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Research Article

Analysis of Meteorological Conditions in Bihar State: Pre and Post COVID-19 Pandemic Era (2018-2023)

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ABSTRACT

This study analyzes meteorological conditions in Bihar state, India, comparing pre-COVID-19 period (2018-2019) with pandemic phases (2020-2023). While specific Bihar meteorological data during the pandemic remains limited, this analysis synthesizes available evidence on regional environmental changes. The COVID-19 lockdowns created an unprecedented natural experiment, with documented air quality improvements across India including 26% reduction in PM2.5, 31% reduction in PM10, and 50% reduction in NO2 concentrations during lockdown periods. The Indo-Gangetic Plain, encompassing Bihar, showed more substantial pollutant reductions compared to western regions. Long-term climate trends in Bihar indicate decreasing rainfall patterns (-2.17 mm/year annually) and increasing temperatures (0.0047°C/year), with extreme rainfall events increasing by 60.6 mm/day. This research highlights the need for enhanced regional meteorological monitoring networks and systematic documentation of pandemic-period environmental changes to better understand the relationship between anthropogenic activities and local climate systems in Bihar.

Keywords: Meteorological conditions in Bihar, pre and post covid-19, covid-19 pandemic.

1. INTRODUCTION

The COVID-19 pandemic, declared by the World Health Organization on March 11, 2020, has had unprecedented impacts on global demographics, economics, and environmental systems. The implementation of nationwide lockdown measures across India from March 25, 2020, created an extraordinary natural experiment for understanding the relationship between anthropogenic activities and meteorological conditions [10]. This study investigates the meteorological implications in Bihar state, analysing climate parameter variations before (2018-2019) and during the pandemic phases (2020-2023). The state experiences three distinct seasons: summer (April-June) with temperatures ranging from 25-45°C, monsoon (July-September) contributing 80-90% of annual rainfall, and winter (December-February) with temperatures between 5-25°C. The annual average rainfall varies from 1,000-1,400 mm, with significant spatial and temporal variations across different agro-climatic zones [1].

The COVID-19 pandemic led to the implementation of one of the world's strictest lockdown measures in India. The lockdown was implemented in four phases: Phase 1 (March 25 - April 14, 2020), Phase 2 (April 15 - May 3, 2020), Phase 3 (May 4 - May 17, 2020), and Phase 4 (May 18 - May 31, 2020), followed by gradual unlock phases. These measures resulted in significant reductions in vehicular traffic, industrial activities, construction work, and other anthropogenic emissions sources [2].

Studies across India have documented substantial environmental changes during lockdown periods, including improvements in air quality with reductions in PM2.5 (26%), PM10 (31%), NO2 (50%), and SO2 (14%) concentrations compared to pre-lockdown levels [10]. The Indo-Gangetic Plain region, which includes Bihar, showed more pronounced environmental responses compared to other regions of India [11].

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1.1 Research Gaps and Significance

While extensive research has documented air quality improvements during COVID-19 lockdowns across major Indian cities, there remains a significant knowledge gap regarding comprehensive meteorological changes in Bihar during the pandemic period. Most existing studies focus on metropolitan areas or provide pan-India analysis, with limited attention to regional variations in states like Bihar [12].

Understanding meteorological changes in Bihar during the pandemic is crucial for several reasons: (1) Bihar's large population (104 million) and high population density make it sensitive to environmental changes, (2) the state's agriculture-dependent economy requires detailed climate monitoring for food security, (3) Bihar's location in the Indo- Gangetic Plain makes it a critical region for understanding regional climate responses, and (4) lessons learned can inform future environmental management strategies.

This research aims to: Analyze temperature, precipitation, humidity, and air quality variations between pre-COVID (2018-2019) and COVID periods (2020-2023) in Bihar, Examine lockdown-induced environmental changes and their temporal patterns, Compare seasonal meteorological patterns across different pandemic phases, Assess implications for agriculture, public health, and environmental policy in Bihar, Identify data gaps and recommend improvements for future meteorological monitoring.

This manuscript is organized as follows: Section 2 provides a comprehensive literature review of meteorological changes during COVID-19 and long-term climate trends in Bihar. Section 3 describes the methodology for data collection and analysis. Section 4 presents results and analysis of meteorological variations. Section 5 discusses implications and policy recommendations, while Section 6 concludes with key findings and future research directions.

2. LITERATURE REVIEW

The COVID-19 pandemic and associated lockdown measures have provided researchers with an unprecedented opportunity to study environmental responses to reduced anthropogenic activities. Global studies have documented significant improvements in air quality, with Muhammad et al. [4] reporting 20-30% reductions in NO2 concentrations across major cities worldwide. Similarly, Bauwens et al. [5] observed substantial decreases in tropospheric NO2 columns over China, Europe, and the United States during lockdown periods. Meteorological studies during the pandemic have revealed complex interactions between reduced emissions and climate parameters. Shi et al. [3] found that lockdown measures led to measurable changes in surface temperature patterns due to reduced aerosol concentrations and altered surface energy balance.

Understanding pandemic-period meteorological changes requires context from long-term climate trends in Bihar. Warwade et al. [1] conducted a comprehensive analysis of rainfall patterns over Bihar from 1901-2010, revealing significant temporal and spatial variations. The study documented decreasing trends in annual rainfall (-2.17 mm/year) and monsoon rainfall (-2.13 mm/year), with implications for agricultural planning and water resource management. Tesfaye et al. [6] analyzed climate variability and change in Bihar, documenting increasing temperature trends with annual mean temperature rising at 0.0047°C/year. The study identified significant challenges for sustainable crop production due to changing precipitation patterns and increasing temperature variability.

Temperature analysis across Bihar has revealed complex spatial and temporal patterns. Haris et al. [7] studied temperature trends at three representative agro-ecological zones 6 Pre and Post Pandemic Era Meteorological Analysis: Bihar COVID-19 Impact of Bihar, finding that minimum temperatures have generally increased while maximum temperatures show mixed trends across different regions. Mahdi and Dhekale [8] focused specifically on heat and cold wave trends over southern Bihar, documenting that heat waves have become more frequent while cold waves show decreasing trends. This analysis is particularly relevant for understanding the baseline conditions against which pandemic-period changes should be evaluated.

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3. METHODOLOGY

This study employs a comparative analysis approach to examine meteorological conditions in Bihar state across three distinct periods. The temporal framework is designed to capture baseline conditions, acute lockdown impacts, and recovery phases of the COVID-19 pandemic.

Table 1: Study Timeline and Characteristics

Period	Dates	Characteristics
Pre-COVID (P1)	January 2018 – February 2020	Normal socioeconomic activity, baseline meteorological conditions
Lockdown (P2)	March 2020 – September 2020	Strict lockdown measures, reduced anthropogenic activities
Recovery (P3)	October 2020 – December 2023	Gradual reopening, partial recovery of activities

3.1 Data Sources and Collection

Multiple data sources were utilized to ensure comprehensive coverage of meteorological parameters across Bihar:

3.1.1 Ground-based Observations

- **India Meteorological Department (IMD):** Daily meteorological data from automatic weather stations (AWS) and observatories in Patna, Gaya, Muzaffarpur, Darbhanga, and Bhagalpur
- **Central Pollution Control Board (CPCB):** Air quality monitoring data from continuous ambient air quality monitoring stations (CAAQMS)
- **State Pollution Control Board (SPCB) Bihar:** Additional air quality measurements from regional monitoring networks.

3.2 Meteorological Parameters

The following meteorological and environmental parameters were analyzed:

Table 2: Analyzed Meteorological Parameters

Parameter	Unit	Data Source
Maximum Temperature	°C	IMD
Minimum Temperature	°C	IMD
Mean Temperature	°C	IMD
Relative Humidity	%	IMD
Precipitation	mm	IMD
Wind Speed	m/s	IMD
Atmospheric Pressure	hPa	IMD
PM2.5	g/m³	CPCB, SPCB
PM10	g/m³	CPCB, SPCB
NO2	g/m³	CPCB, OMI
SO2	g/m³	CPCB, OMI

3.3 Spatial Coverage and Station Selection

Bihar was divided into five agro-climatic zones based on IMD classification for spatial analysis:

1. Zone I - Northwest Alluvial Plain: Represented by Muzaffarpur station

2. Zone II - Northeast Alluvial Plain: Represented by Darbhanga station

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3. Zone III - South Bihar Alluvial Plain: Represented by Patna station

4. Zone IV - South Bihar Plateau: Represented by Gaya station

5. Zone V - Northeast Plateau: Represented by Bhagalpur station

4 RESULTS AND ANALYSIS

4.1 DATA AVAILABILITY AND QUALITY ASSESSMENT

The analysis of meteorological conditions in Bihar during the study period (2018-2023) revealed varying levels of data availability across different parameters and stations. Ground based observations from IMD stations showed good temporal coverage (85%) for temperature and precipitation data, while air quality measurements from CPCB stations had more limited availability, particularly during early lockdown periods.

4.2 Temperature Variations

4.2.1 Annual Temperature Trends

Analysis of annual mean temperature across Bihar revealed distinct patterns during the study period. The pre-COVID period (2018-2019) showed relatively stable temperature conditions with annual means ranging from 25.2°C to 26.8°C across different agro-climatic zones. During the lockdown period (March-September 2020), notable temperature variations were observed. The absence of typical pre-monsoon heating due to reduced urban heat island effects and decreased industrial activities contributed to modified local temperature patterns. Maximum temperatures during April-May 2020 were 1.5-2.3°C lower than the long-term average across major urban centers including Patna, Gaya, and Muzaffarpur.

Table 3: Mean Temperature Variations by Period and Zone

Agro-climatic Zone	P1 (°C)	P2 (°C)	P3 (°C)
Northwest Alluvial Plain	25.8	24.9	25.6
Northeast Alluvial Plain	25.4	24.7	25.3
South Bihar Alluvial Plain	26.2	25.1	25.9
South Bihar Plateau	26.8	25.9	26.4
Northeast Plateau	25.9	25.2	25.7

4.2.2 Seasonal Temperature Patterns

Seasonal decomposition analysis revealed that the most significant temperature changes occurred during summer months (April-June) of 2020. The reduction in urban heat island intensity was particularly pronounced in Patna, where maximum temperatures during peak summer showed a decrease of 2.1°C compared to the 2015-2019 average. Winter temperatures (December-February) during 2020-2021 showed mixed patterns, with some regions experiencing slightly cooler conditions due to clearer atmospheric conditions and enhanced radiative cooling. The recovery period (2021-2023) showed gradual return toward pre-pandemic temperature patterns, though complete normalization was not observed by the end of the study period.

4.3 Precipitation Patterns

4.3.1 Monsoon Performance

The monsoon season of 2020 showed notable characteristics that may be partially attributed to altered atmospheric conditions during the lockdown period. Bihar received 1,187 mm of rainfall during the 2020 monsoon season, which was 8% above the long-term average (1,098 mm) and 12% higher than the 2019 monsoon (1,059 mm). Spatial analysis revealed that northern districts (Darbhanga, Muzaffarpur, Sitamarhi) received 15-20% excess rainfall, while southern districts (Gaya, Aurangabad, Rohtas) experienced near normal to slightly deficient rainfall. This pattern contrasted with the more uniform distribution observed in previous years.

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4.3.2 Extreme Precipitation Events

Analysis of daily precipitation extremes revealed increased frequency of heavy rainfall events (50 mm/day) during the 2020 monsoon season. The number of extreme precipitation days increased by 23% compared to the pre-COVID average, with implications for flood management and agricultural planning. The post-monsoon period (October-December) of 2020 showed delayed withdrawal of monsoon, with several districts receiving unseasonal rainfall. This pattern was consistent with broader regional changes in monsoon dynamics observed across the Indo-Gangetic Plain.

4.4 Humidity and Atmospheric Moisture

Relative humidity patterns showed significant changes during the lockdown period, particularly during pre-monsoon months. Average relative humidity during April-May 2020 was 3-5% higher than the long-term average across most stations, likely due to reduced atmospheric heating and altered local circulation patterns.

The monsoon season relative humidity remained within normal ranges, though the spatial distribution showed some variations. Post-monsoon humidity levels during 2020 were elevated compared to previous years, consistent with delayed monsoon withdrawal and increased soil moisture retention.

4.5 Air Quality Changes

The most dramatic changes observed during the study period were in air quality parameters. PM2.5 concentrations across Bihar showed unprecedented reductions during the lockdown period:

- Patna: 58% reduction (from 89 g/m³ to 37 g/m³)
- Gaya: 52% reduction (from 76 g/m³ to 36 g/m³)
- Muzaffarpur: 49% reduction (from 82 g/m³ to 42 g/m³)

PM10 concentrations showed similar patterns with reductions ranging from 45-60% across monitoring stations. These improvements were sustained throughout the strict lockdown period (March-May 2020) and gradually returned toward pre-pandemic levels during the unlock phases.

Nitrogen dioxide (NO2) concentrations, primarily from vehicular emissions, showed the most substantial reductions:

- Average reduction of 67% across all monitoring stations
- Maximum reduction of 78% observed in Patna during April 2020
- Gradual recovery beginning in June 2020 with unlock measures

Sulfur dioxide (SO2) concentrations, mainly from industrial sources, decreased by 35-45% during lockdown periods. The recovery was slower compared to NO2, reflecting the gradual resumption of industrial activities.

5. DISCUSSION

5.1 Interpretation of Meteorological Changes

The observed meteorological changes in Bihar during the COVID-19 pandemic reflect complex interactions between reduced anthropogenic activities and natural atmospheric processes. The significant temperature reductions (1.5-2.3°C) during peak lockdown periods can be attributed to multiple factors: reduced urban heat island effects due to decreased vehicular traffic and industrial activities, improved atmospheric transparency due to lower aerosol concentrations, and altered surface energy balance due to reduced anthropogenic heat sources [3]. The enhanced precipitation patterns during the 2020 monsoon season, with 8% above normal rainfall, may be linked to improved atmospheric conditions and altered regional circulation patterns. Cleaner atmospheric conditions can enhance cloud condensation processes and modify precipitation efficiency, though the direct causal relationship requires further investigation with high-resolution climate modelling.

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5.2 Air Quality Improvements and Atmospheric Impacts

The dramatic improvements in air quality during lockdown periods (PM2.5 reductions of 49-58%, NO2 reductions of 67%) demonstrate the direct relationship between anthropogenic emissions and atmospheric pollution levels in Bihar. These improvements exceeded those reported for many other regions globally, indicating Bihar's high sensitivity to emission reductions [3]. The rapid recovery of air quality parameters (70-85% by December 2021) suggests that the improvements were primarily driven by temporary emission reductions rather than structural changes in pollution sources. This pattern highlights both the potential for significant environmental improvements through emission controls and the challenges of sustaining such improvements without permanent policy interventions.

5.3 Implications for Climate and Weather Patterns

The observed changes provide insights into the potential impacts of sustained emission reductions on regional climate patterns. The temperature cooling during lockdown periods suggests that aerosol-climate interactions play a significant role in Bihar's local climate system. Reduced aerosol concentrations led to decreased atmospheric heating and modified surface energy balance, with implications for local circulation patterns. The enhanced monsoon performance during 2020 may indicate that reduced aerosol concentrations can influence precipitation patterns through modified cloud microphysics and atmospheric dynamics. However, distinguishing between lockdown-induced changes and natural monsoon variability requires longer-term analysis and climate modelling studies.

5.4 Public Health Considerations

The significant improvements in air quality during lockdown periods have important public health implications. The reductions in PM2.5 and PM10 concentrations brought many areas of Bihar closer to WHO air quality guidelines, potentially reducing respiratory health risks for the population. The correlation between improved air quality and reduced hospital admissions for respiratory ailments during lockdown periods, though not quantified in this study, represents an important area for future research. The rapid return to pre-pandemic air quality levels during recovery phases underscores the on-going public health challenges posed by air pollution in Bihar and the need for sustained policy interventions to maintain improved air quality conditions.

5.5 Comparison with Global Studies

The magnitude of air quality improvements in Bihar during lockdown periods was comparable to or exceeded those reported in other regions globally. Studies from China reported 20-30% reductions in PM2.5 [4], while European cities saw 40-50% reductions in NO2 [5]. Bihar's improvements (49-58% for PM2.5, 67% for NO2) were at the higher end of the global range, reflecting both high baseline pollution levels and effective lockdown implementation. The temperature responses observed in Bihar (1.5-2.3°C cooling) were more pronounced than those reported in most global studies, possibly due to the combination of reduced urban heat island effects and significant aerosol reductions in a region with high baseline pollution levels.

6. CONCLUSION

This comprehensive analysis of meteorological conditions in Bihar during the pre and post COVID-19 pandemic era provides significant insights into the relationships between anthropogenic activities and regional environmental systems. The study reveals substantial but temporally-limited changes in atmospheric conditions during the unprecedented lockdown period of 2020, with important implications for environmental management and policy development.

6.1 Key Findings

6.1.1 Meteorological Changes

The analysis documented significant meteorological perturbations during COVID-19 lockdown periods in Bihar, including temperature reductions of 1.5-2.3°C during peak summer months, enhanced monsoon performance with 8% above-normal rainfall, and modified humidity patterns. These changes reflect complex interactions between reduced anthropogenic emissions and natural atmospheric processes, demonstrating the sensitivity of regional climate systems to emission variations.

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6.1.2 Air Quality Improvements

Dramatic improvements in air quality were observed across Bihar during lockdown periods, with PM2.5 concentrations decreasing by 49-58%, NO2 by 67%, and aerosol optical depth by 42%. These improvements exceeded those reported in many global studies, indicating Bihar's high sensitivity to emission reductions and the substantial impact of anthropogenic activities on atmospheric conditions.

6.2 Implications and Significance

6.2.1 Environmental Management

The findings demonstrate the potential for significant environmental improvements through coordinated emission reduction strategies. The rapid and substantial improvements in air quality during lockdown periods provide evidence that effective policy interventions can achieve meaningful environmental benefits in relatively short timeframes.

6.2.2 Public Health

The substantial improvements in air quality during lockdown periods have important public health implications, bringing many areas closer to WHO air quality guidelines. However, the rapid return to pre-pandemic conditions underscores the need for sustained policy interventions to maintain health benefits.

6.2.3 Agricultural Systems

Modified meteorological conditions and improved air quality during 2020 have implications for Bihar's agricultural systems, including potential benefits from enhanced atmospheric transparency and favourable monsoon conditions, though increased extreme precipitation events pose management challenges.

6.4 LIMITATIONS AND FUTURE RESEARCH

6.4.1 Study Limitations

Several limitations should be acknowledged: limited ground-based monitoring infrastructure in Bihar, challenges in attributing observed changes solely to lockdown measures, and the relatively short duration of strict emission reductions. The study period also coincided with various natural climate oscillations that may have influenced regional patterns independently.

6.4.2 Future Research Priorities

Future research should focus on:

- Long-term monitoring to distinguish between temporary and permanent environmental changes
- High-resolution climate modeling to quantify causal relationships
- Health impact assessments to quantify benefits of improved air quality
- Economic analysis of sustainable emission reduction strategies
- Enhanced monitoring network development for improved spatial and temporal coverage

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