# Geo-statistical relation between NO₂ and precipitation in the Southern parts of Tamil Nadu using Geo AI tools

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**Abstract- This study investigates the spatial relationship between nitrogen dioxide (NO₂) concentrations and precipitation patterns in the southern regions of Tamil Nadu by employing advanced geospatial artificial intelligence (Geo AI) techniques. The study combines satellite data, geo-statistical models, and AI-driven spatial analysis to examine how precipitation affects NO₂ dispersion across districts. The findings reveal significant inverse correlations between precipitation and NO₂ levels, emphasizing the role of monsoonal precipitation in mitigating air pollution. The application of Geo AI tools enhances the temporal resolution and accuracy of spatial correlation analysis, providing valuable insights for environmental management and policy formulation. The outcomes underscore the importance of incorporating meteorological variables into urban air quality strategies, especially in monsoon-affected regions, to foster sustainable environmental policies.**

**Keywords- NO₂, precipitation, geo-statistics, Geo AI, spatial analysis, Tamil Nadu, air quality, satellite data, environmental management**

## I. INTRODUCTION

Air pollution, especially nitrogen dioxide (NO₂), has become a significant environmental concern in rapidly urbanizing and industrial regions of India, including the southern districts of Tamil Nadu. NO₂ primarily originates from vehicular emissions, industrial activities, and biomass burning, contributing to adverse health effects and environmental degradation [1]. The spatial distribution and concentration levels of NO₂ are heavily influenced by meteorological factors such as wind, temperature, and notably, precipitation. Precipitation acts as a natural scavenger for airborne pollutants, reducing their concentration in the atmosphere through wet deposition processes [2] Recent advances in remote sensing and geospatial technologies have enabled detailed monitoring of air quality parameters over large geographical extents [3]. Satellite-based sensors, such as Sentinel-5P, provide high-spatial resolution NO₂ data, facilitating the analysis of spatial variability in pollution levels [4]. Simultaneously, precipitation data derived from MODIS and other sources help to understand the environmental conditions influencing pollutant dispersion and removal. The integration of geo-statistical analysis with artificial intelligence (AI) tools referred to as Geo AI offers powerful capabilities to model complex spatio-temporal relationships, identify pollution hotspots, and predict pollutant behavior under varying meteorological scenarios [5],[6]. In the context of Tamil Nadu's southern districts, characterized by diverse geography consisting of coastal plains, inland plains and hill terrains, the interaction between NO₂ and precipitation is vital for developing targeted air quality management strategies. Understanding this relationship through advanced geo-statistical and AI techniques can reveal the extent to which precipitation mitigates NO₂ pollution, informing policy decisions, especially during monsoon seasons.

## II. OBJECTIVE

1. To analyze the spatial correlation between NO₂ concentrations and precipitation across the southern districts of Tamil Nadu.

2. To utilize Geo AI tools for high-resolution geo-statistical modeling of the relationship between precipitation and $NO_2$ levels.
3. To identify pollution hotspots where precipitation has a significant impact on $NO_2$ dispersion.
4. To provide data-driven insights to policymakers for optimizing air quality management during the monsoon season.

### III. STUDY AREA

The study area encompasses the 11 southern districts of Tamil Nadu, namely Dindigul, Pudukottai, Sivagangai, Madurai, Theni, Virudhunagar, Ramanathapuram, Thoothukudi, Tenkasi, Tirunelveli, and Kanyakumari, each showcasing diverse geographical, climatic, and ecological characteristics. The skilled work force and the history of industrial policy have driven this region significant for the establishment of industry units in diverse sectors like textiles, minerals, leather goods, auto components and agriculture. The infrastructure in transport and connectivity in road, rail, air and sea has contributed to the development of urban units of various sizes attracting dense population.
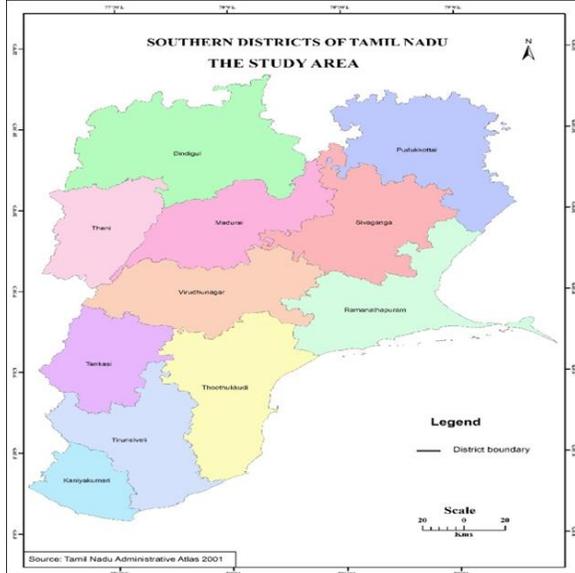


Figure 1 Study area

The coastal districts of Thoothukudi and Ramanathapuram are marked by sandy beaches, mangroves, and their proximity to the Gulf of Mannar, which influences their semi-arid climate, characterized by low precipitation and frequent dry spells. In contrast, districts like Tirunelveli, Kanyakumari, Theni, and Tenkasi, located along the Western Ghats, featuring mountainous terrain, dense tropical forests, and significant precipitation, making them vital for biodiversity and hydrological balance. The inland districts, including Madurai, Virudhunagar, Dindigul, Sivagangai, and Pudukottai, are primarily plains with hot climates and sparse vegetation, dominated by scrublands and thorn forests (Figure 1). These regions are significant for dry land agriculture but face challenges like water scarcity during summer months. Climatically, the southern districts display notable variability, influenced by monsoonal winds and the orographic effects of the Western Ghats. The northeast monsoon is the primary source of annual precipitation, with inland regions experiencing temperature extremes and coastal districts benefitting from moderating sea breezes. Ecologically, the Western Ghats regions, particularly in Kanyakumari, are recognized for their tropical evergreen forests, biodiversity, and ecological significance, while the coastal districts play a crucial role in supporting marine ecosystems and fisheries. Inland districts contribute to agricultural production and water resource management. This diversity in geography, climate, and ecology makes the southern districts of Tamil Nadu an essential area for understanding spatiotemporal variations in climatic parameters, particularly trends in precipitation over time.

### IV. METHODOLOGY

This study employs a multi-stage approach, incorporating geo-artificial intelligence techniques, to monitor and analyze air pollutant parameters and associated meteorological conditions in Southern Tamil Nadu. The stages are as follows:
1. Data Collection
Satellite-based $NO_2$ data were obtained from Sentinel-5P, while precipitation data were sourced from MODIS-based precipitation datasets via Google Earth Engine. The temporal scope covers the past decade, focusing on monsoon months, paving way for the application of advanced geo-statistical techniques.
2. Pre-processing & Data Integration
Satellite images were processed for cloud masking, spatial alignment, and noise reduction using AI-enhanced image processing algorithms. Data were aggregated into spatial grids for analysis.
3. Geo-statistical Analysis

Using GIS platforms, spatial autocorrelation methods were applied to identify clustering of $NO_2$ levels and their relation to precipitation distribution.

4. Geo AI Tool Implementation

AI-driven geo-statistical model, including spatial regression with machine learning algorithms, were employed to analyze the correlation between $NO_2$ concentrations and precipitation. This model facilitated the identification of regions where precipitation significantly influences $NO_2$ dispersion.

## V. RESULTS AND DISCUSSION

The analysis demonstrated a clear inverse relationship between precipitation and $NO_2$ levels across southern Tamil Nadu, with higher precipitation reducing $NO_2$ concentrations through wet deposition. Spatial statistical tools confirmed significant negative correlations, especially in coastal regions affected by monsoon winds. The use of Geo AI models provided high-resolution insights into how meteorological factors influence air quality, emphasizing the role of precipitation in natural pollution mitigation. These findings suggest that environmental management strategies should consider seasonal precipitation patterns to effectively address air pollution hotspots. Future efforts should integrate ground data and expand pollutant analysis for more comprehensive insights.

Tropospheric $NO_2$ Concentration Analysis

The analysis identified several regions with elevated tropospheric $NO_2$ concentrations, particularly in areas characterized by intense industrial activity and high population density. Thoothukudi emerged as a significant hotspot, largely due to emissions from its thermal power plants and manufacturing industries. In comparison, Madurai and Virudhunagar, both densely populated urban centers also showed high $NO_2$ levels, though not as severe as in Thoothukudi. These findings highlight the impact of localized industrial and urban activities on air quality. A distinct seasonal pattern was observed in the distribution of tropospheric $NO_2$. Concentrations were generally higher during the pre-monsoon period (January to May) compared to the monsoon season (June to December). This variation is attributed to reduced atmospheric dispersion during the dry months, which allows pollutants like $NO_2$ to accumulate more easily in the lower atmosphere. Urban areas, in particular, experienced pronounced increases during this period, as illustrated in Figure 2. The analysis made during the years 2019 to 2021 a marked reduction in $NO_2$ levels was recorded across the studied regions. This decline underscores the significant influence of anthropogenic activities such as industrial operations and vehicular traffic on air pollution levels. The temporary improvement in air quality during the lockdown period provided a unique insight into how rapidly environmental conditions can respond to decreased human activity.
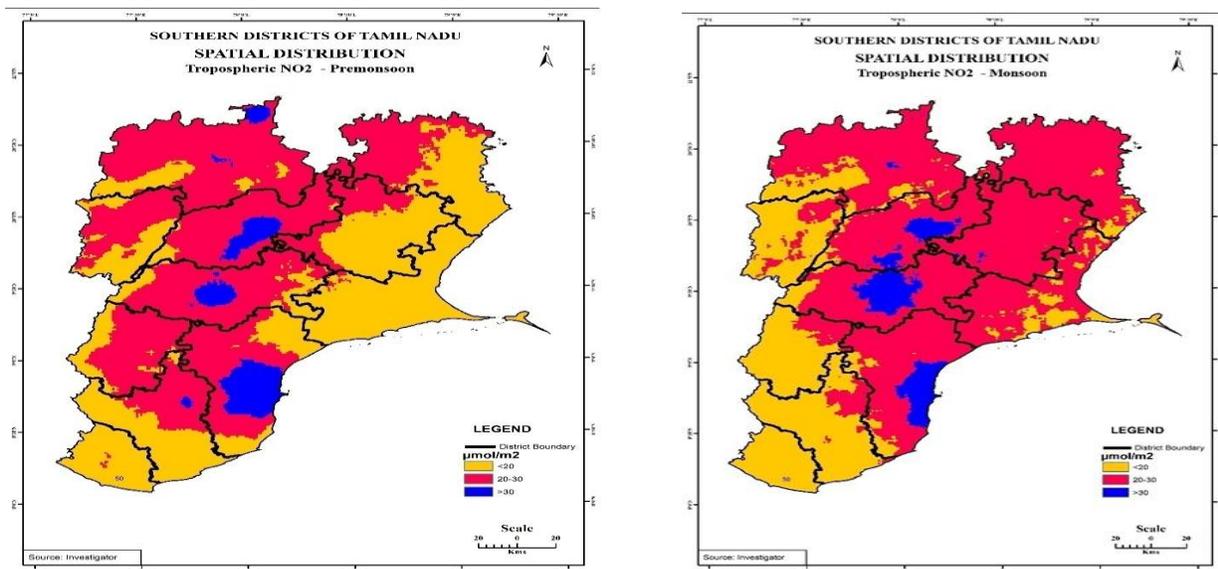


Figure 2 Tropospheric $NO_2$ Concentration Analyses

Meteorological Impacts on Air Quality

A strong negative correlation was found between precipitation and NO₂ concentrations, highlighting the effect of rain in dispersing pollutants. Wet seasons contribute to lower pollutant concentrations, particularly in regions with significant vegetation and water bodies. The precipitation patterns depicted in Figure 3 highlight the contrast between monsoon and pre-monsoon precipitation in the southern districts. During the pre-monsoon season, precipitation is relatively low, with occasional showers that are typically scattered and short-lived. These rains, while not substantial in volume, play a crucial role in soil moisture buildup and agricultural preparation. In contrast, the monsoon season shows a significant surge in precipitation, characterized by sustained and heavy precipitation. This indicates peak precipitation in the months of June to August, aligning with the southwest monsoon's active phase. The intensity and consistency of monsoon rains are vital for agriculture, water resources, and overall ecological balance in the region.
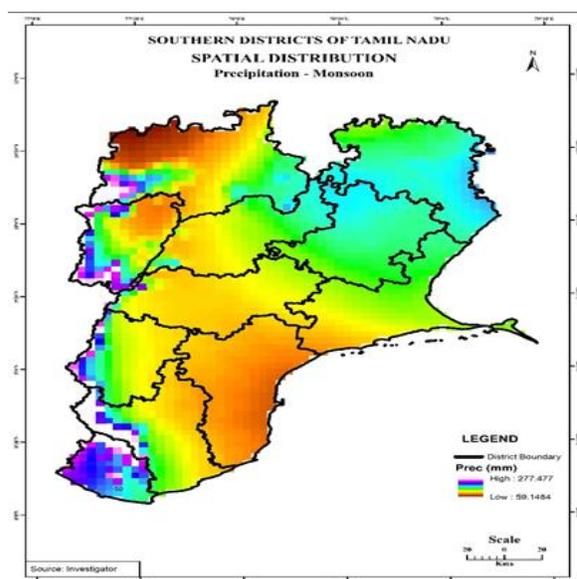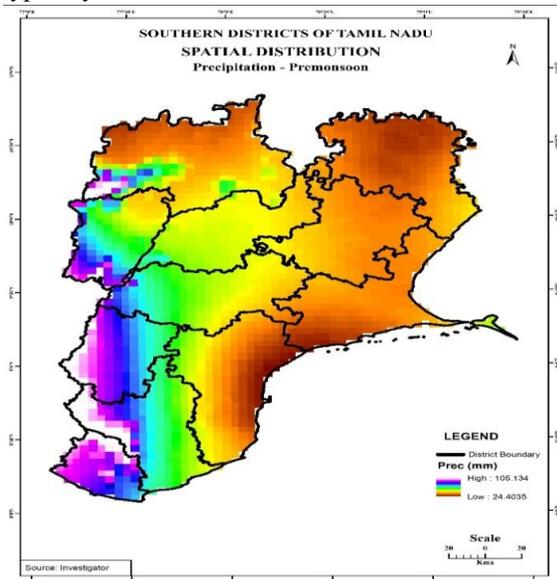


Figure 3 Precipitation pattern – Monsoon and Pre-monsoon in southern districts

Autocorrelation Maps and Dispersion Patterns

A geo AI based spatial autocorrelation analysis provided valuable insights into the clustering and spatial distribution of air pollutants. These maps revealed notable regional variability, with industrial zones often forming isolated high-concentration clusters, indicating localized emission sources such as power plants, chemical industries, and manufacturing facilities. Thoothukudi and parts of Ramanathapuram, for example, stood out as pollution hotspots. On the other hand, urban centers such as Madurai and Virudhunagar displayed more diffused but interconnected pollution patterns. These patterns are typically associated with sources like vehicles, domestic combustion, and construction activities. Unlike industrial pollution that is localized, urban pollution tends to disperse due to wind currents and the dynamic nature of emission sources. The autocorrelation results also highlighted the influence of topography and meteorological conditions on pollutant dispersion, underlining the need for region-specific air quality interventions that consider both emission sources and geographical factors (Figure 4).
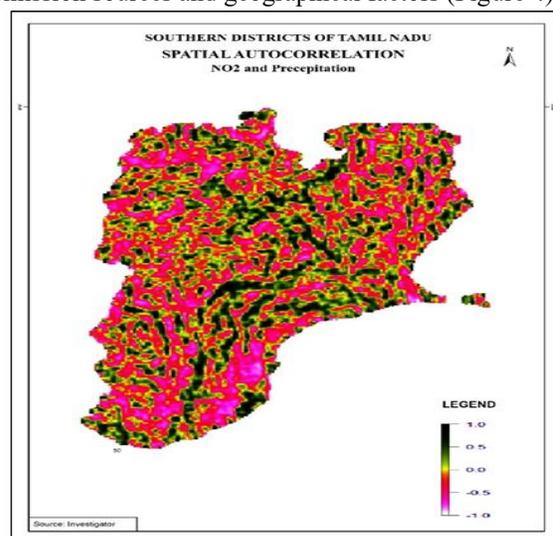


Figure 4 Spatial autocorrelation of NO2 and Precipitation

The above map (Figure 4) provides a detailed view of the spatial autocorrelation between NO2 and precipitation in the southern districts of Tamil Nadu. By highlighting regions with different correlation patterns, it aids in understanding how precipitation variations affect NO2 levels. This information is crucial for developing targeted air quality management and ensuring that interventions are effective and region-specific.

1. For easy interpretation, the legend is color-coded as follows:

Yellow to Green Areas: Represent regions with a positive correlation between NO2 and precipitation, indicating that as precipitation increases, NO2 levels also tend to increase. The spatial correlation index is greater than 1.

Pink to Red Areas: Represent regions with a negative correlation between NO2 and precipitation, indicating that as precipitation increases, NO2 levels tend to decrease. The spatial correlation index is less than 1 (i.e. Negative values)

2. Spatial Distribution:

Western Regions: Predominantly green, indicating a very high positive correlation. The coefficient values is greater than 0.5. These areas show increased NO2 levels with increased precipitation. These areas show a strong positive correlation between NO2 and precipitation. This could be due to factors such as increased emissions during wet conditions or localized atmospheric conditions that trap NO2 near the surface during precipitation events. Vegetation in these dense forests in the western ghats also plays an important role in trapping NO2 by reducing the air flow essential to flush out the pollutant. Only some parts of Thoothukudi near the coast and western Pudhukottai show this.

Central and Northern Regions: Predominantly pink, suggesting a strong negative correlation (greater than -0.5). These areas experience decreased NO2 levels during periods of higher precipitation. Thoothukudi, Dindigul districts show a significant negative correlation between NO2 and precipitation. This suggests that higher precipitation levels lead to a reduction in NO2 levels, possibly due to the washing away of pollutants from the atmosphere.

Southern and Coastal Regions: A mix of green and pink areas, indicating both positive and negative correlations. In these areas, the relationship between precipitation and NO2 levels varies. These areas exhibit both positive and negative correlations, indicating diverse local environmental conditions. Central parts of Tirunelveli and Madurai district show this and factors such as coastal breezes, land-sea interactions, and varied land use might influence these patterns.

Need for Tailored Air Quality Strategies

The observed spatial heterogeneity in pollutant distribution strongly suggests that a uniform approach to air quality management would be ineffective for Southern Tamil Nadu. Instead, a nuanced strategy is required one that addresses the unique challenges of each region. For example, while industrial areas require technological upgrades and regulatory interventions, urban areas may benefit more from traffic management, waste regulation, and improved public infrastructure. Policymakers should consider the spatial correlation findings to prioritize interventions in critical zones with the highest pollution levels. Furthermore, long-term air quality goals must be integrated with sustainable development plans, ensuring that economic growth does not come at the expense of environmental health. Collaborative governance involving state authorities, local municipalities, and environmental agencies will be crucial in implementing such tailored solutions.

Enhanced Industrial Emission Controls

Industrial hubs in Southern Tamil Nadu, particularly in Thoothukudi and Ramanathapuram, are major contributors to ambient air pollution. These areas host power plants, chemical units, and other heavy industries that release large volumes of $NO_2$ into the atmosphere. To address this, stringent emission standards need to be enforced, along with mandatory adoption of cleaner production technologies, such as flue gas desulfurization, electrostatic precipitators, and low-NOx burners. Real-time emission monitoring systems should also be installed to ensure compliance and transparency. Additionally, industrial zones must undergo regular environmental audits, and penalties for non-compliance should be increased to act as a deterrent. Such measures, if properly implemented, can lead to significant improvements in air quality

while encouraging industries to adopt more sustainable practices.

Seasonal Pollution Management
Air quality in Southern Tamil Nadu exhibits notable seasonal fluctuations, with pre-monsoon months (January to May) typically recording higher pollutant levels. This is primarily due to reduced precipitation, higher temperatures, and lower humidity, which together result in poor atmospheric dispersion and increased accumulation of pollutants. During this dry period, urban centres experience heightened vehicular and construction activities, further compounding pollution levels. Therefore, seasonal pollution control strategies must be implemented—particularly during pre-monsoon months. These could include time-based traffic restrictions, promotion of public transportation, stricter controls on construction dust, and awareness campaigns on energy conservation. Seasonal forecasting and early warning systems could also help inform the public and authorities in advance, allowing them to take precautionary measures to minimize exposure and reduce emissions.

Green Cover Expansion
Expanding urban and peri-urban green spaces presents a long-term, sustainable solution to improving air quality. Vegetation not only filters air pollutants but also contributes to microclimate regulation, noise reduction, and improved urban aesthetics. Strategies for increasing green cover should include the development of urban parks, roadside tree plantations, green rooftops, and vertical gardens. Industrial zones can also incorporate green belts around their premises to act as buffer zones that limit the spread of pollutants to nearby residential areas. The planning of new infrastructure projects must include environmental impact assessments that prioritize the preservation of existing green cover and the integration of new green spaces. In particular, placing vegetative buffers along highways, industrial peripheries, and densely populated areas can significantly reduce pollution exposure and contribute to healthier living environments.

Public Health Monitoring

The elevated levels of $NO_2$ in industrial and urban regions pose a significant threat to public health, especially for vulnerable populations such as children, the elderly, and individuals with pre-existing respiratory conditions. Long-term exposure to these pollutants is linked to a range of health issues, including asthma, bronchitis, cardiovascular diseases, and even premature mortality. Therefore, a robust public health monitoring system is essential. This should involve regular epidemiological surveys, hospital-based data collection, and the establishment of air pollution health registries. Public awareness campaigns must also be launched to educate communities on the risks of air pollution and promote protective behaviours, such as using masks during high pollution days and minimizing outdoor activities during peak hours. Additionally, local healthcare facilities in high-risk areas must be strengthened to handle pollution-related illnesses, ensuring timely diagnosis and treatment for affected individuals.

## VI. CONCLUSION

In conclusion, the geo-statistical analysis using Geo AI tools reveals a significant inverse relationship between $NO_2$ levels and precipitation in Southern Tamil Nadu. Increased precipitation contributes to the natural dispersion and reduction of $NO_2$ pollution, highlighting the importance of seasonal and meteorological factors in air quality management. These findings demonstrate the crucial role of precipitation in mitigating pollutant concentrations, emphasizing the need for incorporating weather patterns into pollution control policies. Furthermore, the application of Geo AI tools provides valuable spatial insights that can aid policymakers in identifying high-risk areas and implementing targeted interventions. Overall, integrating geo-statistical analysis with environmental management strategies can enhance efforts to improve air quality and protect public health in the region.

## ACKNOWLEDGEMENT

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