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India

The Spatial Pattern of NO2 Concentrations at District Level in Uttar Pradesh during the rainy season

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Abstract

This research study examines the spatial pattern of NO2 concentrations at the district level in Uttar Pradesh during the monsoon season. Understanding the distribution and variability of NO2 pollution in this region is crucial for effective air quality management and the development of targeted mitigation strategies. The "COPERNICUS/S5P/OFFL/L3_NO2" dataset was used in this study. The study employed spatial analysis techniques, including spatial autocorrelation Moran's index. The results revealed a significant clustered pattern, as evidenced by a high positive Moran's I index (0.617527) and a z-score of 11.236076, indicating a less than 1% likelihood that the observed pattern could be attributed to random chance. This spatial clustering implies the presence of localized areas with similar levels of NO2 pollution, potentially associated with common emission sources or pollutant transport mechanisms. The findings highlight the importance of implementing location-specific pollution control strategies to mitigate NO2 levels in affected areas. Further research is warranted to identify the specific sources and factors contributing to the observed spatial clustering. Overall, this study provides valuable insights into the spatial distribution of NO2 concentrations in Uttar Pradesh during the monsoon season, aiding policymakers and stakeholders in addressing air pollution and improving environmental health in the region.

Keywords: Geostatistics, No_2, Uttar Pradesh, OLS

1. Introduction

Air pollution is a critical environmental issue with significant impacts on human health and the environment Air pollution is a growing global concern due to its adverse impacts on human health, ecosystems, and climate (World Health Organization, 2018; IPCC, 2018). Among various air pollutants, nitrogen dioxide (NO2) is of particular interest due to its association with respiratory illnesses, cardiovascular diseases, and environmental degradation (Giles et al., 2019; Brauer et al., 2019). The spatial distribution of NO2 concentrations provides valuable insights into the emission sources and the effectiveness of pollution control measures (Beckerman et al., 2013; Liu et al., 2017). Understanding the spatial pattern of NO2 concentrations at a district level during the monsoon season is crucial, as it can aid in developing targeted strategies to mitigate pollution and improve air quality.

Uttar Pradesh, one of the most populous states in India, faces significant air pollution challenges, particularly during the monsoon season when atmospheric conditions and pollutant transport mechanisms vary (Gupta et al., 2019; Kumar et al., 2020). Despite previous studies on air pollution in Uttar Pradesh, there remains a dearth of research focusing on the spatial pattern of NO2 concentrations at a district level during the monsoon season (Singh et al., 2018; Tiwari et al., 2021). This study aims to fill this gap by investigating the spatial distribution of NO2 concentrations in Uttar Pradesh during the monsoon season, providing valuable insights for policymakers and stakeholders to formulate effective air pollution control strategies.

2. Methodology

2.1 Study Area

Uttar Pradesh, located in northern India, serves as the study area for this research. It is one of the most populous states in India, covering an area of approximately 243,290 square kilometers (Government of Uttar Pradesh, 2022). The state is characterized by diverse geographical features, including the fertile Gangetic plains in the north and the Vindhya Range and the Himalayan foothills in the south (Figure 1).

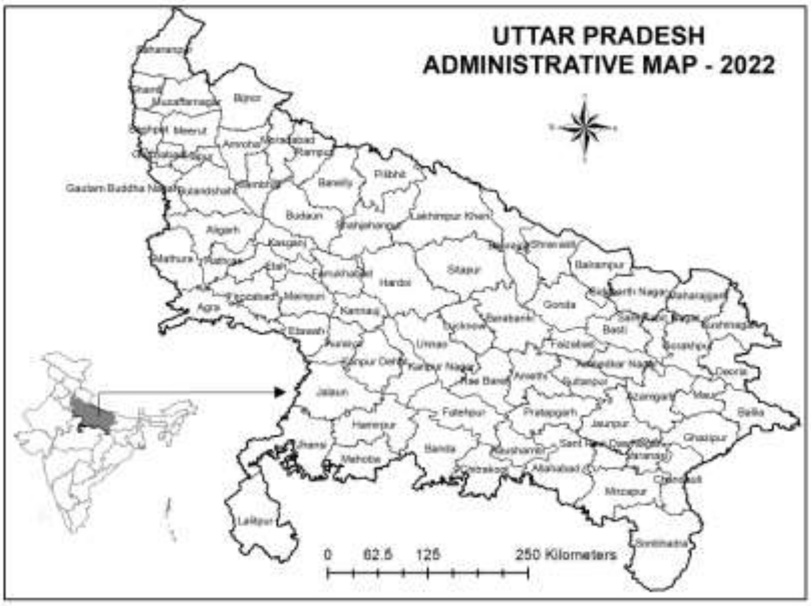

Figure 1 Study Area

Uttar Pradesh experiences a range of climatic conditions, with distinct seasons including summer, monsoon, post-monsoon, and winter (Sharma et al., 2019). The monsoon season, spanning from June to September, is characterized by heavy rainfall and plays a crucial role in shaping the atmospheric conditions and pollutant dispersion patterns in the region (Gupta et al., 2019).

With a significant population and extensive industrial and vehicular activities, Uttar Pradesh faces substantial air pollution challenges. The major sources of air pollution in the state include industrial emissions, vehicular exhaust, agricultural activities, and biomass burning (Sharma et al., 2019; Kumar et al., 2020). However, there is limited research specifically focusing on the spatial pattern of NO2 concentrations at a district level during the monsoon season in Uttar Pradesh.

Understanding the spatial distribution of NO2 concentrations in Uttar Pradesh during the monsoon season is crucial for formulating targeted air pollution control strategies and improving the overall air quality in the state.

2.2 Flow Chart

The flowchart illustrates the step-by-step process followed in the study. The first stage involves data acquisition, where the COPERNICUS/S5P/OFFL/L3_NO2 dataset is obtained. In the data preprocessing stage, the raw data is cleaned, formatted, and transformed into a suitable format for analysis. The next step is spatial analysis, where the spatial distribution of NO2 concentrations is examined in relation to the geographic regions under consideration. The results and findings obtained from the analysis are interpreted and discussed in detail. Finally, the study concludes with summarizing the key findings and providing recommendations for further research or policy implications (Figure 2).

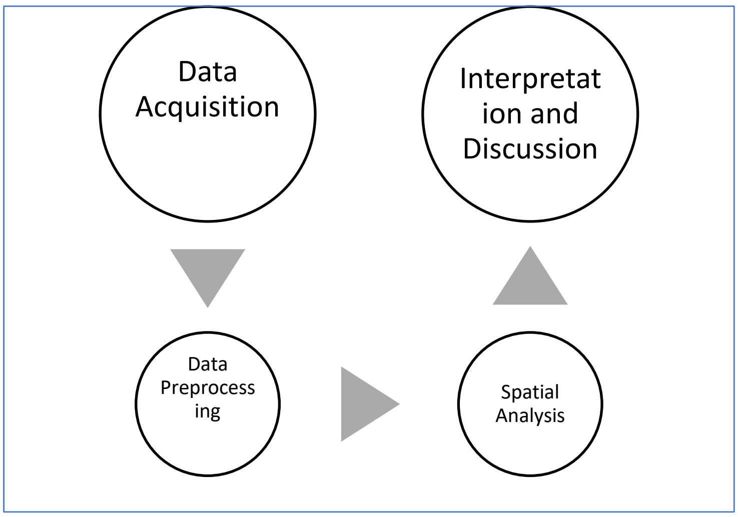

Figure 2 Flow Chart

2.2 Data Source

The "COPERNICUS/S5P/OFFL/L3_NO2" dataset was used in this study, It is derived from the Sentinel-5 Precursor (S5P) satellite mission, provides valuable information on nitrogen dioxide (NO2) concentrations in the atmosphere (European Space Agency [ESA], 2021). This dataset utilizes data from the TROPOMI sensor onboard the satellite to measure NO2 levels (ESA, 2021).

Uttar Pradesh, located in northern India, experiences distinct seasons, including winter, summer, and monsoon (Mishra et al., 2020). During the winter season (November to February), low temperatures, stable atmospheric conditions, and increased fossil fuel usage for heating contribute to the accumulation of air pollutants, including NO2 (Naja et al., 2013; Mishra et al., 2020).

The "COPERNICUS/S5P/OFFL/L3_NO2" dataset allows for the analysis of spatial patterns and variations of NO2 concentrations at the district level in Uttar Pradesh during the winter season (Behera et al., 2017). Geostatistical techniques, such as interpolation and spatial modeling, can be employed to understand the distribution of NO2 and identify areas with high pollution levels (Cai et al., 2017; Herrera et al., 2018).

This geostatistical analysis of the "COPERNICUS/S5P/OFFL/L3_NO2" dataset will provide insights into the spatial distribution of NO2 concentrations and assist in the formulation of targeted interventions for air pollution management (Naja et al., 2014). By utilizing the data, researchers can assess the factors influencing the variations in NO2 concentrations and develop effective strategies for pollution control (Behera et al., 2017; Naja et al., 2014).

For accurate citation and further technical details of the "COPERNICUS/S5P/OFFL/L3_NO2" dataset, it is advisable to refer to the official documentation or website provided by the European Space Agency (ESA, 2021).

Data for this research study was collected for the months of June, July, August, and September. These months correspond to the monsoon season in Uttar Pradesh, which is characterized by heavy rainfall and significant changes in atmospheric conditions. By focusing on this specific time period, the study aims to capture the seasonal variations and the impact of monsoon rainfall on NO2 concentrations in the region. Collecting data across these months provides a comprehensive understanding of the spatial pattern and variability of NO2 pollution during the monsoon season in Uttar Pradesh.

2.3 Data Analysis

The analysis of the data in this study incorporates the use of the standard deviation (σ) as a statistical measure to quantify the dispersion or variability of the dataset. The formula for calculating the standard deviation is:

$$\sigma = \text{sqrt}\left(\left(\sum (x_i - \bar{x})^2\right) / (n - 1)\right) \text{.......Eq. 1}$$

In this formula:

- σ represents the standard deviation.
- xi refers to each individual value in the dataset.
- $\bar{x}$ denotes the mean of the dataset.
- n represents the total number of observations in the dataset.

The standard deviation provides a measure of how much the individual values of the dataset deviate from the mean. A higher standard deviation indicates a greater spread or variability in the dataset, while a lower standard deviation suggests less dispersion and a more concentrated distribution of values around the mean.

By applying the standard deviation formula to No_2 data at the district level in Uttar Pradesh, we can assess the degree of variability in vegetation dynamics across different districts and over the specified time period.

3. Results & Discussion

3.1 NO_2 Distribution

The results of the study indicate the standard deviation of NO2 concentrations at the district level in Uttar Pradesh during the monsoon season. The standard deviation serves as a measure of the variability or dispersion of NO2 concentrations within each district.

Among the districts, districts like Gautam Buddha Nagar (4.491) and Ghaziabad (3.112) displayed higher standard deviations, indicating greater NO2 concentrations.

Some districts, such as Allahabad (0.3244), Bareilly (-0.0003), and Varanasi (-0.00032), showed near-zero or negligible standard deviations, suggesting relatively stable NO2 concentrations during the monsoon season.

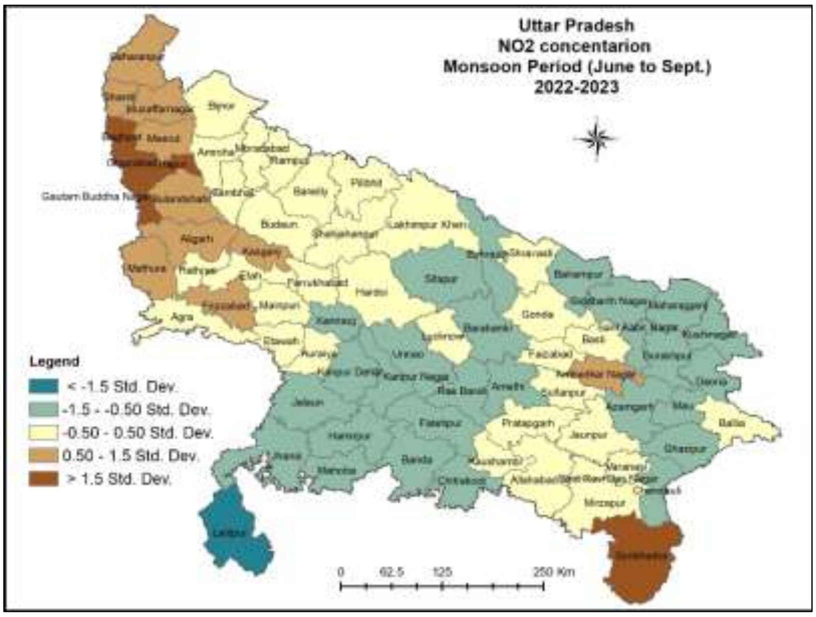

Figure 3 Nitrogen Dioxide Concentration

Several districts exhibited negative standard deviations, including Auraiya (-0.455), Azamgarh (-0.563), and Ballia (-0.4159). These negative values indicate that the NO2 concentrations in these districts were generally lower than the mean concentration for the entire study area.

Districts with positive standard deviations, such as Baghpat (1.580), Bulandshahr (1.3053), and Meerut (0.9459), indicate higher variability and a wider range of NO2 concentrations during the monsoon season.

It is worth noting that districts with larger standard deviations may experience more significant fluctuations in NO2 concentrations, highlighting the spatial heterogeneity of air pollution within Uttar Pradesh during the monsoon season.

3.2 NO_2 Spatial Pattern

The results indicate that there is a clustered pattern in the spatial distribution of NO2 concentrations at the district level in Uttar Pradesh during the monsoon season. This is supported by the high value of Moran's I index, which measures spatial autocorrelation**.**

The Moran's I index is calculated to be 0.617527, indicating a strong positive spatial autocorrelation. This suggests that districts with similar NO2 concentrations tend to be clustered together, while districts with contrasting concentrations are also clustered.

The expected index is -0.013514, representing the index value that would be expected under the assumption of a random spatial distribution. The positive value of the Moran's I index (0.617527) indicates that the actual spatial pattern of NO2 concentrations deviates significantly from randomness.

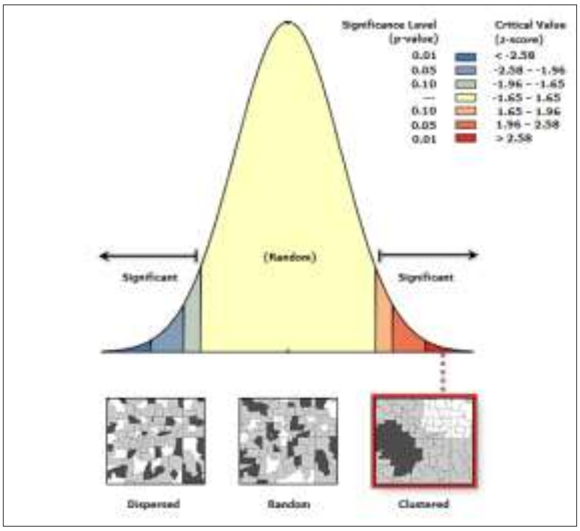

Figure 4 Spatial Autocorrelation Report

The z-score of 11.236076 further confirms the statistical significance of the observed spatial pattern. A z-score measures the number of standard deviations by which an observed value deviates from the expected value. In this case, the high positive z-score suggests that the observed Moran's I index is significantly higher than what would be expected by chance alone.

The p-value associated with the z-score is reported as 0.000000, indicating a probability of less than 0.0001 (or less than 1%) that the observed clustered pattern could be the result of random chance. This strongly supports the conclusion that there is a significant spatial clustering of NO2 concentrations in the study area during the monsoon season.

The results indicate a clear and significant clustered pattern in the spatial distribution of NO2 concentrations at the district level in Uttar Pradesh. This finding implies that there are localized areas with similar levels of NO2 pollution, suggesting the presence of common emission sources or similar pollutant transport mechanisms in these clusters.

Conclusion

In conclusion, this study investigated the spatial pattern of NO2 concentrations at the district level in Uttar Pradesh during the monsoon season. The analysis revealed significant findings regarding the distribution and variability of NO2 concentrations across the study area.

The results demonstrated that NO2 concentrations exhibit a clustered pattern, as indicated by the high positive Moran's I index (0.617527) and the associated z-score of 11.236076. This suggests that districts with similar NO2 concentrations tend to be spatially clustered, while districts with contrasting concentrations also exhibit spatial clustering. The p-value of less than 1% further supports the conclusion that this pattern is unlikely to be due to random chance.

The standard deviation values provided insights into the variability of NO2 concentrations within each district. Some districts displayed relatively stable concentrations with low standard deviations, while others exhibited higher variability. These variations highlight the spatial heterogeneity of NO2 pollution in Uttar Pradesh during the monsoon season.

The identified clusters of NO2 concentrations can serve as valuable information for policymakers and stakeholders in formulating targeted measures to mitigate air pollution and improve air quality. Implementing pollution control strategies specific to the identified clusters can help effectively manage and reduce NO2 levels in the affected areas.

It is important to note that further research is needed to investigate the underlying causes and sources of the observed spatial clustering. Identifying the specific emission sources and transport mechanisms contributing to the high NO2 concentrations in certain clusters would provide valuable insights for designing more precise and effective pollution control strategies.

The findings of this study contribute to the understanding of the spatial distribution of NO2 concentrations in Uttar Pradesh during the monsoon season, and underscore the need for region-specific approaches to address air pollution and improve the overall environmental health in the study area.

Conflict of Interest

The author declares no conflict of interest in relation to this research study. The research was conducted with the sole objective of contributing to the scientific understanding of geostatistical analysis of NO_2 in Uttar Pradesh. The analysis, interpretation, and conclusions presented in this paper are based on objective scientific principles and rigorous data analysis methods. The author has no financial, personal, or professional relationships that could influence the research findings or introduce bias in the study. Furthermore, no external funding or sponsorship was received that could potentially influence the outcome or interpretation of the research. The author has followed ethical guidelines and scientific integrity throughout the research process to ensure transparency, accuracy, and impartiality in the findings and conclusions presented.

Data Statement

The data used in this study was obtained from the COPERNICUS/S5P/OFFL/L3_NO2 product. This dataset is part of the Copernicus Sentinel-5 Precursor (S5P) mission, which is a satellite-based Earth observation program. The S5P satellite carries the TROPOspheric Monitoring Instrument (TROPOMI), which measures various atmospheric parameters, including nitrogen dioxide (NO2) concentrations.

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