensive public outreach for air quality management at a decentralized scale. The AQI is calculated based on the concentration of eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb). In case of unavailability of data, it can be calculated with at least three pollutants, out of which one of them must be $PM_{2.5}$ or PM_{10}. The six AQI categories are Good, Satisfactory, Moderate, Poor, Very Poor, and Severe (CPCB, 2014).

2.3. Air pollution monitoring network

Monitoring air quality is a mainstay component of air quality management as it allows informed decision-making. The first way to measure the smoke was the Ringelmann scale, which is a scale for measuring the apparent density or opacity of smoke. On February 20, 1979, the Indian Standard code for the use of Ringelmann and a miniature smoke chart was issued (Kisan et al., 1979). However, the Air Act, 1981 was the legislation that mandated air quality monitoring and opened the gateway to the monitoring methodologies that are used in India under the supervision of the CPCB.

2.3.1. National ambient air quality monitoring (NAAQM) network

In 1978, for the first time in the country, CSIR-NEERI (Institute of which some authors belong) began monitoring air quality in ten cities (Ahmedabad, Mumbai, Kolkata, Kochi (Cochin), Delhi, Hyderabad, Jaipur, Kanpur, Chennai, and Nagpur). As per the study, the annual average value of SO_2, NO_2, and Suspended Particulate Matter (SPM) in Delhi was found in the range of 7–61 $\mu g/m^3$, 23–37 $\mu g/m^3$, and 296–481 $\mu g/m^3$ respectively. Subsequently, the concentrations were found to be 34–86 $\mu g/m^3$, 36–51 $\mu g/m^3$ and 294–488 $\mu g/m^3$ in 1985. It is observed that annual average SPM were more or less similar in 1978–79 and 1985. However, SO_2 and NO_2 increased significantly, indicating the contribution of industrial and vehicular activities in the city which started in the 1980s (NEERI, 1980; 1988). Later, in 1984–1985, CPCB started the National Ambient Air Quality Monitoring (NAAQM) Network at the national level to assess air quality as per NAAQS, 1982. Initially, seven air quality stations were deployed at Agra and Anpara in 1984. The NAAQM program was later renamed as National Air Quality Monitoring Programme (NAMP). As part of that, the CPCB developed an online system or portal known as the Environment Air Quality Data Entry System (EAQDES), which allows State Pollution Control Boards (SPCBs)/ Pollution Control Committees (PCCs) to upload manually generated data (https://namp.cpcbccr.com/#/login). The data is then scrutinized for outliers and gaps.

At the time of analysis, ambient air quality in India is monitored through a network of 1082 manual and continuous ambient air quality monitoring stations (CPCB, 2020; https://cpcb.nic.in/). In 2019, there were 804 manual stations serving 344 cities, towns, and villages across 28 states and six Union Territories. The manual air quality monitoring

Fig. 2. Legislative History of India for Air Quality Management.

network under NAMP has increased substantial in last 36 years i.e., from 7 in 1984 to 804 in year 2020 (CPCB, 2003, 2020). Fig. 4 depicts the growth of NAMP stations in the country at interval for five years which indicates substantial growth from 1984 to 1992 (new 176 stations) and then 2007 to 2012 (new 231 stations).

2.3.2. Continuous ambient air quality monitoring system (CAAQMS)

The deployment of real-time monitoring stations explored a paradigm shift in technology. Three real-time monitoring stations were first implemented in India in 2006, with Delhi as the pilot city, and later expanded to many other cities after 2016 (Roychowdhury and Somvanshi, 2020). Since then, the country's CAAQM stations has increased to 278 stations covering 147 cities (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing).

Fig. 5 shows the country's current spatial coverage of continuous ambient air quality monitoring stations.

In addition to manual and real-time monitoring, India established the System of Air Quality and Weather Forecasting and Research (SAFAR) network for air quality forecasting. The Indian Institute of Tropical Meteorology (IITM, Pune) first did it for Delhi in 2010, which provides early warning of air quality and acts as a revolutionary technology , which is now expanded to three more cities, namely Pune, Mumbai and Ahmedabad (http://safar.tropmet.res.in/). The fore-mentioned, forecast model was also being utilized in various studies (Shukla et al., 2018; Beig et al., 2019, 2020; Ghude et al., 2020) for guiding policy-makers on contribution of different air polluting activities including dust and biomass burning.

Manual and real-time monitoring stations cover the majority of the air quality monitoring spectrum around the country. However, the re-

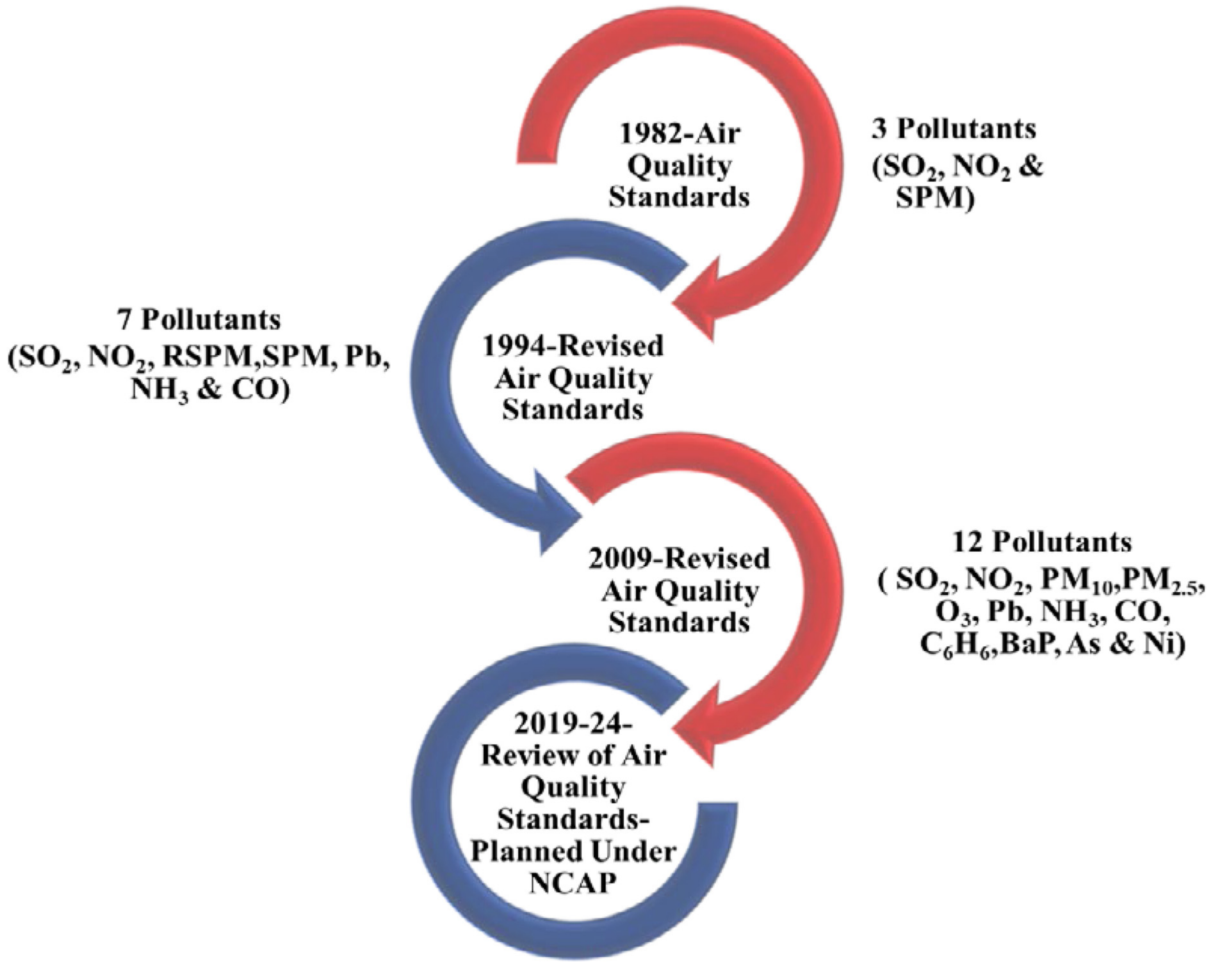

Fig. 3. Evolution of National Ambient Air Quality Standards in India.

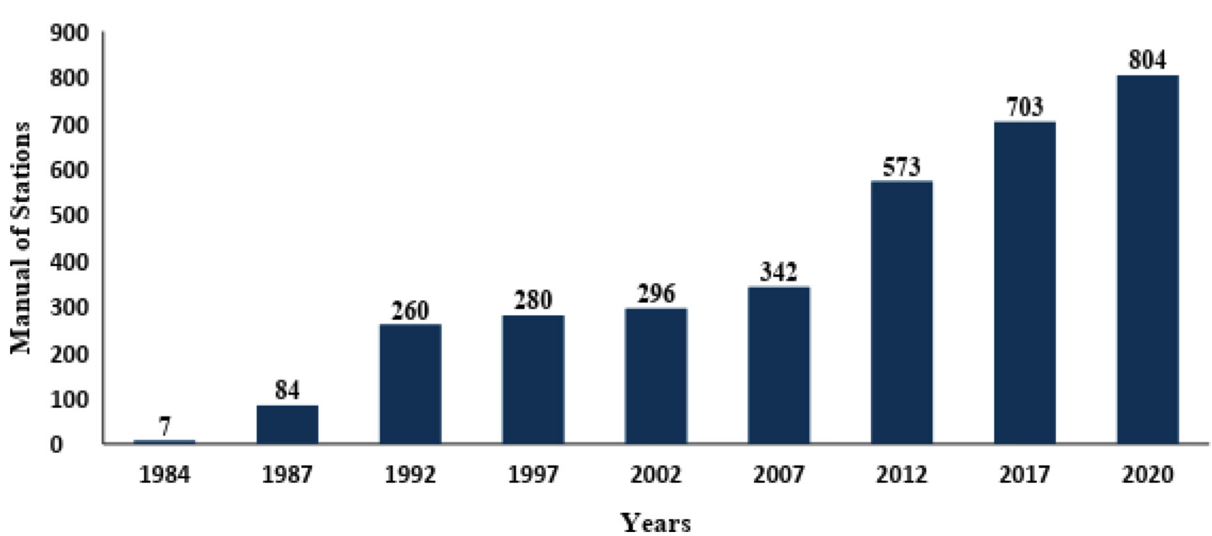

Fig. 4. Expansion of NAMP stations in India (Manual Monitoring System).

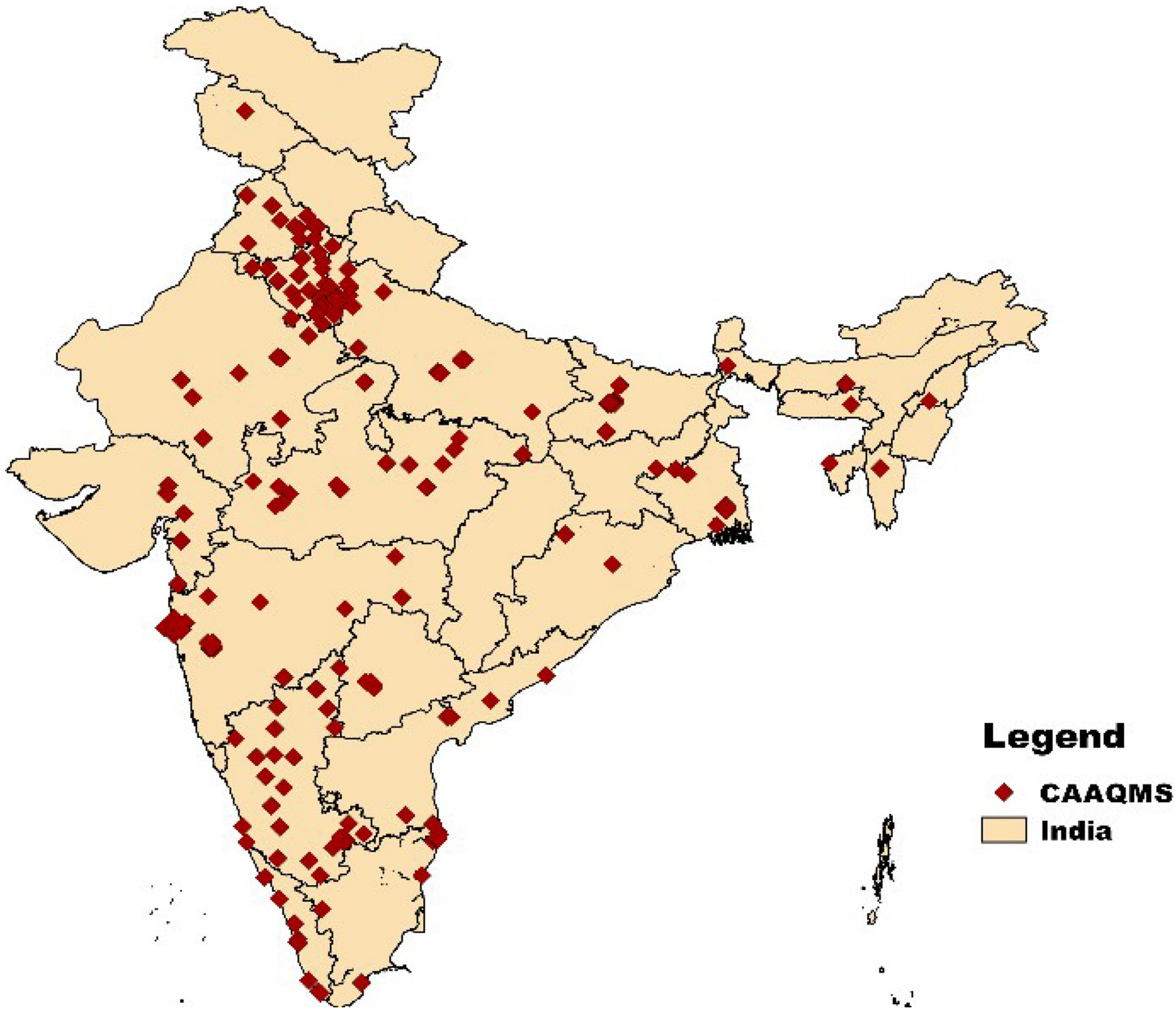

Fig. 5. Network of CAAQMS Stations in India.

search community has now started to explore the use of low-cost sensors for measuring air quality at a finer spatiotemporal scale (Kumar and Gurjar, 2019).

2.4. Evolution of studies on emission load: emission inventory estimation

An emission inventory is a schematic collation of air pollution sources and respective pollutant-specific emission loads over a geographical boundary during specific time intervals. Emissions inventory data assists in developing an air pollution control policy and minimizing emissions to meet clean air targets. An agency can follow two main approaches in estimating emissions: the “top-down” and the “bottom-up” approaches (Mohan et al., 2012). The bottom-up method estimates emissions based on statistical assessments of activity data and country-specific emission factors. In contrast, the top-down approach estimates emissions based on specific expert observations/assumptions on large scale.

CSIR-NEERI began emission inventory data generation by creating source inventory for Mumbai (Bombay) in 1968 (Kumar, 2009). Following this, CPCB initiated the generation of emission inventory data in 1979–1981 and computed the sulfur-dioxide (SO_2) emission load in Agra, Mathura, and Firozabad, which was then used for modeling, culminating in the historic "Taj Trapezium Eco-Sensitive Zone" (CPCB, 1981). Later, between 1980 and 2000, individual plant-level emission data of more than 76 industrial types were documented by CPCB titled "Comprehensive Industries Documents Series or COINDS". The documents were used to develop the industry’s ‘Minimum National Standards’ (CPCB, 1983; Shripad Dharmadhikary, 2017).

Further, Gurjar et al., 2004, have developed a comprehensive emission inventory for Delhi megacity for the period of 1990–2000. Realizing the importance of knowledge of city-specific emission load, CPCB collaborated with prominent institutions to develop a multi-pollutants emission inventory for six cities: Delhi, Mumbai, Kanpur, Chennai, Pune and Bengaluru (CPCB, 2010). Although the development of emission inventory is a critical component of air quality management, at the same time, it comes out as a challenging task as it requires exhaustive survey to collect source specific area wise activity data and a proper management system for handling these data. Therefore, the concept of Geographic Information System (GIS) was explored in developing emission inventory, which could also help policymakers implement the legislation (Behera and Sharma, 2011). A trend of exploiting the secondary database to develop emission inventory came into the picture when the Air Pollution knowledge Assessments (APnA) city program established baseline multi-pollutant high-resolution emissions inventory collating data from multiple resources (http://urbanemissions.info/). APnA city program developed city specific emission inventories by collating infor-

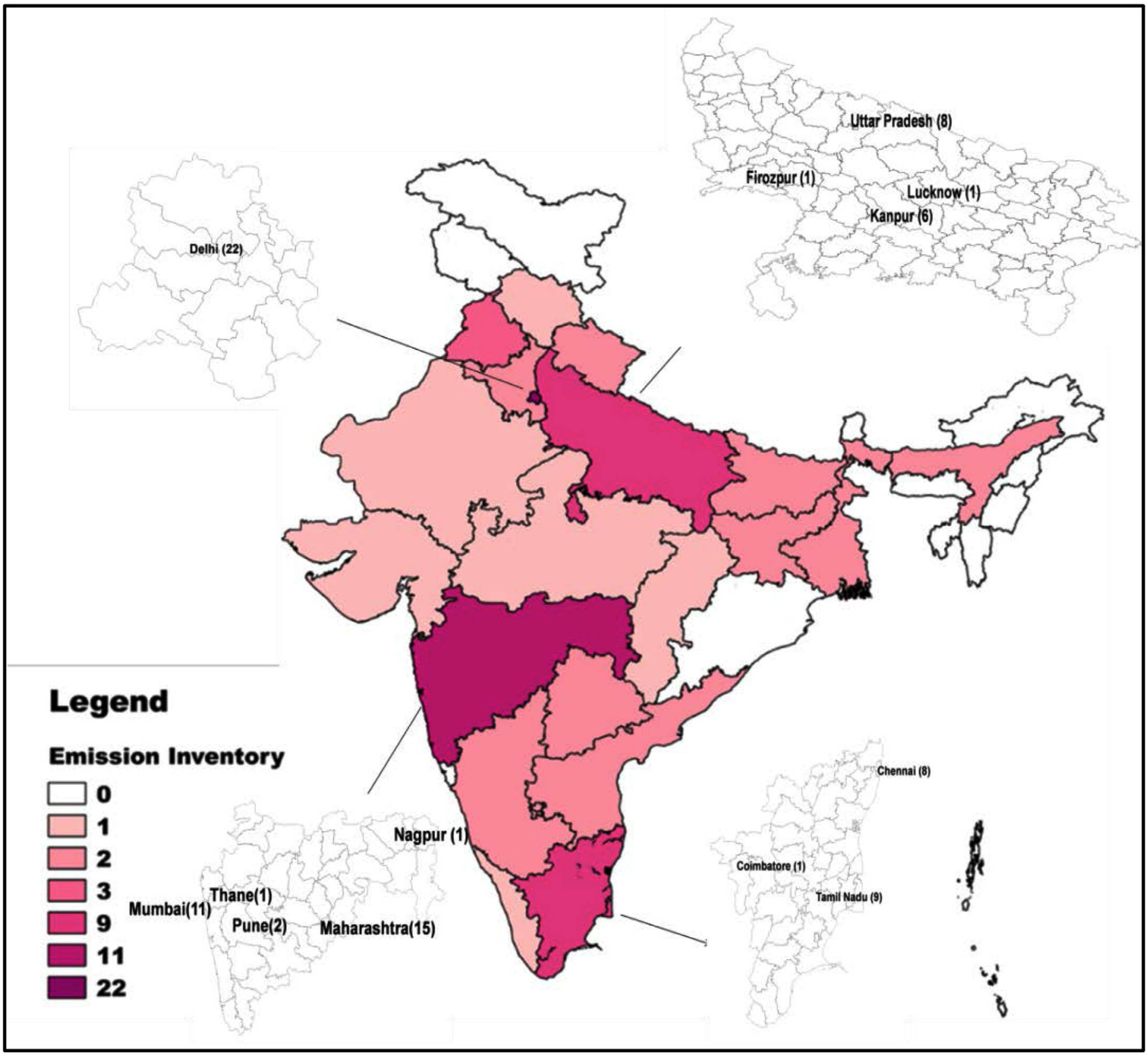

Fig. 6. Spatial Distribution of Emission Inventory (Most of the studies are limited to major cities in each state which are highly populated or high industrial activities).

mation from various past studies and publications. Fig. 6 shows the spatial distribution of the number of studies on emission inventory carried out in India. The emission inventories were highest in number for Delhi, followed by Maharashtra and Uttar Pradesh. At the same time, many states/union territories have no such studies. Recently, TERI has been working on creating national and urban pollution inventories for various air pollutants using secondary data. The latest inventory database for the national scale spatially resolved emission inventory, which covers multiple sources and pollutants such as PM, NOx, SO_2, CO, and NMVOCs at a resolution of 36 × 36 sq. km unit grid size (TERI, 2021).

Management strategies and control polices

The air pollution management system has witnessed various technological advancements, including time-based assessment, which has narrowed down control bodies' working and implementation methods to possess a more focused approach to limit the increasing levels of air pollution. India owes its air pollution management plans and systems primarily to judicial interventions. The Judiciary has been setting many guidelines and various orders, leading to better governance and legislation over the pertaining issues. Thus, the judiciary can be said to have played a significant role in the improvement of air quality (Bhave and Kulkarni, 2015; Roychowdhury and Somvanshi, 2020).

Judicial guidance has led to the framing of several policies and interventions which aims for the abatement of the level of air pollution, which include:

1 Interventions under petitions filed in Hon'ble Supreme Court of India by M.C. Mehta.
   a Control Actions of industrial emission and other air pollution activities in the Taj Trapezium Zone (TTZ)
   b Extensive management action and policies were framed to combat Delhi NCR air pollution.
2 NGT monitors implementation of air quality management plans for notified non-attainment cities, i.e., cities that violated the annual average NAAQS for PM10. Implementation of these action plans is under the ambit of the National Clean Air Programme (NCAP). It includes multi-sector interventions to control the national air quality intensively.

With judicial interventions, various executive involvements have also played a crucial role in limiting air pollution sources which include:

i **Auto Fuel Policy:** Automobile emissions are the major contributor to air pollution in India and call for an immediate corrective action. Since 2000, India has started adopting European emission and fuel regulations for four-wheeled light-duty and heavy-duty vehicles. In 2003, Government of India announced the National Auto Fuel Policy, which identified steps to address different areas where intervention was needed, such as vehicular emission norms, CNG/LPG fuel quality and standards, measures to mitigate emissions from in-use vehicles, automotive technology, air quality data, and R&D. This 2003 document was updated with more stringent fuel and emissions standards in May 2014 when the Auto Fuel Vision and Policy 2025 was issued (GOI, 2014).

ii **Alternative Fuel Infrastructure:** The government is emphasizing the importance of a detailed and inclusive policy on alternative fuels, focusing on options such as CNG, LPG/LNG, bio-diesel, and biofuels, as well as a consistent road map for increasing alternative fuel production while decreasing dependence on fossil fuels (SIAM 2019). Renewable fuels, such as biodiesel blends, compressed natural gas (CNG), liquid petroleum gas (LPG), and liquefied natural gas (LNG), can help minimize emissions. In a similar effort to provide cleaner fuel that maintains air quality and public health, in 2016, the Ministry of Petroleum and Natural Gas (MoPNG) launched the Pradhan Mantri Ujwala Yojana (PMUY), which is a liquefied petroleum gas (LPG) subsidy scheme for poverty-stricken households. Under the PMUY, such households receive a free LPG connection. In its NCAP, the Government of India has acknowledged the PMUY and National Policy on Biofuels 2018 of 20% blending of ethanol in petrol and 5% of blending biodiesel in diesel by 2030 (NCAP, 2019).

iii **Thermal Power Plant Emissions Management Actions:** India has one of the world's largest electricity markets, equivalent to many developed nations (IEA, 2020). Coal-based power generation accounts for one of the dominant sources of air pollution in India. MoEF&CC notified 'Environment (Protection) Amendment Rules, 2015′ for Thermal Power Plants (TPPs) on 07.12.2015 regarding standards for particulate matter (PM), SO_2, NOx and mercury emissions. The new deadline set for all the power stations in the country to comply with the directions under EPA rule 2015 is December 2022. Flue Gas Desulphurisation (FGD) for SO_2 reduction and Selective Catalytic Reduction (SCR)/ Selective Non-Catalytic Reduction (SNCR) for NOx reduction needs to be implemented by the thermal power plants. Measures such as combustion modification and retrofit of Electro-Static Precipitator (ESP) must be taken wherever necessary to control the emission within specified limits by MoEFCC (Raghav, 2020). The government of India has also announced the National Solar Mission to generate 100 GW solar power by 2022 to cope with the rising energy demand (Hairat and Ghosh, 2017).

iv **Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME):** Another executive action taken up by the government of India is to offer subsidies on the purchase of Electric Vehicles (EVs) (Shao et al., 2019).

3. Gap identification and assessment

Based on the available compiled studies in the repository, an attempt has been to distribute the studies based on location/region and identify areas that are less studied and need more attention.

Air quality monitoring

Almost 200 monitoring and assessment-related research studies spanning 1983 to 2019 were compiled in the IndAIR repository. These studies include assessment of the level of pollutants using manual and real-time data. Particulate matter has been identified as a significant pollutant in India as a result of the strengthening of the monitoring network and associated research studies. Consequently, many studies were performed on monitoring and analyzing PM wherein Delhi, Uttar Pradesh, and Maharashtra have the highest number of such studies. However, it has been observed that very few studies are carried out in central India. Most studies are based on North India due to seasonal smog and high air pollution concentrations in the IGPs. Majorly, studies regarding air quality monitoring are well researched in West Bengal, the Northern States and Maharashtra. However, northeastern, central and southern states remain understudied.

Emission inventory

Emissions Factors (EFs) are the fundamental tool in developing national, regional, state, and local emissions inventories for air quality management decisions and developing control strategies. The earliest study on emission factors was conducted in 1985 about particulate emission from thermal power plant. Estimation of sectoral emission load is undoubtedly a concern for urban air quality management. In the case of emission factors, more than half of the studies in the industry category are about estimating emission factors for coal in thermal power plants. The studies in the transport sector category are primarily about emission factor production of various vehicle types, with a few city-based studies related to EFs development for difficult vehicle categories – 2/3 wheelers, passenger cars, buses, and heavy-duty vehicles. Most studies on emission inventory development are in Delhi, Maharashtra, and Uttar Pradesh (CPCB, 2010; Sharma and Saraf, 2018; Sharma and Dixit, 2015). Developing emission inventories only at metro scales would not bring the intended results as emissions have no boundaries. Henceforth, it is imperative to employ a transformative approach that quantifies cross-border pollutant specific loads in urban or rural areas.

Transport sector

Most transport-related air pollution studies are based on emission load estimation on vehicle types, fuel types, and the development of emission factors. Out of total 253 million registered motor vehicles (mechanically propelled vehicles) as of 31st March 2017, the State of Maharashtra accounted for 11.9 percent, followed by Uttar Pradesh (10.4%), Tamil Nadu (10.3%), Gujarat (8.7%), and Karnataka (7.1%) (GOI, 2017). However, still, these states do not have studies related to health impacts or policies regarding vehicular emissions. Moreover, emission inventory and source apportionment studies specific to transport are found only in metro cities like Delhi, Mumbai, Kolkata and very limited in other upcoming tiers II & tier III cities. Following several countries, India is gradually shifting towards E-vehicles. However, only three studies on E-Vehicles have been conducted in India (Dhar et al., 2017; Amjad et al., 2016; GGGI and CSTEP, 2015). These studies are based on control measures like implementing and evaluating change-over speed in plug-in hybrid electric two-wheeler and Electric Buses in India: Technology, Policy, and Benefits.

Air pollution policies and health effects

Air quality policy studies mainly include co-benefit analysis, performance assessment, and socioeconomic policy changes such as integrating alternative clean fuels and technologies in transport and industrial sectors above sections. The government has implemented various initiatives and policies with immediate effect in Delhi NCR. As a result, the region has been observed with the most studies on policy framework assessment among other Indian regions. There are 314 studies conducted in India between 1989 – 2020 on health in various parts of India. While significant research is happening in India concerning health impacts (Aggarwal and Jain, 2015; Ranjan et al., 2016; Dholakia et al., 2014) the availability of relevant data on the subject continues to be a challenge to the research community and policymakers.

In summary, the Eastern States and Northeastern states followed by Central Indian states of the country are not adequately studied for air

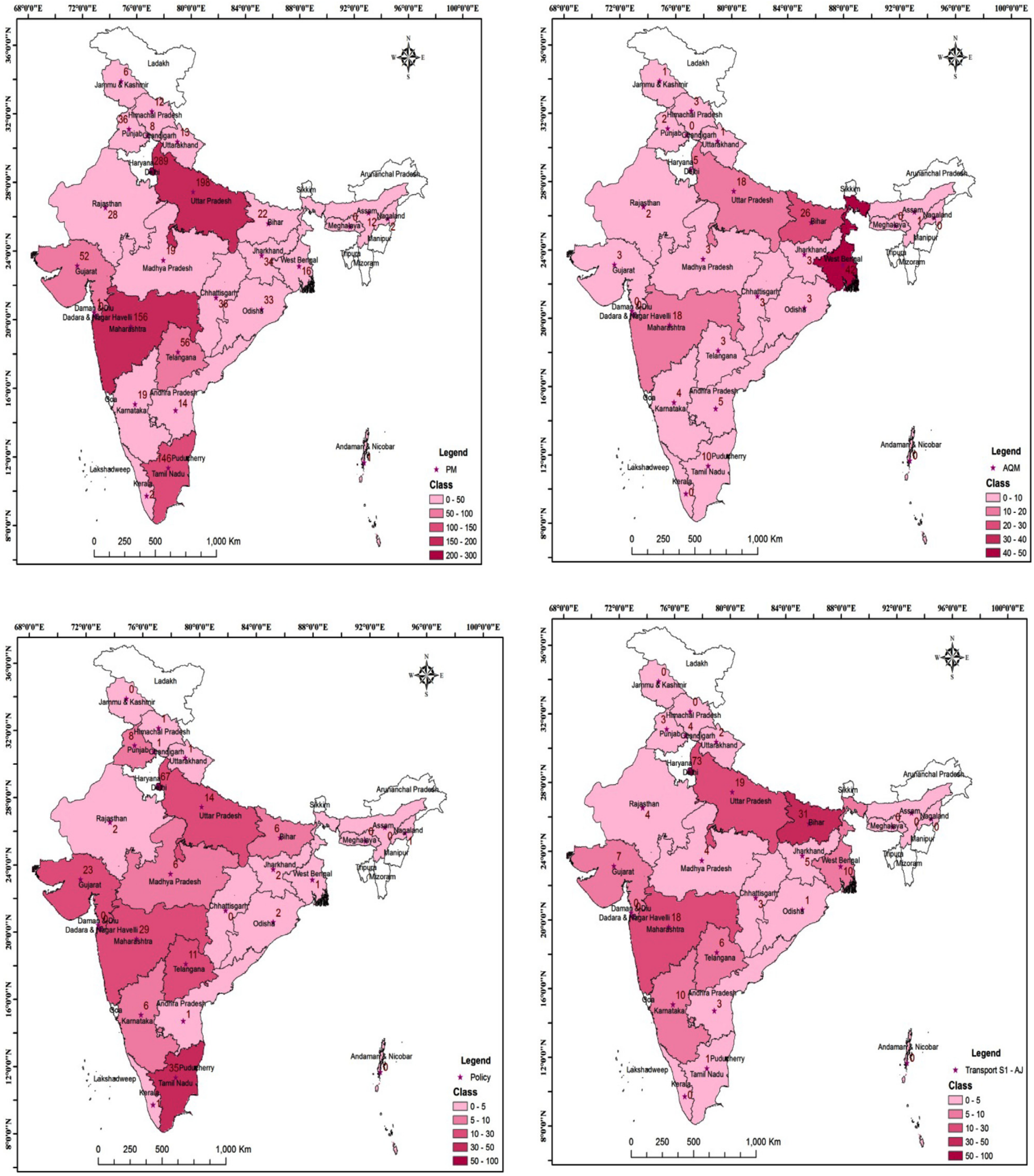

Fig. 7. Spatial Distribution of researches in India. (i) Particulate matter (ii) Air Quality Monitoring (iii) Policy (iv) Transport (Most of the studies are limited to major cities in each state which are highly populated or high industrial activities).

pollution and associated sectors. Fig. 7 shows the spatial distribution of research in India on selected key topics.

4. Recent trend in air quality status in indian city

Based on the literature available on IndAIR, it was observed that the maximum number of studies on air pollution and associated problems were conducted in North Indian cities/states along with metro cities of the country. Further, to verify the above observations, air pollutant concentration ($PM_{2.5}$ & NO_x) data was collected from Continuous Ambient Air Quality Monitoring Station (CAAQMS) located in the selected cities throughout the country and spatially distributed over the country map. The evolution of air quality monitoring networks including manual and real time, is discussed in the following section. $PM_{2.5}$ was monitored through Beta Attenuation Method (BAM)/ Tapered Element Oscillating Microbalance (TEOM). NO_x was monitored through Gas-phase Chemiluminescence (CPCB, 2011). The data of missing hours were excluded from the statistical analysis. $PM_{2.5}$ and NOx levels during the winter sea-

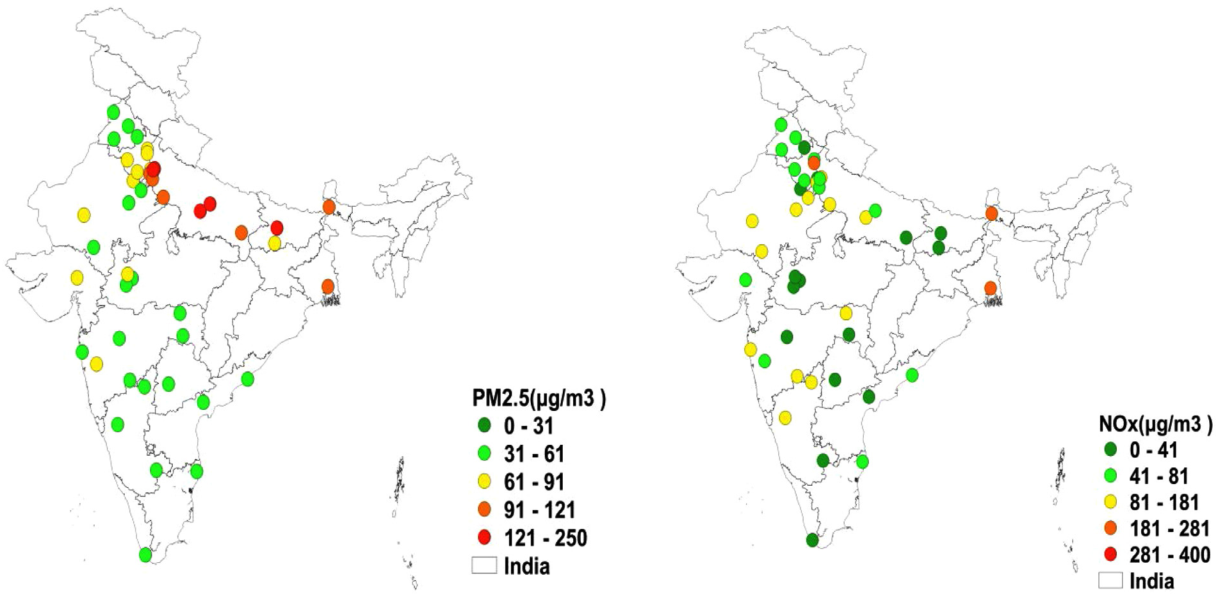

Fig. 8. Spatial Distribution of $PM_{2.5}$ and NO_x concentration in India during the winter season (Jan.-Feb., 2020).

son (January–February months) of 2020 were collected across 43 cities across the country, as shown in **Table S1** of supplementary information, indicating that $PM_{2.5}$ and NOx concentrations were higher in northern cities, while NOx levels were also found to be on the higher side in some metropolises like Mumbai and Kolkata as depicted in **Fig 8**. Therefore, these cities remained under the surveillance of research communities resulting in a higher number of studies as observed through the IndAIR database.

In year 2020, air quality in the country has witnessed a dramatic change in its trends during the COVID-19 pandemic restriction period, where every state has shown a decline in pollutants levels (Gulia et al., 2021). The government of India has put a restriction on activities from 25th March 2020 (except essential commodities and emergency services) due to which many air-polluting activities have been put to a halt, resulting in lower anthropogenic emissions and pollution levels (Dasgupta and Srikanth, 2020). In an ironic twist, the pandemic has provided an opportunity for city air quality managers and researchers to exploit the situation to assess the benefits of restricted activities (Shehzad et al., 2020). Numerous studies were conducted wherein ambient air quality data were analyzed through different tools real time monitoring at surface, satellite data and using modeling (Vadrevu et al., 2020; Sathe et al., 2021; Sharma et al., 2020).

Major metropolises, including Delhi, Mumbai, and Kolkata, experienced significant decline levels of air pollutants during lockdown period. Amongst these maximum reduction in $PM_{2.5}$ levels was reported in Kolkata, followed by Mumbai, Chennai, and New Delhi during the lockdown period (Ravindra et al., 2021). In terms of the criteria pollutants in megacities, Delhi and Mumbai, maximum reductions were reported in concentration of PM_{10} and NO_2, whereas a minimum reduction was reported in NH_3 during the lockdown period as compared to previous years (Shehzad et al., 2021).

Studies also reported that the ozone was observed to have a distinct increasing pattern in comparison with other pollutants during the lockdown period (Bera et al., 2021; Gautam et al., 2021). In terms of regional air quality, studies reported the highest reduction in PM for the northwest and IGPs and provide the scope to contain air pollution strategically at a regional scale (Singh et al., 2020; Gulia et al., 2021; Karuppasamy et al., 2020; Das et al., 2021)). Some of the studies correlated meteorological parameters and pollutant concentration with COVID positive instances, in addition to assessing changes in pollutant concentration (Sekhara et al., 2021).

5. Conclusion

Despite significant advancements in air pollution control technology and management techniques, the desired outcome remains a long way off. Hence, there is a need to strengthen available policies and technologies on the identified research gaps in India's air pollution related aspects. Further, the identified gaps can be divided into three areas research, policies and economic scale. First, a research constraint has been identified that necessitates a calibrated management system based on data generated by a broad countrywide network to take legislative steps to procure development and growth in the arena of air quality management while addressing prevalent lacunas. Second, this review also identifies a policy constraint in which a country's national air quality standards must be revisited in light of higher background concentrations of pollutants. Third, the vehicle sector contributes significantly to air pollution which needs to be manage through strategic phasing of reduction of tail pipe emission. The review highlights that the sector has all three identified gaps, indicating that more study is needed to establish region-specific vehicle emission factors and assess real-time vehicular emissions to reinforce control activities.

Analyzing gaps through air quality studies aims to suggest policymakers and regulators for adequately managing air quality by paying crucial attention to least studied regions and domains and offering a strategically planned pathway for air quality management, considering the future national scenario.

A country like India should adopt a holistic approach to manage the increasing air pollution. The management approach should be comprehensive, including all the critical components of AQMP (Gulia et al., 2018; Longhurst et al., 1996), and should not be limited to a research study that highlights the sources and their contribution. In addition, the air quality manager should closely work with the enforcement agency to properly implement the suggestive actions and measure the effectiveness of the implemented control actions after 1–2 years.

Disclaimer

The information about the number of studies, their distribution in different areas of the country and interpretation of data analysis is based on the literature review by authors as compiled in the repository, called IndAIR. The actual number of studies can be varied and accordingly the gap analysis findings. The literature in the repository are limited to indigenous studies carried out by Indian authors.

Author's contribution

Sunil Gulia: Methodology Design, Data Analysis, Review and Rewrite; Nidhi Shukla: Original writing; Lavanya Padhi: Review of literature, Data analysis and Review; Parthaa Bosu: Conceptualization and Review; S.K. Goyal: Critical Review and Corrections; Rakesh Kumar: Review and corrections.

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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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100431.

Reference

Abbafati, 2019. Five insights from the Global Burden of Disease Study, 2019. Lancet 396, 1135–1159. doi:10.1016/S0140-6736(20)31404-5.

Aggarwal, A.N., Karia, V.K., 1988. Pollution control - Regulation and legal provisions in India. Water Sci. Technol. 20, 57–62. doi:10.2166/wst.1988.0124.

Aggarwal, P., Jain, S., 2015. Impact of air pollutants from surface transport sources on human health: a modeling and epidemiological approach. Environ Int 83, 146–157. doi:10.1016/j.envint.2015.06.010.

Amjad, S., Rudramoorthy, R., Sadagopan, P., Neelakrishnan, S., 2016. Implementation and evaluation of change-over speed in plug-in hybrid electric two-wheeler. Energy 109, 858–865. doi:10.1016/j.energy.2016.05.025.

Beig, G., et al., 2019. Anatomy of the winter 2017 air quality emergency in Delhi. Sci. Total Environ. 681, 305–311. doi:10.1016/j.scitotenv.2019.04.347.

Beig, G., Sahu, et al., 2020. Objective evaluation of stubble emission of North India and quantifying its impact on air quality of Delhi. Sci. Total Environ. 709, 136126. doi:10.1016/j.scitotenv.2019.136126.

Bera, B., Bhattacharjee, S., Shit, P.K., et al., 2021. Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. Environ Dev Sustain 23, 6913–6940. doi:10.1007/s10668-020-00898-5.

Bhave, P., Kulkarni, N., 2015. Air Pollution and Control Legislation in India. J. Inst. Eng. Ser. A 96, 259–265. doi:10.1007/s40030-015-0125-z.

Census, 2011. India's population. https://censusindia.gov.in/. (Accessed on March 12 2021,).

CPCB, 1981. Inventory and Assessment of Pollution Emission in and Around Agra-Mathura Region; Series Control of Urban Pollution:CUPS/7 /1981 . 82. Central Pollution Control Board (Accessed on 31 March 2021).

CPCB, 1983. Emission Regulations; Series Comprehensive Industry Document (COINDS) COINDS/17/1983-84. Central Pollution Control Board http://cpcbenvis.nic.in/scanned%20reports/COINDS-17%20EMISSION%20REGULATIONS%20PART_1.pdf.

CPCB, 2003. Guidelines For Ambient Air Quality monitoring; series:NAAQMS/... /2003-04. Central Pollution Control Board https://tinyurl.com/y8r54a3z.

, 2009. In: National Air Quality Standards, 534. Gazette of India, pp. 6–9.

CPCB, 2010. Air Quality monitoring, Emission Inventory and Source Apportionment Study For Indian cities. Central Pollution Control Board (CPCB), 2010 http://www.indiaenvironmentportal.org.in/content/322584/air-quality-monitoring-emission-inventory-and-source-apportionment-study-for-indian-cities/.

CPCB, 2011. Guidelines For the Measurement of Ambient Air Pollutants VOLUME-ii. Central Pollution Control Board, Ministry of Environment, Forest and Climate Change Available at: http://cpcb.nic.in/NAAQSManualVolumeII.pdf .

CPCB, 2014. National Air Quality Index. Control of urban pollution series CUPS 82/2014–15. https://tinyurl.com/y78slqnq. (Accessed on 16 April 2021).

, 2017. Graded Response Action Plan for Delhi & NCR. Govt. of India, pp. 1–4.

CPCB, 2020. National Ambient Air Quality Status & Trends 2019 53, 1689–1699. Central Pollution Control Board https://cpcb.nic.in/upload/NAAQS_2019.pdf.

Das, M., Das, A., Sarkar, R., et al., 2021. Regional scenario of air pollution in lockdown due to COVID-19 pandemic: evidence from major urban agglomerations of India. Urban Climate 37, 100821. doi:10.1016/j.uclim.2021.100821.

Dasgupta, P., Srikanth, K., 2020. Reduced air pollution during COVID-19: learnings for sustainability from Indian. Cities. Global Transitions 2, 271–282. doi:10.1016/j.glt.2020.10.002.

Dhar, S., Pathak, M., Shukla, P.R., 2017. Electric vehicles and India's low carbon passenger transport: a long-term co-benefits assessment. J Clean Prod 146, 139–148. doi:10.1016/j.jclepro.2016.05.111.

Dharmadhikary, Shripad, 2017. Setting environmental standards. Environment 41, 93–100.

Dholakia, H.H., Bhadra, D., Garg, A., 2014. Short term association between ambient air pollution and mortality and modification by temperature in five Indian cities. Atmos Environ 99, 168–174. doi:10.1016/j.atmosenv.2014.09.071.

Gautam, A.S., Dilwaliya, N.K., Srivastava, A., et al., 2021. Temporary reduction in air pollution due to anthropogenic activity switch-off during COVID-19 lockdown in northern parts of India. Environment. Development and Sustainability 23, 8774–8797. doi:10.1007/s10668-020-00994-6.

Ghude, et al., 2020. Evaluation of $PM_{2.5}$ forecast using chemical data assimilation in the WRF-Chem model: a novel initiative under the Ministry of Earth Sciences Air Quality Early Warning System for Delhi, India. Curr. Sci. 118, 1803–1815. doi:10.18520/cs/v118/i11/1803-1815.

Global Green Growth Institute (GGGI) and Centre for Study of Science, Technology and Policy (CSTEP), 2015. Electric Buses in India: Technology, Policy and Benefits. Electric Buses India Technology Policy Benefits, GGGI, Seoul, Republic Korea https://gggi.org/site/assets/uploads/2016/10/2016-08-Electric-Buses-in-India-Technology-Policy-and-Benefits.pdf.

GOI, 1981. The Air (Prevention and Control of Pollution) Act, 1981, New Delhi, India. https://legislative.gov.in/sites/default/files/A1981-14.pdf. (Accessed on 10 March 2021).

GOI, 2014. Report of Expert Committee On Auto Fuel Vision and Policy 2025. Ministry of Petroleum and Natural Gas http://petroleum.nic.in/sites/default/files/autopol.pdf.

GOI, 2017. Road Transport Year Book 2016-17. Ministry of Road Transport and Highways https://morth.nic.in/sites/default/files/Road%20Transport%20Year%20Book%202016-17.pdf.

Gulia, S., Goyal, N., Mendiratta, S., et al., 2021. Covid 19 lockdown-air quality reflections in Indian cities. Aerosol Air Qual Res 21. doi:10.4209/aaqr.200308.

Gulia, S., Nagendra, S.M.S., Barnes, J., Khare, M., 2018. Urban local air quality management framework for non-attainment areas in Indian cities. Sci. Total Environ. 619–620, 1308–1318. doi:10.1016/j.scitotenv.2017.11.123.

Gurjar, et al., 2018. South Asian perspective: a case of urban air pollution and potential for climate co-benefits in India. Explore. Urban Chang. South Asia 77–98. doi:10.1007/978-981-10-5816-5_3.

Gurjar, B.R., Van Aardenne, J.A., Lelieveld, J., Mohan, M., 2004. Emission estimates and trends (1990-2000) for megacity Delhi and implications. Atmos. Environ. 38, 5663–5681. doi:10.1016/j.atmosenv.2004.05.057.

Hairat, M.K., Ghosh, S., 2017. 100 GW solar power in India by 2022 – A critical review. Renew. Sustain. Energy Rev. 73, 1041–1050. doi:10.1016/j.rser.2017.02.012.

IARC, 2015. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Outdoor Air Pollution. International Agency for Research on Cancer, monographs.

IEA, 2020. India 2020: Energy Policy Review. https://iea.blob.core.windows.net/assets/2571ae38-c895-430e-8b62-bc19019c6807/India_2020_Energy_Policy_Review.pdf.

IHME, 2020. State of Global Air 2020: A Special Report on Global Exposure to Air Pollution and Its Health Impacts. https://www.stateofglobalair.org/resources. (Accessed on 30 March 2021).

IQAir, 2020. World Air Quality Report. 2020 World Air Qual. Rep. 1–35. https://www.iqair.com/world-most-polluted-cities/world-air-quality-report-2019-en.pdf.

Kapoor, M., 2017. Managing Ambient Air Quality Using Ornamental Plants-An Alternative Approach. Universal Journal of Plant Science 5, 1–9. doi:10.13189/ujps.2017.050101.

Karuppasamy, M.B., Seshachalam, S., Natesan, U., et al., 2020. Air pollution improvement and mortality rate during COVID-19 pandemic in India: global intersectional study. Air Quality, Atmosphere & Health 13, 1375–1384. doi:10.1007/s11869-020-00892-w.

Khandare, J.P., 2016. Role of National Green Tribunal in Protection Environment. SSRN Electron. J. doi:10.2139/ssrn.2713728.

Khilnani, G.C., Tiwari, P., 2018. Air pollution in India and related adverse respiratory health effects: past, present, and future directions. Curr Opin Pulm Med 24, 108–116. doi:10.1097/MCP.0000000000000463.

Kumar, A., Gurjar, B.R., 2019. Low-Cost Sensors for Air Quality Monitoring in Developing Countries - A Critical View. Asian Journal of Water, Environment and Pollution. 16, 65–70. doi:10.3233/AJW190021.

Kumar, R., 2009. Emission Inventory and Source Apportionment in Indian Cities Understanding of Air Quality in India Major emphasis on emission loads. http://www.jari.or.jp/Portals/0/resource/pdf/india_2009/Session3-1_E.pdf. (Accessed on 20 March 2021).

Lancet., 2020. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. The Lancet Planetary Health 5, e25–e38. doi:10.1016/S2542-5196(20)30298-9, (Accessed on March 15 2021,).

Longhurst, J.W.S., Lindley, S.J., Watson, A.F.R., Conlan, D.E., 1996. The introduction of local air quality management in the United Kingdom: a review and theoretical framework. Atmos. Environ. 30 (23), 3975–3985. doi: 10.1016/1352-2310%2896%2900114-8.

Maharajan, K., Samual, K., 2010. Impact of environmental pollution on health: a sociological study in Tuticorin industrial town, TN, India. Journal of Ecobiotechnology 2 (2). 2010 Jun 28 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1061.1087&rep=rep1&type=pdf.

Mohan, Manju, Bhati, Shweta, P.G, P.M, 2012. Emission Inventory of Air Pollutants and Trend Analysis Based on Various Regulatory Measures Over Megacity Delhi. Intech 32, 137–144.

Motor Vehicles (Amendment) Act, 2019. Ministry of Law and Justice, 2019. https://egazette.nic.in/WriteReadData/2019/210413.pdf.

National Clean Air Programme (NCAP), 2019. Gov. India.Ministry of Environment, Forest and Climate Change (MoEFCC). https://moef.gov.in/wp-content/uploads/2019/05/NCAP_Report.pdf. (Accessed on 20 March 2021).

National Green Tribunal Act, 2010. Ministry of Law and Justice. https://greentribunal.gov.in/sites/default/files/act_rules/National_Green_Tribunal_Act_2010.pdf.

NEERI, 1980. Air Quality in Selected Cities in India 1978-79. National air Quality Monitoring Network. National Environmental Engineering Research Institute, Nagpur.

NEERI, 1988. Air Quality in Selected Cities in India 1982-85. National air Quality Monitoring Network. National Environmental Engineering Research Institute, Nagpur.

Raghav, P., Saxena, A.K., 2020. Emissions Control in Thermal Power Stations: Issues, Challenges, and the Way Forward. The Energy and Resources Institute (TERI), pp. 1–20.

Ranjan, O., Menon, J.S., Nagendra, S.M.S., 2016. Assessment of Air Quality Impacts on Human Health and Vegetation at an Industrial Area. Journal of Hazardous, Toxic, and Radioactive Waste 20 (4), A4016002. doi:10.1061/(asce)hz.2153-5515.0000316, 2016 Oct 1.

Ravindra, K., Singh, T., Biswal, A., et al., 2021. Impact of COVID-19 lockdown on ambient air quality in megacities of India and implication for air pollution control strategies. Environmental Science and Pollution Research 28, 21621–21632. doi:10.1007/s11356-020-11808-7.

Roychowdhury, A., Somvanshi, A., 2020. Breathing Space; How to Track and Report Air Pollution Under the National Clean Air Programme. Center for Science and Environment https://www.cseindia.org/content/downloadreports/9923.

Sailesh, N., Behera, Sharma, Mukesh, O.D, S.P.S, 2011. Development of GIS-aided Emission Inventory of Air Pollutants for an Urban Environment. Intech 32, 137–144. doi:10.5772/17008.

Sankar, U., 1998. Laws and Institutions Relating to Environmental Protection in India. The role of Law and Legal Institutions in Asian economic Development. Erasmus University, Rotterdam.

Santhi, S., Radha, R., 2019. The Indian Act In Environment: A Historical Perspective.

Sathe, Y., Gupta, P., Bawase, M., et al., 2021. Surface and satellite observations of air pollution in India during COVID-19 lockdown: implication to air quality. Sustainable cities and society 66, 102688. doi:10.1016/j.scs.2020.102688.

Sekhara, S., Kolluru, R., Kumar, A., Nagendra, S.M.S., 2021. Association of air pollution and meteorological variables with COVID-19 incidence: evidence from five megacities in India. Environ. Res. 195. doi:10.1016/j.envres.2021.110854.

Shao, J., Yang, H., Zhang, A., 2019. Adoption of electric vehicles. J. Transp. Econ. Policy 53, 175–198.

Sharma, M., Dixit, O., 2015. Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi. https://cerca.iitd.ac.in/uploads/Reports/1576211826iitk.pdf.

Sharma, S., Saraf, M.R., 2018. Source Apportionment of $PM_{2.5}$ & PM_{10} Concentrations of Delhi NCR for Identification of Major Sources. TERI ARAI 30. https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf.

Sharma, S., Zhang, M., Anshika, et al., 2020. Effect of restricted emissions during COVID-19 on air quality in India. Sci. Total Environ. 728, 138878. doi:10.1016/j.scitotenv.2020.138878.

Shehzad, K., et al., 2020. The impact of COVID-19 as a necessary evil on air pollution in India during the lockdown. Environ. Pollut. 266 (2020), 115080. doi:10.1016/j.envpol.2020.115080.

Shehzad, K., Xiaoxing, L., Ahmad, M., et al., 2021. Does air pollution upsurge in megacities after Covid-19 lockdown? A spatial approach. Environ. Res. 197 (2021), 111052. doi:10.1016/j.envres.2021.111052.

Shukla, K., et al., 2018. Air Quality Simulations over Delhi Using WRF-Chem: effects of Local Pollution and Regional-Scale Transport. In: AGU Fall Meeting Abstracts pp, pp. A42A–A401.

SIAM, 2019. White Paper on Alternative Fuels for Vehicles Vision & Recommendations Alternative Fuels in India. https://www.siam.in/uploads/filemanager/159SIAMWhitePaperonAlternativeFuelsforvehicles.pdf. (Accessed on 20 March 2021).

Singh, V., Singh, S., Biswal, A., et al., 2020. Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India. Environ. Pollut. 1, 266. doi:10.1016/j.envpol.2020.115368, 115368.

TERI, 2021. Development of Spatially Resolved Air Pollution Emission Inventory of India. Available at https://www.teriin.org/sites/default/files/2021-05/Exxon-Report.pdf . Accessed on 26.08.2021.

Udara, P., 2016. Air pollution in urban areas and health effects. J. Antarabangsa Alam dan Tamadun Melayu 4 (SI), 25–33.

Vadrevu, K.P., Eaturu, A., Biswas, S., et al., 2020. Spatial and temporal variations of air pollution over 41 cities of India during the COVID-19 lockdown period. Sci Rep 10, 1–15. doi:10.1038/s41598-020-72271-5.

Vito, et al., 2018. Air pollution in Delhi: a review of past and current policy approaches. WIT Trans. Ecol. Environ. 230, 441–451. doi:10.2495/AIR180411.

, 2014. World Health Statistics. World Health Organization, p. 2014.

WHO, 2021. WHO “Global Air Quality Guidelines” Organization. https://apps.who.int/iris/handle/10665/345329. (Accessed on 15 October 2021).