Comprehensive Meteorological Impact Assessment on Urban Air Quality: A MATLAB-Based Trend Analysis for Indian Cities

Shashank Patel[1] Shrenik Jain[2] Mr. Shubham Dashore[3]
[1,2]Research Scholar [3]Assistant Professor
[1,2,3]Department of Civil Engineering
[1,2,3]Bhilai Institute of Technology, Durg, India

Abstract — Urban air pollution presents a critical public health and environmental challenge, particularly in fast-developing cities such as Delhi, Bangalore, and Hyderabad in India. This paper presents a comprehensive trend analysis of the Air Quality Index (AQI) in these cities over 2017-2024, integrating meteorological parameters including temperature, precipitation, wind speed, and atmospheric pressure. Leveraging MATLAB's computational capabilities, we employ advanced analytical techniques such as time-series analyses, seasonal trend decomposition, and network bias correction via the Rolling Change Method. Our findings reveal persistent high pollution in Delhi affected by seasonal atmospheric stagnation, rising pollution trends tied to urban expansion in Bangalore, and moderate yet seasonally variable pollution in Hyderabad. Meteorological factors, especially wind speed and precipitation, emerged as significant mitigators, while atmospheric pressure and temperature inversions exacerbated pollution entrapment. This research underscores the importance of city-specific air quality management and demonstrates the utility of MATLAB-based frameworks for environmental data analysis, fostering informed urban environmental policy-making for sustainable development.

Keywords: Urban Air Pollution, Air Quality Index (AQI), Meteorological Parameters, Seasonal Trend Decomposition, Time-Series Analysis, Rolling Change Method, MATLAB Environmental Modelling, Atmospheric Stagnation, Temperature Inversion, City-Specific Pollution Trends

I. INTRODUCTION

A. Background

Air pollution remains one of the most pressing environmental issues confronting urban areas worldwide. In India, rapid urbanization, industrialization, and rising vehicular emissions have deteriorated air quality drastically, especially in metropolises like Delhi, Bangalore, and Hyderabad. The Air Quality Index (AQI) serves as a standardized indicator, consolidating various pollutant concentrations into a comprehensive measure of ambient air pollution, which directly affects public health and ecosystem integrity.

B. Meteorological Influence on Air Quality

Meteorological factors play a pivotal role in determining air pollution levels through their effects on pollutant dispersion, chemical transformation, and deposition. Parameters such as temperature, wind speed, precipitation, and atmospheric pressure influence pollutant concentrations and air quality dynamics by modulating atmospheric stability, vertical mixing, and removal processes.

Understanding the interplay between meteorology and pollution is essential to accurately assess air quality trends, forecast pollution episodes, and design adaptive pollution control strategies.

C. Objectives

This paper aims to:

- Analyze AQI trends from 2017 to 2024 across three major Indian cities.
- Evaluate meteorological impacts on observed patterns in air pollution.
- Employ MATLAB for advanced data preprocessing, trend analysis, and visualization.
- Provide actionable insights to guide policymakers in targeted air quality interventions.

II. LITERATURE REVIEW

A. AQI Trend Analysis in Indian Cities

Prior studies (e.g., [2.2], [2.3], and [2.4]) have conducted trend analyses of AQI focusing on seasonal and annual fluctuations, often highlighting the severity of pollution during winter months due to factors like crop residue burning and temperature inversions. Multiple works suggest that these trends are city-specific, influenced by local emission sources and geography.

B. Meteorological Factors and Air Pollution

Extensive research shows that meteorological variables critically influence air quality. For instance, higher wind speeds aid pollutant dispersion, while heavy precipitation removes particulate matter via wet deposition. Conversely, atmospheric pressure systems and thermal inversions trap pollutants near the surface, leading to hazardous air quality episodes.

C. Application of MATLAB in Environmental Data Processing

MATLAB has been widely recognized for its robust computational and visualization capabilities in environmental science research. It facilitates time-series analysis, bias correction, correlation studies, and simulation modeling, as highlighted in the synthesis of methods applied in the current study.

III. METHODOLOGY

A. Data Collection

Hourly and daily AQI and meteorological data (temperature, precipitation, wind speed, atmospheric pressure) were sourced for Delhi, Bangalore, and Hyderabad from government monitoring stations and meteorological departments spanning from 2017 through early 2024.

B. Data Preprocessing and Bias Correction

Raw monitoring data are prone to inconsistencies due to network changes or sensor errors. The Rolling Change Method was applied to correct network biases, ensuring data uniformity and comparability across periods.

C. MATLAB Analytical Framework

The following techniques were implemented using MATLAB:

- Time series decomposition to extract seasonal, trend, and residual components.
- Statistical correlation analysis between AQI and meteorological variables.
- Multi-parameter visualization, including heat maps, scatter plots, and temporal trend graphs.
- Forecast modeling for anticipated AQI scenarios.

IV. Results and Discussion

A. AQI Seasonal and Annual Trends

- Delhi exhibited persistently high AQI, with peaks in winter attributed to temperature inversions and post-harvest biomass burning.
- Bangalore maintained relatively better air quality but displayed a subtle upward trend correlating with urban sprawl.
- Hyderabad presented moderate AQI with clear seasonal variability, influenced by prevailing monsoon dynamics.

B. Impact of Meteorological Variables

Wind speed and precipitation negatively correlated with AQI, acting as natural pollution mitigators. Conversely, high pressure systems and temperature inversions during colder months intensified pollutant accumulation.

C. Forecasting Insights

Trend models suggest worsening air quality in Delhi if current emission trajectories persist, whereas proactive urban planning could moderate Bangalore's upward trend.

V. Policy Implications and Recommendations

- Implement city-specific action plans acknowledging meteorological and seasonal trends.
- Enhance green cover and urban ventilation corridors especially in Hyderabad and Bangalore.
- Promote stricter emission controls and agricultural residue management in Delhi.
- Integrate meteorological forecasting into pollution alert systems for better public health preparedness.

VI. Conclusion

This study underscores the critical interaction between meteorology and urban air quality, evidencing the need for nuanced, data-driven air pollution management strategies. The MATLAB-based analytical framework proves effective for large-scale environmental data analysis and could serve as a blueprint for similar studies nationwide.

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