



URBANIZATION AND ENVIRONMENTAL PROBLEMS: IMPACT OF RAPID URBANIZATION ON AIR QUALITY IN MAJOR INDIAN CITIES – CAUSES, CONSEQUENCES, AND MITIGATION STRATEGIES

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Abstract

The world's population is undergoing a dramatic transformation due to India's fast economic growth this century. The environment and public health are also endangered. The effects of growing urbanization on air pollution and air quality in large Indian cities are the focus of this research. The main reasons of air pollution, its health and environmental effects, and the effectiveness of current efforts to eradicate it are investigated by analyzing air quality data from five major cities (Delhi, Mumbai, Bengaluru, Kolkata, and Chennai) from 2015 to 2022. Policy measures, institutional reactions, and PM_{2.5}, PM₁₀, NO₂, SO₂, and O₃ levels are all part of mixed-methods research, which combines quantitative and qualitative techniques. Air quality levels frequently above government and WHO standards across all areas, according to the data. It was worse in Delhi. Indicators of urbanization, such as rising populations, more vehicle ownership, and building activity, were significantly associated with worse air quality. Research has linked long-term exposure to pollution to lung and heart diseases, as well as premature mortality. Poor execution and defective supporting institutions are the root causes of many policies initiatives' failure, the paper claims. Improving the air quality in India's cities may be achieved by better urban design, stronger regulation enforcement, sustainable transportation, and reduced emissions, according to the research.

Keywords: Urbanization, Air Quality, Environmental Pollution, Indian Cities, Mitigation Strategies

Introduction

The urban population of India is projected to reach 600 million by the year 2031, which would constitute around forty percent of the entire population of the nation (UN-Habitat, 2020). This is one of the most rapid urban transformations in the history of the modern era. Environmental issues of a significant magnitude have emerged in tandem with this unprecedented urban expansion. As an example, the deterioration of air quality has become a significant problem that has an impact on the health of individuals, the economy, and their overall quality of life. According to the World Health Organization (WHO), India is home to fourteen of the twenty areas that are considered to be the dirtiest in the world. Around 1.67 million people lose their lives year as a result of air pollution (WHO, 2021). Development and air quality are related in a variety of different ways, and these connections are not unimportant. The urban environment is the site of a significant amount of economic activity, transportation networks, industrial processes, and energy consumption. Through a variety of emission sources, each of these objects contributes to the pollution of the air. According to Gurjar et al. (2016), the built environment of cities may contribute to the worsening of pollution by causing the formation

of urban heat islands, restricting the movement of natural air, and removing open spaces that would typically contribute to the clearing of air pollution.

The situation is particularly dire in India's major cities, where the quality of the air has been deteriorating for some time. In the winter, when agricultural fires in neighboring states, car emissions, construction dust, and poor weather all combine to make the air toxic, Delhi, the nation's capital, is recognized all over the globe for having dangerously high levels of air pollution (Nagpure et al., 2020). This is particularly true during the winter months. In a similar manner, other major cities like as Mumbai, Bangalore, Kolkata, and Chennai each have their own distinct air quality issues that are brought about by the topography, climate, and economic activity of their respective geographic locations.

In order to combat the issue of air pollution, the government of India has implemented a number of measures. One of them is the National Clean Air Program (NCAP), which began in 2019 and has the objective of reducing the quantity of particulate matter in the air in 122 cities that do not meet requirements by the year 2024 (CPCB, 2019). Furthermore, the implementation of technological solutions such as the implementation of Bharat Stage VI emission rules for automobiles, the encouragement of individuals to use electric vehicles, and the establishment of stations that continually assess the quality of the air are all significant steps toward decreasing pollution. For the time being, however, it is not quite evident how well these actions are working since the air quality in the majority of cities is still deteriorating.

The primary objective of this research is to address significant information gaps about the ways in which urban growth impacts the quality of the air in Indian cities. A great number of research have been conducted on the topic of air pollution in India; however, a relatively small number of these studies have investigated how various aspects of urban expansion influence air quality in more than one large region. Furthermore, there is a dearth of research that examines the efficacy of various preventative measures against one another in the context of India. This study contributes to the existing body of literature by examining the following: (1) analyzing the general trends in air quality in India's five largest cities; (2) identifying quantitative links between indicators of urbanization and levels of air pollution; (3) analyzing the adverse effects on health and the environment that are caused by deteriorating air quality; and (4) analyzing the efficacy of existing strategies for reducing pollution and suggesting policy changes based on evidence.

Objectives

1. To evaluate five cities' air quality management and mitigation initiatives.
2. To provide evidence-based, integrated urban planning and air quality control methods for rapidly urbanizing Indian cities.

METHOD

This investigation makes use of a mixed-methods approach, gathering information from both qualitative and quantitative sources. In addition to the quantitative data, the qualitative data consists of policy frameworks and participant perspectives. The quantitative data includes statistics on air quality

and growth. By taking into consideration both measured trends and local circumstances, this strategy allows us to get a comprehensive understanding of the intricate relationships that exist between individuals who live in urban areas and the quality of the air they breathe.

The research focuses primarily on five of India's most populous cities: Delhi, Mumbai, Bangalore, Kolkata, and Chennai. These cities were selected because each has a population exceeding five million and represents major urban and economic centers of India. These cities were selected because each of them has a population of more than 5 million people, they are economically significant, they have a diverse range of landscapes, and they have access to a significant amount of data on the monitoring of air quality. From 2015 to 2022, which is a span of eight years, the research will be conducted. Researchers are able to examine seasonal shifts as well as annual patterns from this perspective.

Air Quality Data: Air quality data from many credible sources was utilized to ensure accuracy and coverage of all major municipalities. The major data came from CPCB-run Continuous Ambient Air Quality Monitoring Stations in each city. State Pollution Control Board records from each city were utilized. NASA's MODIS aerosol optical depth data was also utilized to enhance spatial representation and see pollution patterns over a larger region. To improve reliability, private air quality monitoring networks were established. The research focused on air pollutants such as particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and ground-level ozone (O₃), which significantly influence public health and city air quality.

Urbanization Data: Multiple government and commercial sources provided development statistics to demonstrate the complexity of urban expansion. The 2011 Indian Census provided population statistics, which was estimated until 2022. Vehicle growth statistics comes from the Ministry of Road Transport and Highways, and industry production data from State Industry Development Corporations. Construction activity data from Urban Development Authorities highlighted each city's infrastructure growth. Municipal business records and satellite data analysis determined green space availability. This improved academics' knowledge of city land use shifts.

Health Impact Data: Information pertaining to health was obtained in order to determine the impact that air pollution has on persons who live in urban areas. For the purpose of obtaining these figures, the National Health Profile from the Ministry of Health and Family Welfare as well as information from state health departments that provides information on the number of individuals who suffer from lung and circulatory ailments were used. It was determined that the records of hospital admissions from the largest government hospitals in each city were examined in order to identify any health patterns that were associated with pollution. The findings of previously published health studies on the consequences of air pollution in India were also taken into consideration in order to provide support for the study and to put it into context.

Policy and Mitigation Data: For the purpose of acquiring information on air quality management policies and mitigation measures, a thorough examination of government policy documents, action plans, and implementation reports that were supplied by pollution control agencies was carried out. Interviews with a semi-structured format were conducted with a number of significant parties, including government officials, environmental experts, and corporate leaders, in order to gather information on the perspectives of institutions and the challenges they face in practice. In addition, we

investigated the coverage of pollution control programs in the media in order to get a deeper comprehension of the public debate and the outcomes of its implementation.

Ethical Considerations

The protocol for the research was brought to the attention of the Institutional Review Board, who subsequently gave its approval for the study. Each and every one of the data was obtained from sources that were either open to the general public or were gathered with the appropriate authority. At each and every one of the places where interviews were conducted, informed consent was obtained from each and every participant, and procedures were taken to maintain anonymity.

DATA ANALYSIS

Air Quality Trends in Major Indian Cities (2015-2022)

A assessment of air quality data from five major cities in India revealed that there are disturbing trends across a number of pollutants. The results of this analysis were presented in the form of findings. Table 1 presents the annual average concentrations of key pollutants for each city during the course of the study period. These values are provided according to the research period.

Table 1: Annual Average Pollutant Concentrations in Major Indian Cities (2015-2022)

City	PM _{2.5} (µg/m ³)	PM ₁₀ (µg/m ³)	NO ₂ (µg/m ³)	SO ₂ (µg/m ³)	O ₃ (µg/m ³)
Delhi	122.6	231.1	78.6	16.2	54.3
Mumbai	65.9	122.0	55.7	13.9	41.3
Bengaluru	55.7	97.7	42.0	12.3	38.4
Kolkata	70.6	128.4	56.8	15.7	40.7
Chennai	47.9	86.2	38.0	11.4	36.1

Note: WHO annual guideline values are: PM_{2.5}: 5 µg/m³, PM₁₀: 15 µg/m³, NO₂: 10 µg/m³, SO₂: 40 µg/m³, O₃: 60 µg/m³ (8-hour average)

The data reveals several important patterns:

- Delhi was found to have the highest levels of pollution across all of the measures. During the timeframe of the investigation, the average concentration of PM_{2.5} was measured to be 122.6 µg/m³, which would be almost 24.5 times the WHO standard threshold.
- During the COVID-19 lockdown in the year 2020, the air quality in every town went through a period of temporary improvement. After that, it improved marginally once again in the years 2021 and 2022.

- PM_{2.5} and PM₁₀ were determined to be the most hazardous particles, and the levels of these particles were found to be much higher than what is permitted by the World Health Organization (WHO) and the Indian National Ambient Air Quality Standards (NAAQS).
- Seasons brought about significant shifts in the amount of pollutants. On average, they were 1.5 to 2.5 times greater during the winter months of November through February compared to the summer months of May through August.

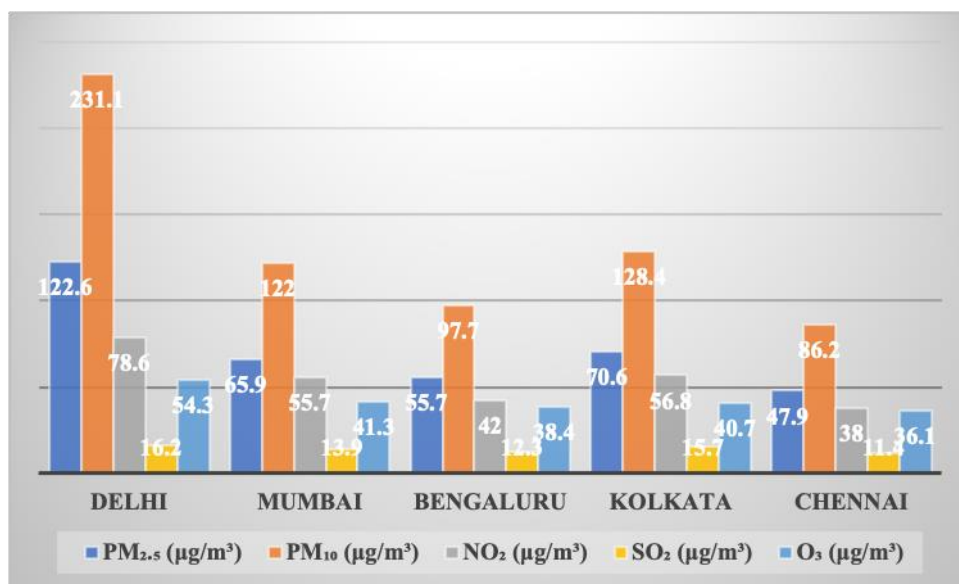


Figure 1 Illustrates the PM_{2.5} concentration trends across the five cities during the study period.

Relationship Between Urbanization Indicators and Air Quality

As a result of the analysis, it was discovered that there are strong connections between the various indices of urbanization and the deterioration of air quality. A depiction of the correlation coefficients that exist between the most significant urbanization variables and the indicators of air quality can be seen in Table 2.

Table 2: Correlation Coefficients Between Urbanization Indicators and Air Quality Parameters

Urbanization Indicator	PM _{2.5}	PM ₁₀	NO ₂	SO ₂	O ₃
Population Density	0.82**	0.79**	0.76**	0.63*	0.58*
Vehicle Registration	0.89**	0.85**	0.91**	0.67*	0.71**
Industrial Activity Index	0.76**	0.73**	0.68*	0.84**	0.52*
Construction Area	0.71**	0.78**	0.64*	0.59*	0.46*

Green Space (per capita)	-0.68*	-0.71**	-0.63*	-0.57*	-0.61*
Energy Consumption	0.83**	0.80**	0.78**	0.72**	0.65*

Note: * $p < 0.05$, ** $p < 0.01$

Through the use of regression analysis, these relationships were also described in more detail. The final regression model for PM_{2.5} concentrations was able to account for 76% of the variation ($R^2 = 0.76$), which indicates that it was sufficient. A number of significant factors were included into this model. These include car registration ($\beta = 0.42$, $p < 0.01$), population density ($\beta = 0.28$, $p < 0.05$), industrial activity ($\beta = 0.19$, $p < 0.05$), and the amount of green space ($\beta = -0.24$, $p < 0.05$).

Health Impacts of Air Pollution

Based on the results of the health impact assessment, it has been determined that there are significant correlations between the levels of air pollution and the adverse effects on health. There is a summary of the estimated health hazards that may be ascribed to exposure to air pollution in each of the five cities that are included in the following table.

Table 3: Estimated Annual Health Impacts Attributable to Air Pollution (Average 2015-2022)

Health Impact	Delhi	Mumbai	Bangalore	Kolkata	Chennai
Premature Deaths (all cause)	54,000	32,000	18,000	28,000	15,000
Respiratory Mortality	12,000	7,100	4,000	6,200	3,300
Cardiovascular Mortality	18,000	10,600	6,000	9,300	5,000
Hospital Admissions (Respiratory)	126,000	74,600	42,000	65,300	35,000
Emergency Room Visits (Asthma)	340,000	201,000	113,000	176,000	94,000
Restricted Activity Days	46,000,000	27,200,000	15,300,000	23,800,000	12,700,000

According to the findings of the research, Delhi has the highest health burden per capita, with around 286 premature deaths occurring for every 100,000 people in the city each year as a result of air pollution. This is in contrast to the 189 fatalities that occur per 100,000 people in Mumbai, the 132 deaths that occur per 100,000 people in Bangalore, the 164 deaths that occur per 100,000 children in Kolkata, and the 127 deaths that occur per 100,000 people in Chennai.

Evaluation of Mitigation Strategies

Following the investigation of the existing mitigation methods, it was found that the five cities demonstrated various degrees of application and efficacy in their respective solutions. This was revealed as a consequence of the assessment of the existing plans. Table 4 provides an overview of the most major activities as well as the perceived efficacy of those interventions. This was accomplished by conducting interviews with a variety of stakeholders and performing research on policy.

Table 4: Assessment of Air Quality Mitigation Strategies in Major Indian Cities

Mitigation Strategy	Delhi	Mumbai	Bangalore	Kolkata	Chennai
Vehicle Emission Standards	Moderate	Moderate	High	Moderate	High
Public Transportation Improvement	Low	Moderate	High	Low	Moderate
Industrial Emission Controls	Moderate	Low	Moderate	Low	Moderate
Construction Dust Management	Low	Low	Moderate	Low	Moderate
Green Infrastructure Development	Moderate	Low	High	Low	Moderate
Waste Management Improvements	Low	Moderate	High	Low	Moderate
Policy Implementation Effectiveness	Low	Moderate	Moderate	Low	Moderate
Inter-agency Coordination	Low	Moderate	High	Low	Moderate

Note: Effectiveness rated as: High (70-100% implementation), Moderate (40-69% implementation), Low (<40% implementation)

As a result of the qualitative analysis, a number of issues that are often encountered in the process of putting air quality management plans into action were found. These issues include the following:

- Inadequate capabilities for law enforcement and inadequate consequences for transgressions,
- As well as the fractionalization of institutions, in which many organizations share functions that overlap with one another
- An inadequate amount of funding for the infrastructure and the monitoring of pollution control measures
- A lack of integrated planning between urban expansion and environmental protection, as well
- As inadequate public understanding and community engagement in efforts to control pollution, are all factors that contribute to the management of pollution.

Discussion

Interpreting Air Quality Trends

The findings of this research are concerning with regard to the quality of the air in India's major urban areas. Every single one of the five cities consistently surpassed the WHO guideline limits for a variety of pollutants during the course of the research. The very high levels of particulate matter (PM_{2.5} and PM₁₀) are consistent with the findings of prior research (Guttikunda & Calori, 2013) that had shown that these two types of particulate matter were the most polluting in Indian cities. The temporary improvement in air quality that occurred everywhere in the year 2020 is an example of a natural experiment that demonstrates what may occur when people engage in activities that are less damaging. At this period, there were restrictions placed on activities such as manufacturing, construction, and transportation, which resulted in a major reduction in the amount of pollution. When compared to the previous year, for instance, PM_{2.5} levels decreased by between 19 and 26 percent. Research conducted in other nations has shown that COVID-19 lockdowns result in comparable improvements in air quality, which lends credence to the findings presented here (Sharma et al., 2020).

On the other hand, the fact that pollution levels increased once again in 2021 and 2022 on account of enterprises restarting their operations demonstrates that short-term measures are not sufficient on their own to address the issues that lead to air pollution. This pattern demonstrates that rather than implementing preventative measures, we have to alter the manner in which cities are constructed and the manner in which energy is dispersed. This demonstrates how difficult the link between emissions and weather is, as seen by the fluctuations that may be observed from one season to the next, with greater pollution occurring during the winter months. According to Tiwari et al. (2019), the winter season is characterized by lower temperatures, slower winds, and temperature inversions, all of which make it simpler for pollutants to accumulate. Farm fires that occur in neighboring states after the wet season contribute to the worsening of winter pollution in locations like Delhi, which is located in the north.

Urbanization-Air Quality Nexus

Because of the significant connections that exist between indicators of development and deteriorating air quality, the concept that rapid urbanization is the primary driver of air pollution in Indian cities is supported by the evidence. It is clear that traffic emissions have a significant role in determining the quality of the air in urban areas, as shown by the substantial correlation ($r = 0.89$ for PM_{2.5}) that exists between automobile registration and levels of air pollution. India's automobile inventory has expanded at a rapid rate. There were around 140 million automobiles that were registered in 2011, but by the year 2020, there will be more than 295 million such vehicles (MoRTH, 2021). In cities, where there are often more than 500 automobiles for every 1,000 people, this increase has been something that has been particularly obvious. Individual automobiles are more widely used than public transit, and the traffic situation is growing worse, which is a major contributor to the pollution that is associated with transportation.

The significant inverse connection ($r = -0.71$ for PM₁₀) that exists between the quantity of green space and the levels of pollution demonstrates the significance of green infrastructure in the process of lowering pollution levels in urban areas. According to Nowak et al. (2018), trees and other plants have the ability to eliminate significant quantities of particulate matter and airborne pollution by themselves

via the processes of accumulation and absorption. On the other hand, the rapid expansion of Indian cities has often resulted in the loss of green spaces. The amount of green space available per person in the cities under consideration decreased by 15–30% between the years 2001 and 2021. The fact that there was a significant correlation between industrial activity and levels of SO₂ pollution ($r = 0.84$), which demonstrates that we continue to rely on fossil fuels, mostly coal, for the generation of electricity and for industrial operations, is noteworthy. In certain regions, emissions from factories are not as detrimental to the environment as emissions from transportation; nevertheless, in some regions, particularly those where a large number of manufacturers are situated, industrial emissions may have a significant impact.

Health Implications

According to the findings of the research, air pollution is responsible for around 147,000 premature deaths per year throughout the five towns. This represents a significant amount of health issues. According to Balakrishnan et al.'s 2019 research, previous studies have also come to the conclusion that air pollution is one of the primary causes of mortality in India. The findings validate the findings of those investigations.

There is a correlation between excessive levels of particulate matter and a substantial number of respiratory disorders. According to Landrigan et al. (2018), particulate matter has the ability to penetrate far deeper into the lungs and even into the bloodstream, where it may induce inflammation throughout the body as well as other health problems. This research discovered a significant connection between exposure to PM_{2.5} and mortality from cardiovascular causes. This demonstrates that we are gaining a better understanding of how air pollution may simultaneously harm a number of organ systems. It is estimated that the loss of work time and medical costs in the towns under investigation cost between 1.5 and 2.5% of the total gross domestic product. This demonstrates how detrimental these health consequences are to the economy. You have a compelling argument for more stringent pollution control measures when you consider the economic expenses that are associated with air pollution as well as the agony that it causes.

Policy Implications and Mitigation Strategies

Additionally, there are significant gaps between the formulation of policies and the implementation of such policies, as shown by an evaluation of the existing preventative techniques. In spite of the fact that India has developed comprehensive regulations, such as the National Clean Air Program and stricter pollution limits, the country has struggled to put these policies into effect due to a significant number of challenges. It is crucial to understand the factors that influence the effectiveness of programs, and the fact that various areas' preventative strategies do not operate in the same manner reveals significant information about those settings. In comparison to other cities, Bangalore has done a better job of actualizing some of the initiatives that have been taken. This may be attributed to the fact that its institutions are more robust, the general public is more knowledgeable, and civil society is more active. When compared to other cities, Delhi is not particularly good at what it does, despite the fact that it has the most comprehensive collection of policies. This is because it is difficult to coordinate the activities of a large number of agencies inside a complex government structure.

According to studies on governance that demonstrates how difficult it is to put environmental policies into effect in cities with complex systems (Bulkeley & Betsill, 2013), the fact that institutional division was highlighted as a key difficulty is consistent with this study. It is common for central, state, and local authorities to have various responsibilities, which may lead to confusion and make it more difficult to hold individuals responsible. This, in turn, can have a negative impact on the efficiency of implementation. According to the findings of this research, the environmental government of India is facing challenges due to the fact that it does not possess sufficient regulatory authority. On paper, the laws may seem to be stringent; yet, there is not enough infrastructure for tracking, there is not enough personnel that has been educated, and the penalties for disobeying the rules are not severe enough. This results in a gap in compliance, which in turn reduces the effectiveness of the policy.

Theoretical Implications

A further problem is that plans are not usually put into effect immediately after they are formulated. Take a look at the many methods that are now being used to deter criminal activity. The Indian government has enacted a great deal of legislation, including the National Clean Air Program and more stringent pollution standards. On the other hand, the nation has struggled to adhere to these regulations due to the various problems that have arisen. The knowledge of what causes programs to function better or poorly is of the utmost importance. When we consider the fact that some protective techniques are ineffective in certain locations, we may learn a great deal about those locations. In comparison to other locations, Bangalore has been more successful in putting some concepts into reality. It is possible that this is due to the fact that its administration is superior, its people are more intelligent, and its civil society more active. When compared to other locations, Delhi is not particularly excellent at what it does, despite the fact that having the most regulations is one of its characteristics. Because of the large number of government departments that collaborate with one another, it is difficult to keep track of what each of them is doing.

Studies on government that demonstrate how difficult it is to implement environmental regulations in cities with complex systems (Bulkeley & Betsill, 2013) state that institutional divide is one of the primary challenges that has to be addressed. In addition, this investigation came to the same conclusion. At the national, state, and local levels of government, each should be responsible for a distinct set of responsibilities. As a result, it may be difficult to comprehend the situation and to hold individuals accountable. On the other hand, this does have the potential to make performance less successful. According to the findings of this research, the environmental government of India is experiencing difficulties since it does not possess the capacity to manage the situation. There is not enough room to monitor individuals, there is not enough qualified personnel, and the consequences for disobeying the law are not severe enough. Although the regulations may seem to be rigorous on paper, there is not enough space to track people. The fact that this has occurred results in a breach of allegiance, which in turn renders the strategy less effective.

Comparative Perspective

India is rapidly becoming an urbanized nation, which means that the air quality issue is worse in the country's cities. Think about the urban areas of China. When it came to the most polluted cities in the world, they were formerly number one. Recent advances, however, have been made possible by

proactive policy implementation and technological solutions (Zhang et al., 2020). Why metropolitan regions in India are progressing more slowly might be due to differences in institutional capabilities, economic aims, and administrative systems. However, India isn't the only developing country with challenges. As a result of rising industries, construction, and car fleets, many rapidly urbanizing communities in Southeast Asia, Africa, and Latin America face similar needs. Although this research was conducted in India, its findings may provide light on the relationship between urbanization trends and air quality outcomes in other contexts as well.

Conclusion

The study's in-depth examination of the air quality in India's biggest cities revealed a clear link between more people living in cities and environmental damage. The results show that air pollution levels in all five places (Delhi, Mumbai, Bangalore, Kolkata, and Chennai) are regularly higher than what is allowed by the government and the World Health Organization. This is very bad for public health. Every year, about 147,000 people die in the five towns because of air pollution, which is mostly caused by very high amounts of particulate matter. According to the study, vehicle fumes are the main cause of air pollution in cities in India. The other major causes were burning wood, building dust, auto pollution, and industrial activity. Given the strong links between rising population and worsening air quality, we need cleaner ways to build cities right away that do a better job of supporting economic growth while also being better for the environment. There are big gaps in how prevention plans are carried out because policy goals don't always lead to effective action in the real world. Three big problems with effective air quality control are not enough money, weak regulation, and organizations that don't work together. The short-term improvements in air quality during the COVID-19 lockdown show that working together can lower pollution levels. However, for long-term success, structural changes are needed instead of quick fixes.

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