



Strategic Framework for Winter Air Pollution Control in Haryana: Challenges and Opportunities

Anuradha Panwar* and Rahul

Assistant Professor Department of Civil Engineering, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, India-248007

*Corresponding Author

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Abstract— Air pollution in Haryana is a major environmental and health concern, especially during the winter season. The adverse meteorological conditions during the winter enhance the level of air pollution. The present study proposes a strategic framework for the control of air pollution during the winter. The present research focuses on the analysis of the spatio-temporal trends of air quality over several areas in Haryana, covering the period from 2020 to 2024. The results showed that there was an improvement in air quality during the early part of 2023. However, the improvement was not long-lasting, and the areas showed a constant level of pollution during 2024. The areas such as Gurugram, Faridabad, Manesar, etc., showed high levels of pollution, while areas like Panchkula and Karnal showed good trends of air quality. The emphasis is on the need for a multi-sectoral strategy to be implemented through emission control, sustainable transport systems, agricultural management practices, and effective enforcement of regulations. The proposed Winter Action Plan is in line with the national environment policy and is designed to improve the effectiveness of monitoring, enforcement, and public involvement. It is a practical and policy-driven approach to addressing air quality and health risks and is beneficial for sustainable environment management in Haryana.



Keywords— Air Pollution, Winter Action Plan, Haryana, Air Quality Management, Sustainable Environmental Policy

I. INTRODUCTION

The escalating trend of ambient air pollution has emerged as a critical environmental and public health concern in recent years, with peak severity observed during the winter season due to unfavorable dispersion conditions (WHO, 2021; HEI, 2020). The adverse health impacts of air pollution are well documented in scientific literature. A 2019 assessment estimated that prolonged exposure to elevated pollution levels has reduced the average life expectancy of the Indian population by approximately 6–9 years and contributed to nearly 1.7 million premature deaths nationwide. Open burning of solid waste constitutes a major source of atmospheric pollution, particularly in association with unmanaged open dumping practices. Additionally, seasonal combustion of agricultural residues in post-harvest fields represents a substantial contributor to air pollutant emissions, as documented by UNEP (2021). Exposure to

ambient air pollution, both short- and long-term, leads to reduced lung function, respiratory infections, and aggravated asthma. It is also associated with adverse reproductive outcomes and emerging risks such as type 2 diabetes, obesity, systemic inflammation, and neurodegenerative diseases (WHO, 2005; 2013a; EEA, 2020). Empirical studies further indicate that air pollution significantly exacerbates morbidity and mortality risks among individuals suffering from chronic respiratory and cardiovascular disorders, including chronic obstructive pulmonary disease (COPD), lung cancer, ischemic heart disease, stroke, and pneumonia (Kumar et al., 2020; WHO, 2018). Assessment of health impacts from ambient air pollution is complicated by indoor exposure variability, long-term effects of episodic events such as wildfire smoke, and uncertainties related to emerging particulate matter, including brake and tire wear and microplastics (HEI, 2023). Vulnerable population groups, particularly children

and the elderly, are disproportionately affected due to their heightened physiological sensitivity and weaker adaptive capacity (WHO, 2021). Consequently, air pollution must be addressed not only as an environmental degradation issue but also as a pressing public health emergency requiring integrated, multi-sectoral policy interventions. According to global air quality assessments based on World Health Organization (WHO) standards, India ranks third globally in terms of population exposure to PM_{2.5} concentrations exceeding recommended limits, underscoring the urgency of strengthened mitigation and regulatory strategies (IQAir, 2024; WHO, 2021). The mean winter concentration of PM₁₀ is approximately 600 µg/m³, significantly exceeding the permissible limit of 100 µg/m³, while PM_{2.5} levels average around 375 µg/m³ compared to the acceptable standard of 60 µg/m³ (Sharma et al., 2016). Haryana represents a predominantly agrarian economy complemented by a rapidly expanding industrial sector (HSPCB, 2023). Despite its economic growth, the state continues to face substantial environmental pressures, particularly elevated concentrations of particulate matter (PM_{2.5} and PM₁₀), with acute severity during the winter season due to adverse meteorological conditions and transboundary influences (Jain & Sharma, 2021; Singh et al., 2019). Thermal power plants, vehicular emissions, industrial activities,

agricultural practices, and solid waste disposal constitute the primary sources of air pollutant emissions in Indian megacities (Gurjar et al., 2016). The proposed action framework is formulated by critically examining the state's geographical characteristics, emission sources, and socio-economic structure to design sector-specific, technically feasible, and outcome-oriented interventions. The strategy builds upon the prevailing regulatory architecture and is harmonized with national and state environmental policies (MoEFCC, 2019; CPCB, 2023). It integrates directives and standards prescribed by the Central Pollution Control Board (CPCB) and operationalizes state-specific regulatory mechanisms to strengthen enforcement, monitoring, and compliance. This integrated approach ensures systematic and effective implementation of air quality management measures across multiple sectors. The objective of the study is to analyze the spatio-temporal variation of ambient air quality over different districts of Haryana from 2020 to 2024, with specific reference to winter pollution patterns, regional variations, and concentrations of particulate matter (PM_{2.5}, PM₁₀), to formulate a strategic multi-sectoral Winter Action Plan that would cover issues related to emissions, sustainable transport, agriculture, and enforcement.

Table 1: Comparative Assessment of Population-Weighted Annual Mean PM_{2.5} Concentrations in India and Neighbouring Countries Relative to the WHO Annual Guideline (2024)

Country	Population-Weighted Annual Mean PM _{2.5} (µg/m ³)	WHO Annual Guideline (5 µg/m ³)	Exceedance Ratio
Bangladesh	78.0	5	15.6×
Pakistan	73.7	5	14.7×
India	50.6	5	10.1×
Nepal	42.8	5	8.6×

Table 2: Compliance Status of Annual Average PM_{2.5} Concentrations in India and Selected Neighbouring Countries with WHO Guidelines, WHO Interim Target-1, and India's NAAQS {WHO (2021); CPCB (2023)}

Country	Annual Avg. PM _{2.5} (µg/m ³)	Meets WHO 5 µg/m ³ ?	Meets WHO IT-1 (35)	Meets India NAAQS (40)
Bangladesh	78.0	×	×	×
Pakistan	73.7	×	×	×
India	50.6	×	×	×
Nepal	42.8	×	×	×

II. STUDY AREA

Haryana sub-region of the National Capital Region (NCR), a vital economic and administrative zone surrounding New Delhi. Geographically, this territory is situated roughly between 27.65 ° to 29.80 ° latitude and 76.10 ° to 77.55 ° longitude. The visualization highlights a collection of districts that serve as the industrial and urban backbone of Northern India. At the heart of this region is Gurugram, a global corporate hub for IT and finance, alongside Faridabad, one of the state's oldest and largest industrial centers. Moving toward the north and west, the map identifies Sonapat and Panipat, which are critical for their educational institutions, textile industries, and historical significance. The central and southern portions of the map showcase districts like Rohtak, Jhajjar, Rewari, and Palwal. These areas act as strategic transit points, connected by a massive network of highways and the KMP (Kundli-Manesar-Palwal) Expressway, which facilitates seamless logistics bypass around the national capital. To the far north of the NCR boundary lies Karnal, known as the "Rice Bowl

of India," representing the region's strong agricultural foundation. Collectively, this map depicts an integrated urban ecosystem designed to decentralize Delhi's population by providing world-class infrastructure, manufacturing zones, and residential hubs within the state of Haryana (HSPCB, 2023; MoEFCC, 2020).



Fig. 1: NCR region of Haryana

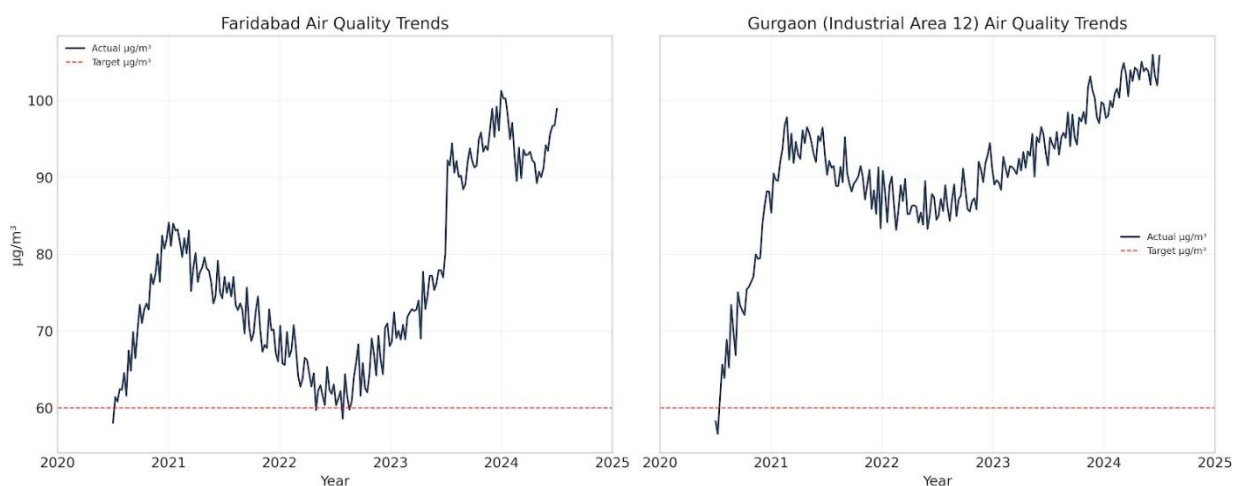


Fig. 2. Comparative Air Quality Trends in Faridabad and Gurgaon (2020–2025)

In Figure 2, the Faridabad Air Quality Trends chart on the left shows a fluctuating trend in particulate matter concentration from 2020 to 2024. After a sharp increase in early 2021, the city saw a significant improvement throughout 2022, where levels briefly approached the 60 $\mu\text{g}/\text{m}^3$ target line. However, this progress reversed in early 2023, as concentrations rose steadily to nearly 100 $\mu\text{g}/\text{m}^3$

by mid-2024. The Gurgaon (Industrial Area 12) Air Quality Trends chart on the right indicates a more severe, ongoing pollution issue. After a rapid rise in late 2020, Gurgaon's air quality stayed consistently poor and never returned to the target level. While there was a slight decrease in 2022, the trend since 2023 has shown a sharp increase, with levels peaking above 105 $\mu\text{g}/\text{m}^3$ by mid-2024.

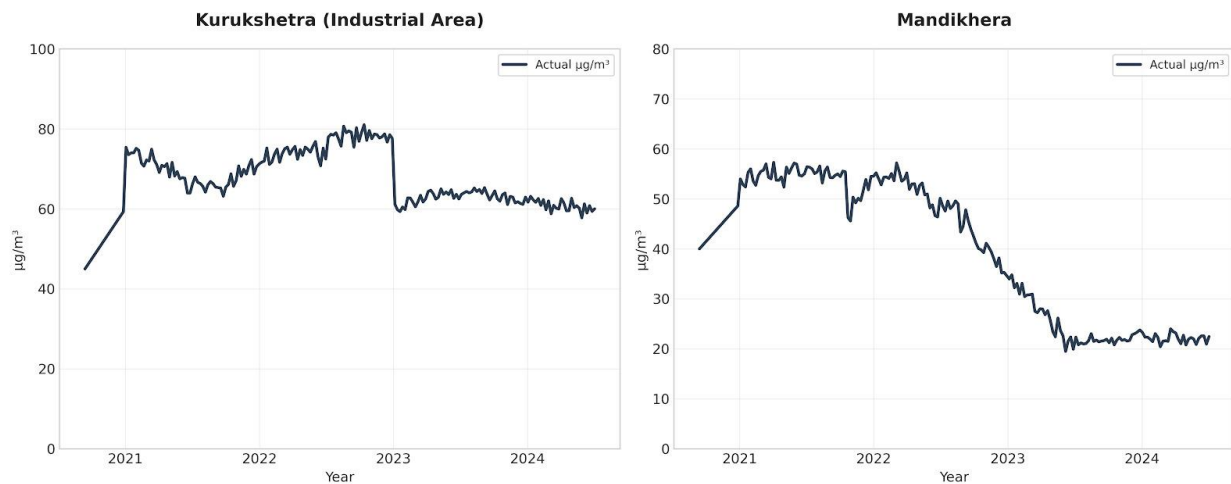


Fig.3. Air Quality Trends in Kurukshetra (Industrial Area) and Mandikhera (2020–2025)

The Kurukshetra (Industrial Area) chart shows a period of high particulate matter starting in 2020. Levels rose from $45 \mu\text{g}/\text{m}^3$ to a peak between 70 and $80 \mu\text{g}/\text{m}^3$ during 2021 and 2022. A sharp drop happened at the beginning of 2023, lowering the concentration to a more stable range of around $60 \mu\text{g}/\text{m}^3$ until mid-2024. The Mandikhera chart reveals a

very positive trend, showing the most significant air quality improvement among the areas studied. After peaking near $60 \mu\text{g}/\text{m}^3$ in early 2022, the concentration steadily declined for the rest of the year. By mid-2023, levels dropped to about $20 \mu\text{g}/\text{m}^3$ and have stayed low through 2024, indicating a successful shift to much cleaner air.

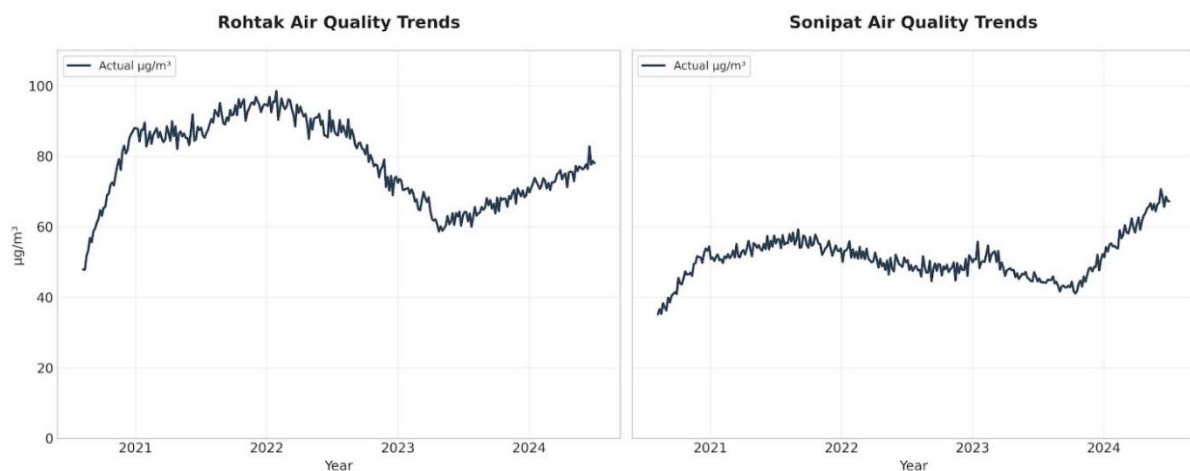


Fig.4. Assessment of PM Concentration Trends in Rohtak and Sonipat

The Rohtak Air Quality Trends chart on the left shows a clear wave-like pattern in particulate matter levels over the four years. After a sharp rise from $50 \mu\text{g}/\text{m}^3$ to nearly $100 \mu\text{g}/\text{m}^3$ by early 2022, Rohtak saw a notable improvement throughout 2023, with levels dropping back down toward $60 \mu\text{g}/\text{m}^3$. However, since the start of 2024, air quality has begun to decline again, steadily rising toward $80 \mu\text{g}/\text{m}^3$ by mid-year. The Sonipat Air Quality Trends chart on the right

reflects a generally lower but increasingly unstable pollution profile. For much of 2021 through 2023, Sonipat maintained stable levels, fluctuating between 40 and $60 \mu\text{g}/\text{m}^3$, which was better than many neighboring regions. This stability ended in early 2024, as the chart shows a sharp and consistent upward trend, with concentrations hitting a four-year high of about $70 \mu\text{g}/\text{m}^3$ by mid-2024.

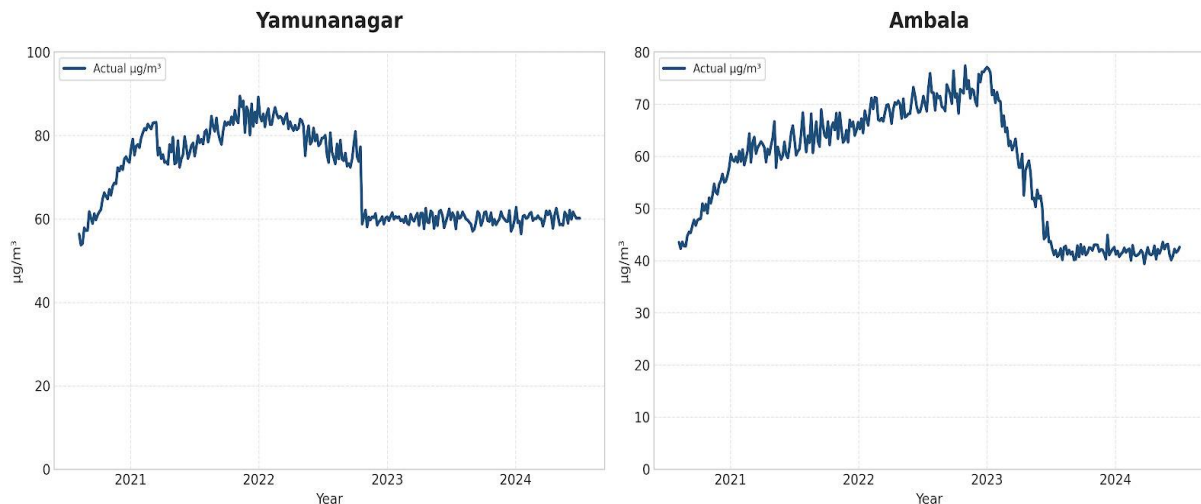


Fig.5. Air Quality Trend Analysis in Yamunanagar and Ambala (2020–2025)

The above figure presents two line graphs representing the recorded air pollutant concentration in $\mu\text{g}/\text{m}^3$ for the cities of Yamunanagar and Ambala from the end of 2020 to the middle of 2024. The cities have a similar long-term pattern, showing a rise in air pollutant concentration from 2021 and 2022, reaching a peak of 80-90 $\mu\text{g}/\text{m}^3$ for Yamunanagar and 75 $\mu\text{g}/\text{m}^3$ for Ambala. It is observed that from early 2023, a

considerable and steep fall in air pollutant concentration was observed for both cities. Subsequently, from 2024, a significant stabilization in air pollutant concentration was observed, reaching a baseline of 60 $\mu\text{g}/\text{m}^3$ for Yamunanagar and 40 $\mu\text{g}/\text{m}^3$ for Ambala, which might be a result of a change in environmental policy for these cities.

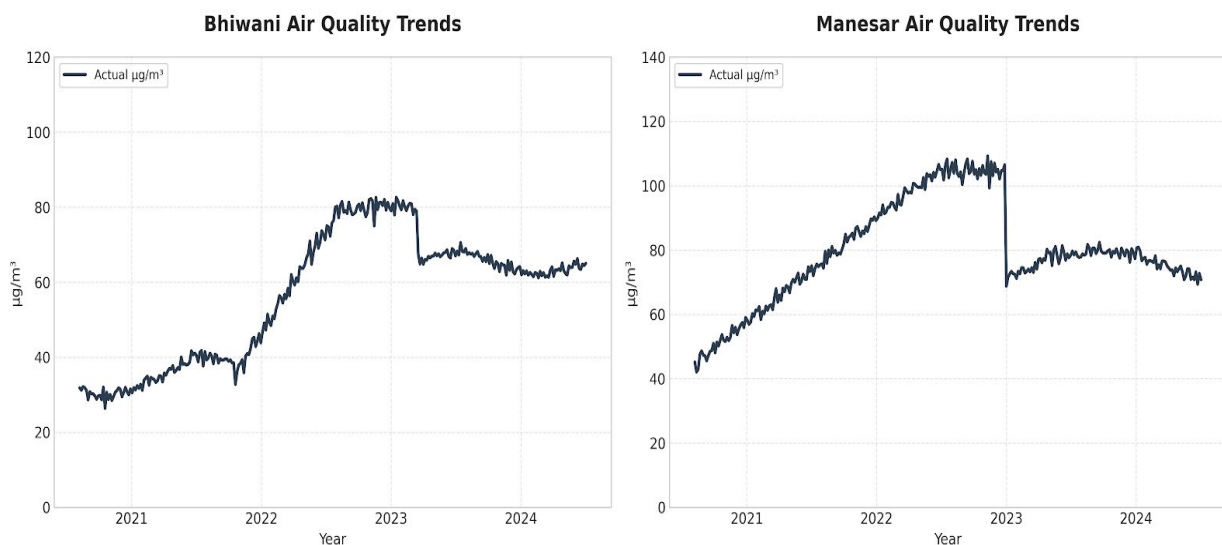


Fig.6. Comparative Assessment of Ambient Air Quality in Bhiwani and Manesar

The figure provided above represents air quality trends for both Bhiwani and Manesar from the end of 2020 until mid-2024, represented in units of $\mu\text{g}/\text{m}^3$. From the figure, it is evident that both cities have shown a steady rise in air quality from the end of 2020 until the end of 2022, at which time both cities reached their peak, with Bhiwani reaching a peak of around 80 $\mu\text{g}/\text{m}^3$, and Manesar reaching a peak of around 105 $\mu\text{g}/\text{m}^3$. Similar to the previous air quality trends

for Yamunanagar and Ambala, both cities showed a sharp, vertical drop in pollutant concentration at the start of 2023. Following this drop, both cities showed air quality levels of around 60-70 $\mu\text{g}/\text{m}^3$ in Bhiwani and around 70-80 $\mu\text{g}/\text{m}^3$ in Manesar until the end of 2024. Both cities are showing higher levels of air quality compared to their starting points at the end of 2020.

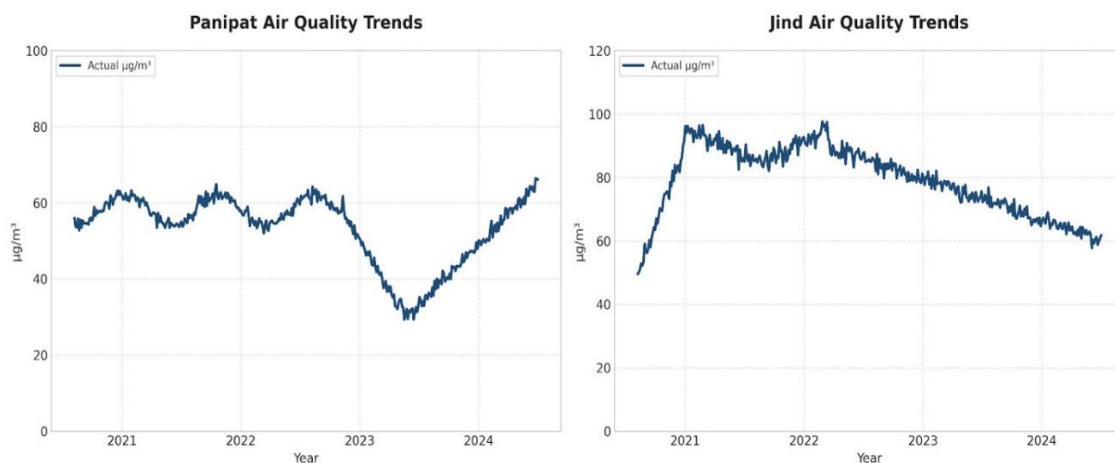


Fig.7. Air Quality Trend Analysis in Panipat and Jind (2020–2025)

The figure provided above represents the air quality trend for Panipat and Jind from the end of 2020 to mid-2024. Unlike the other cities, these cities have shown a gradual and distinct trend. The air quality in Panipat has shown a cyclical trend with peaks around 60–65 $\mu\text{g}/\text{m}^3$ every year. However, there was a sharp decline in early 2023 to a minimum of 30 $\mu\text{g}/\text{m}^3$, and then air quality gradually

increased back to 65 $\mu\text{g}/\text{m}^3$ by 2024. Unlike Panipat, the air quality in Jind increased sharply to reach a peak of almost 100 $\mu\text{g}/\text{m}^3$ by early 2021. However, after reaching this peak, there has been a constant decline in air quality. By mid-2024, the air quality in Jind has decreased to almost 60 $\mu\text{g}/\text{m}^3$.

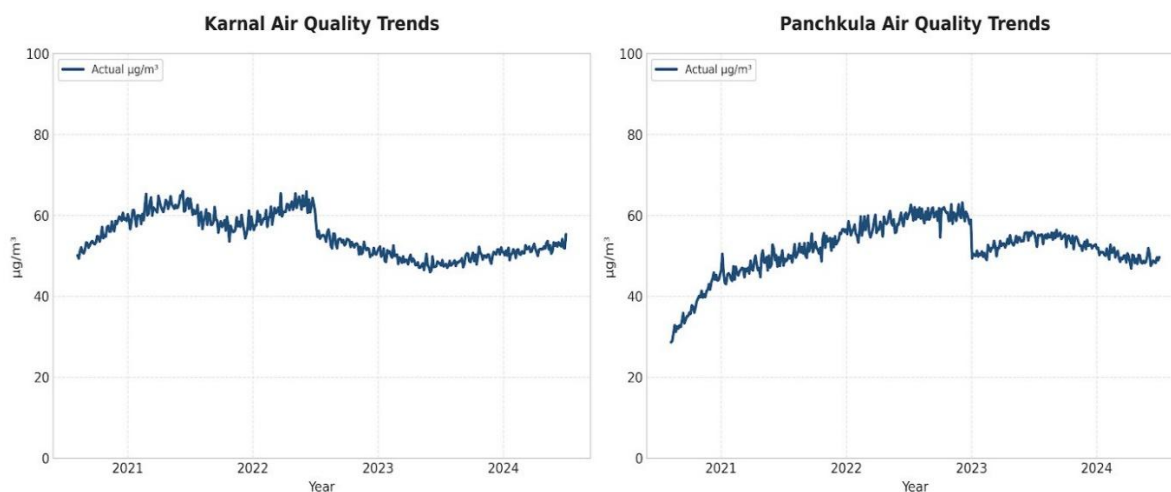


Fig.8. Air Quality Trend Analysis in Karnal and Panchkula (2020–2025)

The figure provided below presents the air quality trends for both cities from late 2020 to mid-2024. As presented in the figure, both cities demonstrate relatively lower overall pollutant concentration compared to previous datasets. The peak concentration for both cities remains below 70 $\mu\text{g}/\text{m}^3$. The air quality trend for Karnal demonstrates a plateau from 2021 to 2022, with concentrations ranging between 55 and 65 $\mu\text{g}/\text{m}^3$. It then reduces moderately by the start of 2023

and increases slightly and steadily to reach 55 $\mu\text{g}/\text{m}^3$ by 2024. The air quality trend for Panchkula demonstrates a sharp increase from a minimum of 30 $\mu\text{g}/\text{m}^3$ in 2020 to a peak of 60 $\mu\text{g}/\text{m}^3$ by the end of 2022. Similar to several cities in this dataset, Panchkula also demonstrates a sharp drop in concentration by the start of 2023. However, by then, Panchkula demonstrates a very stable concentration, with a minor variation around 50 $\mu\text{g}/\text{m}^3$ by mid-2024.

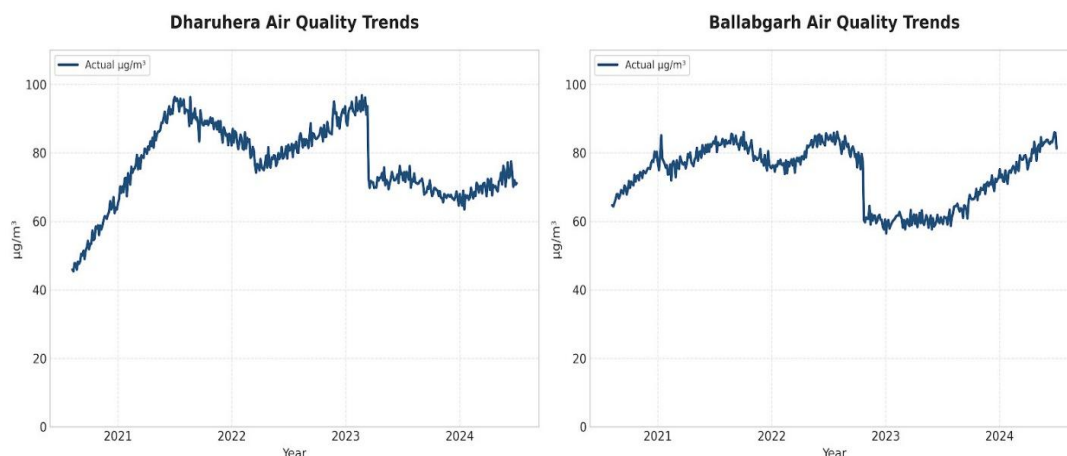


Fig.9. Air Quality Trend Analysis in Dharuhera and Ballabgarh

The figure provided indicates air quality over time for Dharuhera and Ballabgarh from late 2020 to mid-2024. It is represented in units of $\mu\text{g}/\text{m}^3$. As shown in the figure, Dharuhera has a double peak in late 2021 and then again in late 2022, both times reaching almost $100 \mu\text{g}/\text{m}^3$. It then significantly drops to around $70 \mu\text{g}/\text{m}^3$ at the start of 2023. It then plateaus before rising moderately in early 2024.

Ballabgarh follows a similar trend with multiple peaks between 80 and $85 \mu\text{g}/\text{m}^3$ between 2021 and 2022. Similar to several other cities in this dataset, Ballabgarh has a significant vertical drop to a baseline of around $60 \mu\text{g}/\text{m}^3$ at the start of 2023. However, over 2024, there has been a steady and consistent increase. By mid-2024, Ballabgarh has risen back to almost $85 \mu\text{g}/\text{m}^3$.

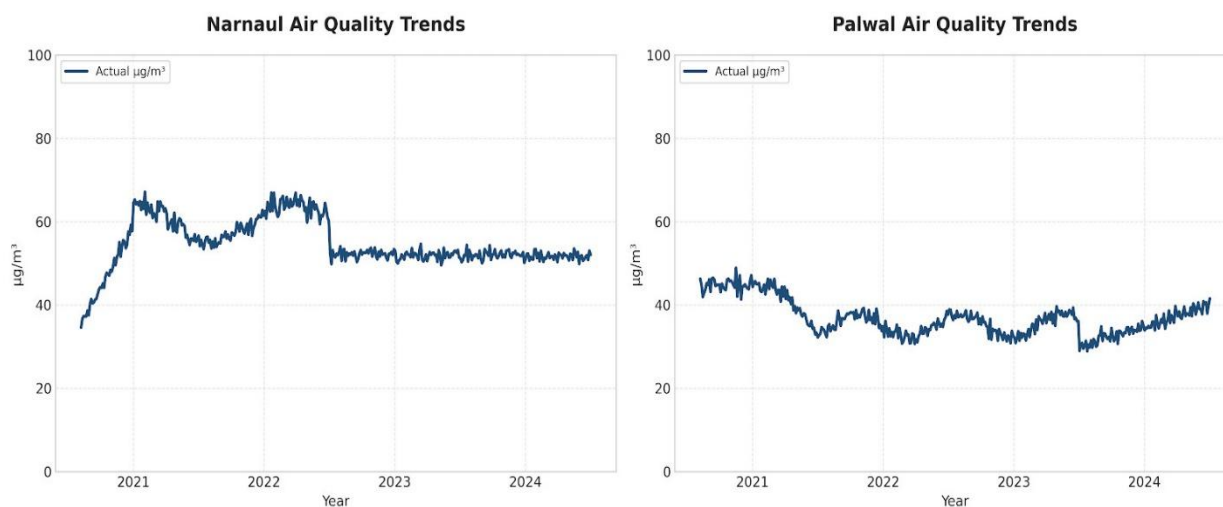


Fig.10. Comparative Analysis of Air Quality Variability in Narnaul and Palwal Regions

The figure provided illustrates the air quality trends for Narnaul and Palwal from late 2020 through mid-2024. Of all the cities considered, these two have the lowest overall pollutant concentrations, with neither city exceeding $70 \mu\text{g}/\text{m}^3$. The city of Narnaul has had two spikes, both of which were about $65 \mu\text{g}/\text{m}^3$, once in early 2021 and once in early 2022, followed by a sharp drop in early 2023. Since then, this city has maintained a remarkably steady state of

about $52 \mu\text{g}/\text{m}^3$ through 2024. The city of Palwal has a fluctuating, cyclical pattern, but with a much lower intensity overall. It started in late 2020, dipping in 2022, and hit a low point of about $30 \mu\text{g}/\text{m}^3$ in early 2023. Unlike all the other cities, which have maintained a horizontal line since the drop in early 2023, the city of Palwal has a steady rise starting in late 2023, reaching back up towards $40 \mu\text{g}/\text{m}^3$ by mid-2024.

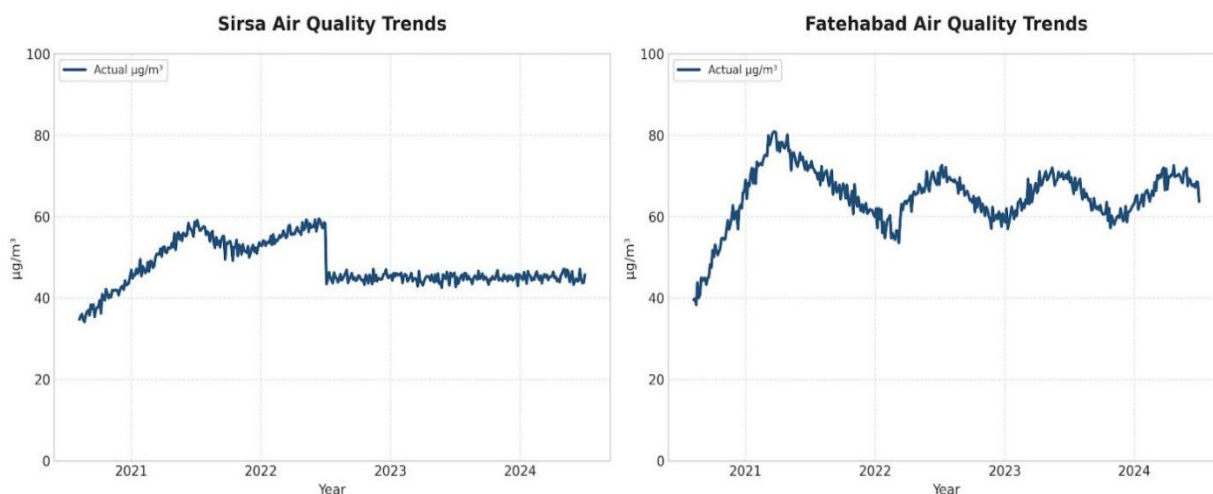


Fig.11. Analysis of Air Quality Variability in Sirsa and Fatehabad Regions

The figure provided plots the trends in air quality for Sirsa and Fatehabad from late 2020 to mid-2024 in terms of $\mu\text{g}/\text{m}^3$. From the figure, it is evident that for Sirsa, the concentration of pollutants increased steadily throughout 2020, starting at a concentration of around $35 \mu\text{g}/\text{m}^3$ before peaking at a concentration of around $60 \mu\text{g}/\text{m}^3$ in late 2022. Following this peak, there is a vertical drop in concentration in early 2023 before settling at a remarkably consistent concentration of around $45 \mu\text{g}/\text{m}^3$ throughout 2024. For

Fatehabad, however, the plot shows a more cyclical pattern for the concentration of pollutants throughout the period. Following a peak concentration in early 2021 of approximately $80 \mu\text{g}/\text{m}^3$, the plot shows annual fluctuations between a concentration of $60 \mu\text{g}/\text{m}^3$ and a concentration of $75 \mu\text{g}/\text{m}^3$. Unlike the remarkably consistent pattern observed for Sirsa, Fatehabad maintains this cyclical pattern throughout the period

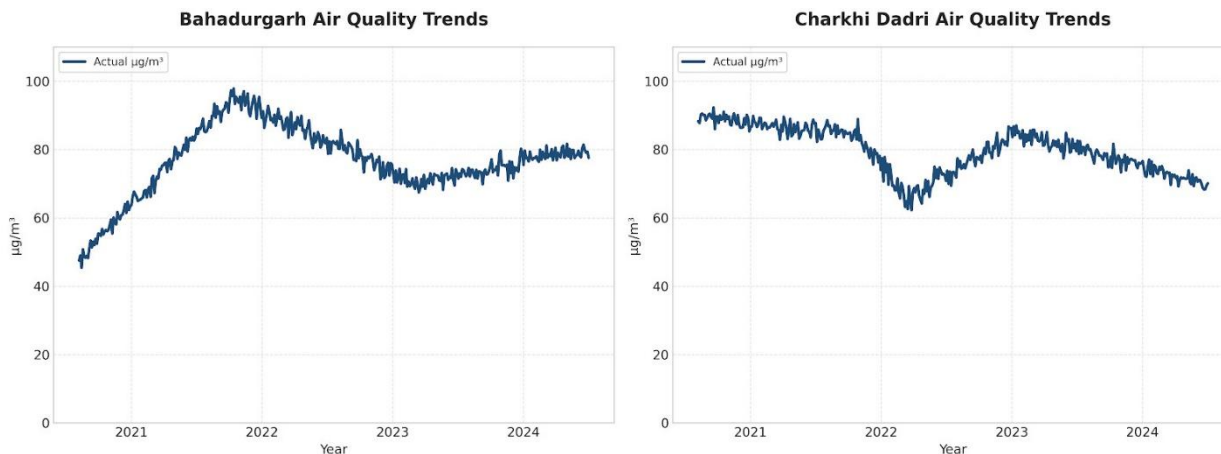


Fig.12. Analysis of Air Quality Variability in Bahadurgarh and Charkhi Dadri Regions

The figure provided indicates the air quality trends for Bahadurgarh and Charkhi Dadri from late 2020 to mid-2024. The air quality is represented in terms of $\mu\text{g}/\text{m}^3$. Bahadurgarh initially recorded a sharp increase in air quality. It began around $50 \mu\text{g}/\text{m}^3$ and peaked around $100 \mu\text{g}/\text{m}^3$ by the end of 2021. It then gradually decreased to a minimum of $70 \mu\text{g}/\text{m}^3$ in 2022 before rising to around $80 \mu\text{g}/\text{m}^3$ in 2024.

In Charkhi Dadri, air quality began at a high point of around $90 \mu\text{g}/\text{m}^3$ in 2020 and continued with a slight decline. It then sharply dropped to around $65 \mu\text{g}/\text{m}^3$ in early 2022. It then rose to a peak of around $85 \mu\text{g}/\text{m}^3$ in early 2023 before maintaining a steady decline to around $70 \mu\text{g}/\text{m}^3$ by mid-2024. Unlike other cities, both cities recorded a gradual and fluctuating change in air quality.

III. CONCLUSION

The air pollution level in Haryana during winters is one of the critical environmental issues, which is affected by the meteorological factors and various emission sources. The analysis reveals the variation in the air pollution level in the districts, which is due to the variation in the level of industrialization, urbanization, and agricultural activities. Although it was observed that significant improvements occurred in the air pollution level during the early part of 2023, it was not sustained over the period, and the trends showed stabilization or increasing trends in 2024. The major cities, such as Gurugram, Faridabad, Manesar, etc., are affected due to higher air pollution levels.

The cities such as Panchkula and Karnal show relatively better air quality trends, which reveal the success of the measures implemented in these regions. The analysis reveals the importance of the long-term measures for the improvement of air quality, along with the immediate measures. The Winter Action Plan focuses on the combination of immediate measures along with the long-term measures for the improvement of air quality.

REFERENCES

- [1] Central Pollution Control Board (CPCB). (2023). *National Air Quality Monitoring Programme (NAMP) Report*. Ministry of Environment, Forest and Climate Change, Government of India, New Delhi, India.
- [2] Central Pollution Control Board (CPCB). (2022). *Guidelines for Air Quality Management in India*. CPCB, New Delhi, India.
- [3] Government of India. (2019). *National Clean Air Programme (NCAP)*. Ministry of Environment, Forest and Climate Change (MoEFCC), New Delhi, India.
- [4] World Health Organization (WHO). (2021). *WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. WHO, Geneva, Switzerland.
- [5] World Health Organization (WHO). (2018). *Ambient air pollution: A global assessment of exposure and burden of disease*. WHO, Geneva, Switzerland.
- [6] Health Effects Institute (HEI). (2020). *State of global air 2020*. Special Report, HEI, Boston, MA.
- [7] Health Effects Institute (HEI). (2023). *State of global air 2023 report*. HEI, Boston, MA.
- [8] Ministry of Environment, Forest and Climate Change (MoEFCC). (2020). *India state-level climate change trends and air quality status report*. Government of India, New Delhi, India.
- [9] Haryana State Pollution Control Board (HSPCB). (2023). *Annual air quality status report of Haryana*. HSPCB, Panchkula, India.
- [10] IQAir. (2024). *World air quality report 2024*. (<https://www.iqair.com>) (accessed Month Day, Year).
- [11] Gurjar, B. R., Ravindra, K., and Nagpure, A. S. (2016). "Air pollution trends over Indian megacities and their local-to-global implications." *Atmospheric Environment*, 142, 475–495.
- [12] Sharma, M., and Dikshit, O. (2016). *Comprehensive study on air pollution and greenhouse gases (GHGs) in Delhi*. Indian Institute of Technology Kanpur, Kanpur, India.
- [13] Kumar, P., et al. (2020). "The nexus between air pollution, climate change and human health in India." *Atmospheric Chemistry and Physics*, 20, 1–21.
- [14] Jain, S., and Sharma, S. K. (2021). "Wintertime air quality deterioration in North India: Role of meteorology and emissions." *Environmental Pollution*, 268, 115–128.
- [15] Singh, V., et al. (2019). "Impact of crop residue burning on air quality in northern India." *Aerosol and Air Quality Research*, 19(5), 1234–1245.
- [16] European Environment Agency (EEA). (2020). *Air quality in Europe – 2020 report*. EEA, Luxembourg.
- [17] United Nations Environment Programme (UNEP). (2021). *Actions on air quality*. UNEP, Nairobi, Kenya.