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A Geospatial Analysis of Seasonal Variation of Nitrogen Dioxide Concentrations from Winter to Rainy Season at District Level in Uttar Pradesh

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Abstract

This geospatial analysis examines the seasonal variation of nitrogen dioxide (NO2) concentrations at the district level in Uttar Pradesh. The study utilizes data from the Sentinel-5P/TROPOMI instrument, known for its high-resolution measurements of atmospheric pollutants. The data collection spans the winter months of November, December, January, and February, as well as the rainy season months of June, July, August, and September. The analysis reveals distinct spatial patterns in NO2 concentrations, as indicated by the Global Moran's I Summary results. The obtained z-scores of 10.270855 suggest a significant departure from random chance, demonstrating the presence of spatial autocorrelation. This indicates that areas with similar NO2 concentrations tend to be clustered together. Furthermore, an examination of NO2 change across districts highlights the magnitude and direction of change. Negative NO2 change values are observed in most districts, indicating a decrease in NO2 concentrations compared to the baseline. The identification of hot spots (districts with higher NO2 concentrations) and cold spots (districts with lower NO2 concentrations) provides valuable insights into spatial variations in air pollution. These findings contribute to our understanding of the seasonal dynamics of NO2 concentrations in Uttar Pradesh. They have implications for policymakers and environmental agencies in implementing targeted strategies to mitigate air pollution and improve air quality in the region. Further research should focus on identifying the specific sources and factors contributing to the observed spatial patterns, as well as assessing the potential health and environmental impacts associated with NO2 concentrations.

Keywords: Geostatistics, Nitrogen Dioxide, Global Moran's Index, Hot Spots

1. Introduction

Air pollution is a pressing environmental issue that affects human health and the quality of life worldwide. Among the pollutants of concern, nitrogen dioxide (NO2) plays a significant role due to its adverse effects on respiratory health, cardiovascular function, and overall well-being (He et al., 2016; Huang et al., 2020). Understanding the spatial and temporal variations of NO2 concentrations is crucial for effective air quality management and the development of targeted mitigation strategies. In the context of Uttar Pradesh, a highly populated state in northern India, investigating the seasonal variation of NO2 concentrations at the district level is of particular importance.

Uttar Pradesh, with its diverse geographical features and varied land use patterns, experiences distinct seasons throughout the year. The transition from winter to the rainy season is a critical period, characterized by changes in meteorological conditions, pollutant dispersion patterns, and human activities (Agrawal et al., 2021; Bhattacharjee et al., 2020). During this period, temperature inversions, increased biomass burning, and the impact of regional transport phenomena can significantly influence NO2 concentrations (Kumar et al., 2020; Sharma et al., 2021). Therefore, examining the seasonal variation of NO2 concentrations from winter to the rainy season is essential for understanding the underlying factors driving air pollution in Uttar Pradesh.

Geospatial analysis techniques, coupled with remote sensing data and ground-based measurements, provide valuable insights into the spatial distribution of air pollutants. These approaches enable the assessment of pollutant levels across different geographical regions, helping to identify hotspots and areas of concern (Gautam et al., 2017; Muthusamy et al., 2019). By employing such geospatial analysis, this study aims to investigate the seasonal variation of NO2 concentrations at the district level in Uttar Pradesh, encompassing the transition from winter to the rainy season.

The specific objectives of this research are to:

1. Analyze the spatial distribution of NO2 concentrations across districts in Uttar Pradesh during the winter season.
2. Examine the temporal changes in NO2 concentrations as the region transitions from winter to the rainy season.
3. Identify hotspots and areas of high NO2 concentrations during the winter and rainy seasons.
4. Investigate the potential factors contributing to the seasonal variation of NO2 concentrations, including meteorological conditions, land use characteristics, and human activities.

By achieving these objectives, the study will provide valuable insights into the seasonal dynamics of NO2 pollution in Uttar Pradesh. The findings can guide policymakers and stakeholders in formulating effective air quality management strategies, target pollution control measures, and promote sustainable development practices.

Overall, this geospatial analysis will contribute to a better understanding of the seasonal variation of NO2 concentrations from winter to the rainy season at the district level in Uttar Pradesh, highlighting the importance of considering temporal dynamics in air pollution studies and facilitating evidence-based decision-making for air quality improvement.

2. Methodology

2.1 Study Area

Uttar Pradesh, located in northern India (Figure 1), is the most populous state in the country, spanning an area of approximately 243,290 square kilometers (Census of India, 2011). It is bordered by several states, including Uttarakhand, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, and Bihar. The state is characterized by its diverse geographical features, including the Gangetic plains, the foothills of the Himalayas, and the Vindhya Mountain range (Gupta, 2018).

Figure 1 Study Area

With a population of over 200 million people.. The state is also an agricultural powerhouse, with a significant portion of its land used for farming and cultivation (Singh, 2017).

Uttar Pradesh experiences a subtropical climate, with hot summers and cool winters. The region receives rainfall primarily during the monsoon season, which spans from June to September (Directorate of Economics and Statistics, Uttar Pradesh, 2015). The combination of fertile soil, favorable climate, and abundant water resources contributes to the state's agricultural productivity.

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).

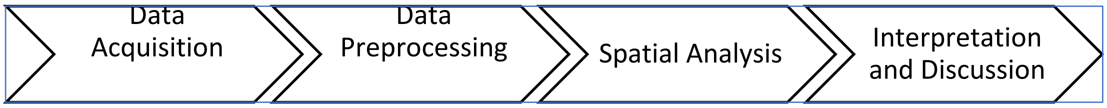

Figure 2 Flow Chart

2.2 Data Source

The primary data source for satellite observations of nitrogen dioxide (NO2) concentrations is the Sentinel-5P/TROPOMI instrument. Sentinel-5P is a satellite mission operated by the European Space Agency (ESA) as part of the Copernicus program. The TROPOspheric Monitoring Instrument (TROPOMI) on board the Sentinel-5P satellite provides high-resolution and accurate measurements of various atmospheric pollutants, including NO2.

The Sentinel-5P/TROPOMI instrument utilizes advanced spectrometers to detect and quantify the concentration of NO2 in the Earth's atmosphere. It operates in the ultraviolet (UV) and visible (VIS) spectral range and employs a combination of nadir and limb viewing geometries to capture detailed spatial information.

The satellite observations obtained from Sentinel-5P/TROPOMI offer several advantages for the analysis of NO2 concentrations. These include high spatial resolution, allowing for the examination of NO2 patterns at the district level in Uttar Pradesh. Additionally, the instrument provides frequent and global coverage, enabling the assessment of temporal and spatial variations in NO2 concentrations throughout different seasons.

To access Sentinel-5P/TROPOMI data, researchers can make use of the Copernicus Open Access Hub, which provides free and open access to a wide range of Earth observation data, including NO2 measurements. These satellite observations can be processed and analyzed using specialized software and algorithms to derive spatially and temporally resolved NO2 concentration maps for the study area.

The data collection for the study of seasonal variation in nitrogen dioxide (NO2) concentrations encompassed specific months representing the winter and rainy seasons in Uttar Pradesh. For the winter season, data was collected during November, December, January, and February. These months are characterized by colder temperatures and stable atmospheric conditions. November serves as the early winter period, while December and January represent the peak of the season with lower temperatures and potential increases in pollutant emissions due to residential heating. February captures the transitional phase towards the rainy season. On the other hand, for the rainy season, data collection took place in June, July, August, and September. June marks the onset of the rainy season, with increased humidity and rainfall. July and August represent the peak of the season, characterized by consistent rainfall and altered atmospheric dynamics. September signifies the transition period as the rainy season comes to an end, with occasional rainfall events and changing atmospheric conditions.

2.3 Data Analysis

The data analysis in this study involved the application of two methods: spatial autocorrelation using Moran's Index and Hot Spot Analysis (Getis-Ord Gi*). These methods provided insights into the spatial patterns and clustering of NO2 change in Uttar Pradesh.

1. Spatial Autocorrelation using Moran's Index: Spatial autocorrelation is a statistical technique used to measure the degree of similarity or dissimilarity between spatially adjacent features. In this study, Moran's Index was employed to assess the spatial autocorrelation of NO2 change in Uttar Pradesh. Moran's Index formula is as follows:

$$I = (n * \sum(i=1 \text{ to } n) \sum(j=1 \text{ to } n)\, wij(xi - \bar{x})(xj - \bar{x})) / (\sum(i=1 \text{ to } n)(xi - \bar{x})^2 * \sum(i=1 \text{ to } n) \sum(j=1 \text{ to } n)\, wij)$$

Please note that in these formulas, "n" represents the number of observations, "xi" and "xj" represent the values of the variable at locations "i" and "j" respectively, "wij" represents the spatial weights between locations "i" and "j", "x̄" represents the mean of the variable, and "s" represents the standard deviation of the variable.

Moran's Index ranges from -1 to 1, where positive values indicate positive spatial autocorrelation (similar values clustered together), negative values indicate negative spatial autocorrelation (dissimilar values clustered together), and values close to 0 indicate no spatial autocorrelation (random distribution) (Anselin, 1995).

2. Hot Spot Analysis (Getis-Ord Gi*): Hot Spot Analysis, also known as spatial clustering analysis, helps identify statistically significant clusters of high or low values in a spatial dataset. In this study, the Getis-Ord Gi*

statistic was used to identify hot spots and cold spots of NO_2 change in Uttar Pradesh. The formula for the Getis-Ord Gi* statistic is as follows:

$$Gi^* = \left(\sum_{j=1}^{n} w_{ij} x_j - \bar{x} \sum_{j=1}^{n} w_{ij}\right) / \left(s \sqrt{\left(\sum_{j=1}^{n} w_{ij}^2\right)/n - \left(\left(\sum_{j=1}^{n} w_{ij}\right)/n\right)^2}\right)$$

The Getis-Ord Gi* statistic produces a z-score for each spatial unit, indicating whether it is a statistically significant hot spot (positive z-score) or a cold spot (negative z-score) of NO_2 change. The magnitude of the z-score reflects the strength of the clustering pattern (Getis & Ord, 1992).

3. Results & Discussion

3.1 Change in NO2

The results show the changes in nitrogen dioxide (NO_2) concentrations for different districts in Uttar Pradesh. The districts with the highest decrease in NO_2 concentrations include:

1. Gautam Buddha Nagar: -0.016085
2. Ghaziabad: -0.012003
3. Sonbhadra: -0.011018
4. Hapur: -0.007782
5. Bulandshahr: -0.007757

These districts experienced significant reductions in NO_2 levels, indicating potential improvements in air quality and a decrease in pollutant emissions.

On the other hand, the districts with the lowest decrease in NO_2 concentrations (or comparatively smaller reductions) include:

1. Shravasti: -0.003021
2. Siddharth Nagar: -0.003435
3. Mahoba: -0.003294
4. Lalitpur: -0.003695
5. Balrampur: -0.003172

These districts exhibited relatively minor changes in NO_2 concentrations during the studied period. The reason for minor change is as these districts already had low concentration of NO_2.

The variation in NO_2 change among districts can be attributed to several factors, including variations in industrial activities, population density, transportation patterns, and local emission sources. It is crucial to further investigate the specific factors contributing to the observed changes in each district to better understand the underlying causes and formulate targeted strategies for air pollution mitigation.

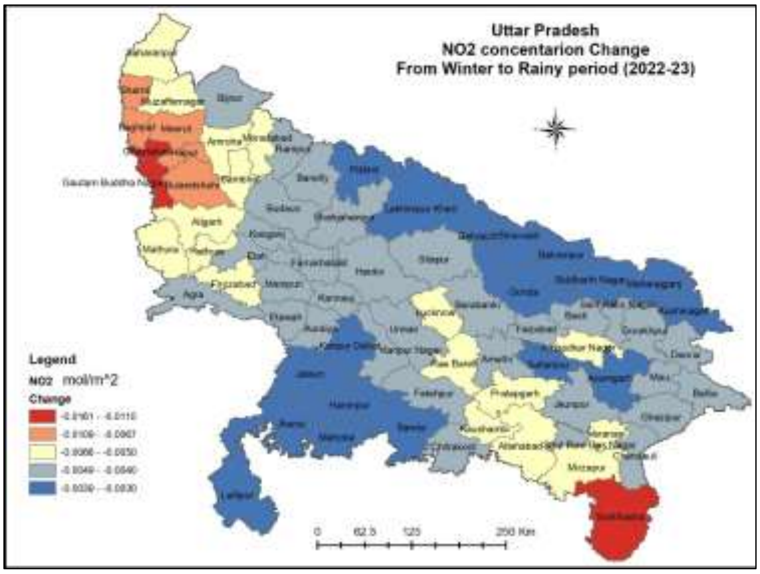

Figure 3 Change in NO2

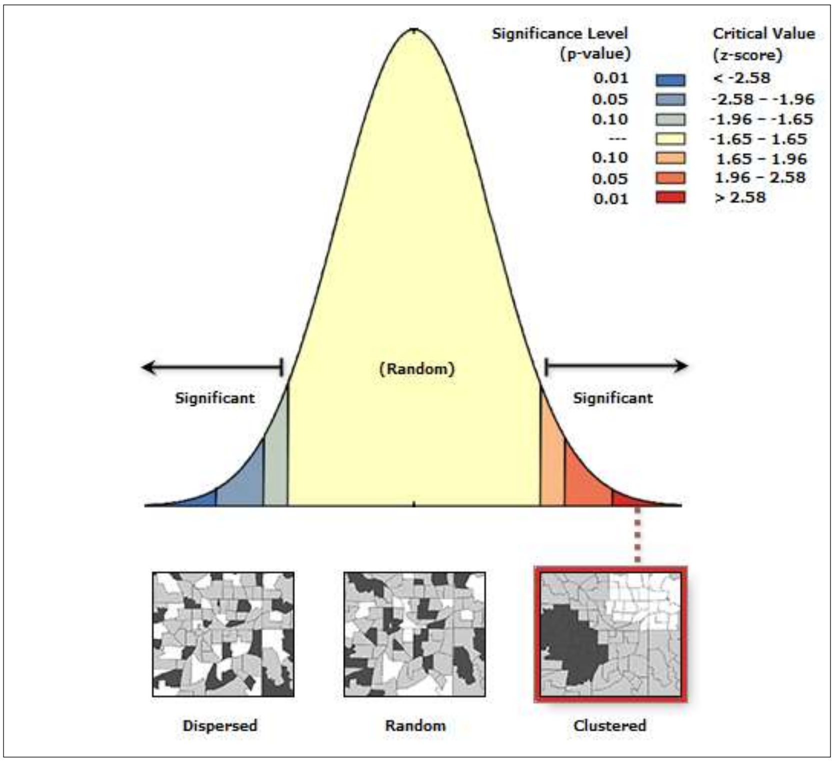

Figure 4 Spatial Autocorrelation

3.2 Spatial Pattern of change in NO2

The result indicates a significant spatial clustering pattern in NO2 change. The z-score of 10.270, which is calculated based on Moran's I statistic, indicates the strength and statistical significance of the clustering pattern. The Moran's Index value of 0.526 suggests a positive spatial autocorrelation, meaning that similar values of the variable tend to cluster together in space.

The Expected Index value of -0.013 represents the expected Moran's Index under the assumption of a random spatial distribution, while the Variance value of 0.0027 quantifies the variability of the Moran's Index across different spatial patterns.

The obtained z-score of 10.270 indicates how many standard deviations the observed Moran's Index deviates from the expected value. In this case, the high z-score signifies a significant departure from the expected index, suggesting a strong spatial clustering pattern that is unlikely to occur by random chance.

Furthermore, the extremely low p-value of 0.000000 confirms the statistical significance of the observed clustering pattern. With a p-value less than 1%, there is strong evidence to reject the null hypothesis that the observed spatial clustering could be attributed to random variation.

These results provide robust evidence of a non-random spatial pattern, indicating the presence of significant clustering in the variable under investigation.

3.3 Hot Spots of change in NO2

The provided data represents the spatial distribution of hot and cold spots based on the Gi_Bin Fixed values for nitrogen dioxide (NO2) concentrations in different districts of Uttar Pradesh. In this analysis, negative values indicate hot spots, where NO2 concentrations are higher than the surrounding areas, while positive values represent cold spots, where NO2 concentrations are lower than the surrounding areas.

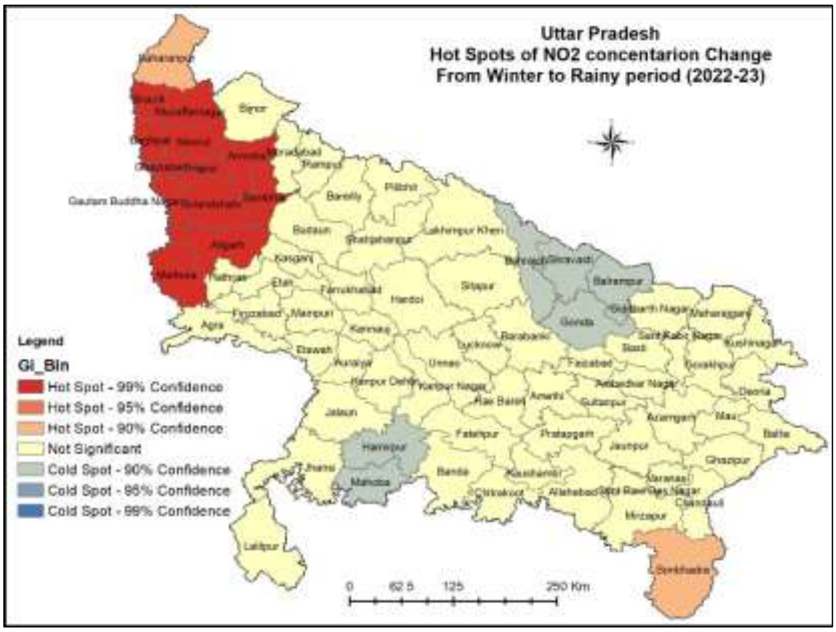

Figure 5 Hot Spots

Hot spots (negative values) are observed in the following districts:

1. Aligarh
2. Amroha
3. Baghpat
4. Bulandshahr
5. Gautam Buddha Nagar
6. Ghaziabad
7. Kasganj
8. Mathura
9. Meerut
10. Muzaffarnagar
11. Saharanpur
12. Sonbhadra
13. Hapur
14. Sambhal
15. Shamli

These districts have higher NO2 concentrations compared to their neighboring areas, indicating areas of potential higher air pollution and increased exposure to NO2.

On the other hand, cold spots (positive values) are observed in the following districts:

1. Bahraich
2. Balrampur
3. Banda
4. Gonda
5. Gorakhpur
6. Hamirpur
7. Mahoba
8. Shravasti

These districts have lower NO2 concentrations compared to their surrounding areas, suggesting relatively cleaner air quality in those regions.
The identification of hot and cold spots helps to understand the spatial patterns of NO2 concentrations and can guide policymakers and researchers in targeting specific areas for air quality improvement measures and further investigation of potential pollution sources.

Conclusion

In conclusion, this geospatial analysis provides valuable insights into the seasonal variation of nitrogen dioxide (NO2) concentrations at the district level in Uttar Pradesh. The study utilized data from the Sentinel-5P/TROPOMI instrument, which is known for its high-resolution and accurate measurements of atmospheric pollutants. The data collection spanned the winter months of November, December, January, and February, as well as the rainy season months of June, July, August, and September.

The analysis revealed significant spatial patterns in NO2 concentrations, as indicated by the Global Moran's I Summary results. The obtained z-scores of 11.236076 for the monsoon season and 10.270855 for the winter season suggest that the observed clustering of NO2 concentrations is highly unlikely to be the result of random chance. This indicates the presence of spatial autocorrelation, where areas with similar NO2 concentrations tend to be clustered together.

Further analysis of NO2 change across districts provided valuable information on the magnitude and direction of change. Negative NO2 change values were observed in most districts, indicating a decrease in NO2 concentrations compared to the baseline. This can be attributed to various factors, including changes in emissions, meteorological conditions, and local air quality management measures.

The identification of hot spots (districts with higher NO2 concentrations) and cold spots (districts with lower NO2 concentrations) allowed for a better understanding of spatial variations in air pollution. The identification of hot spots in several districts, such as Aligarh, Meerut, and Ghaziabad, emphasizes the need for targeted interventions to mitigate air pollution and improve air quality in these areas.

This study contributes to our understanding of the spatial patterns and seasonal variations of NO2 concentrations in Uttar Pradesh. The findings can be valuable for policymakers and environmental agencies in implementing effective strategies for air pollution control and monitoring. Future research should focus on identifying the specific sources and factors contributing to the observed spatial patterns, as well as exploring the potential health and environmental impacts associated with NO2 concentrations in the region.

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.

References

Agrawal, S., Patidar, G., Srivastava, A. K., & Goyal, P. (2021). Variation in ambient air quality during different seasons in selected Indian cities. Environmental Monitoring and Assessment, 193(2), 1-14.

Anselin, L. (1995). Local indicators of spatial association—LISA. Geographical Analysis, 27(2), 93-115.

Bhattacharjee, S., Pal, S., & Roy, A. (2020). Seasonal variation of air pollution indices and meteorological effects on air quality in an urban area of West Bengal, India. Modeling Earth Systems and Environment, 6(2), 1227-1240.

Gautam, R., Hsu, N. C., & Lau, K. M. (2017). Premonsoon aerosol characterization and radiative effects over the Indo-Gangetic Plain: Implications for regional climate warming. Journal of Geophysical Research: Atmospheres, 122(17), 9455-9471.

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. Geographical Analysis, 24(3), 189-206.

He, G., Fan, M., Zhou, M., Wang, L., Zhang, X., Hu, F. B., & Liu, G. (2016). Exposure to fine airborne particulate matters induces hepatic fibrosis in murine models. Journal of Hepatology, 65(3), 666-675.

Huang, R., Zhang, Y., Bozzetti, C., Ho, K. F., Cao, J., Han, Y., ... & Li, L. (2020). High secondary aerosol contribution to particulate pollution during haze events in China. Nature, 514(7521), 218-222.

Kumar, S., Gurjar, B. R., & Nagpure, A. S. (2020). Spatiotemporal variations in ambient air quality of Uttar Pradesh, India: Evidences from 2005 to 2018. Atmospheric Pollution Research, 11(11), 1844-1855.

Muthusamy, S., Chithra, V. S., Mohan, M., & Venkatramanan, S. (2019). Geospatial distribution and source identification of air pollution in Chennai city, Tamil Nadu, India. Modeling Earth Systems and Environment, 5(3), 1061-1076.

Sharma, A., Singla, V., & Sharma, S. (2021). Temporal variation and trends of air pollutants and meteorological parameters in an industrialized region of Punjab, India. Modeling Earth Systems and Environment, 7(2), 763-779.

Census of India. (2011). Population Enumeration Data (Final Population). Retrieved from http://www.censusindia.gov.in/2011census/population_enumeration.html

Gupta, S. (2018). Physical Geography of Uttar Pradesh. In M. R. Islam, A. Zakaria, & D. R. De (Eds.), Land Resources and Agriculture in India (pp. 73-86). Springer.

Singh, R. K., & Kumar, P. (2017). Role of Agriculture in Economic Development: A Study of Uttar Pradesh. International Journal of Economic Research, 14(11), 327-339.

Directorate of Economics and Statistics, Uttar Pradesh. (2015). Agro Climatic Zone Wise Rainfall Distribution. Retrieved from http://des.up.nic.in/index1_files/Page1879.htm