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Spatial variation of air pollutants by using GIS modelling

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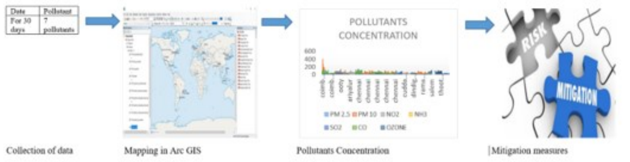
Graphical abstract



Abstract

Air pollution in Tamil Nadu has become a pressing issue, as various pollutants have surpassed the limits established by the pollution control board. The major air pollutants in the region, namely sulphur dioxide, nitrogen dioxide, and suspended particulate matter, have been identified. This study aims to monitor and analyse the levels of air pollution in Tamil Nadu, with a specific focus on key parameters such as SO_2, NO_2, PM2.5, PM10, and ozone. By examining the atmospheric levels of these pollutants and their correlation with temperature fluctuations, the impact on human health and respiratory problems can be evaluated. Moreover, the study will assess the contribution of traffic emissions and vehicular pollution to the concentration of PM10 in different areas. Additionally, GIS technology will be utilized to spatially and temporally investigate pollution concentrations and evaluate their effect on the air quality index. By comparing the pollution concentration from thermal power stations and vehicular pollution, the study will identify the sources of pollutants, with a particular emphasis on SO2 and NOx emissions from vehicles and higher levels of suspended particulate matter from thermal stations. The analysis of these pollutants and their sources will provide valuable insights for the implementation of effective pollution control measures and the management of environmental pollution in Tamil Nadu. Given the concerns regarding pollutants exceeding the prescribed limits set by the pollution control board, monitoring air pollution in Tamil Nadu is of utmost importance.

Keywords: Spatial variation, air pollutants, air quality management, spatial analysis, geographic information systems, air quality monitoring, spatial modelling, exposure assessment.

1. Introduction

Through the use of GIS modelling, the distribution of air pollutants in different areas can be assessed, allowing researchers to identify sources of pollution emissions and gain a comprehensive understanding of air pollution patterns (Bingnan Guo, 2022). This approach can aid in the development of effective strategies to control emissions and mitigate the impacts on human health and the environment (Jie Chen, 2023). By visualizing and analyzing multi-source spatio-temporal data related to air pollution, researchers can improve the efficiency of air pollution law enforcement and control methods, as well as provide valuable insights for air pollution investigation and monitoring (Xiaoshuang Wang, 2022). Additionally, GIS modelling can assist in the establishment of air pollution measurement stations in areas where pollutants are concentrated, enabling better monitoring and assessment of air quality and its potential impacts on the population (Naoum, 2002). The integration of GIS with administrative databases and existing monitoring networks enhances the accuracy and reliability of air pollution forecasts, enabling local administrations to take proactive measures in forecasting alert pollutant levels in urban atmospheres and implementing effective air quality management systems (Jing Luo, 2022). Overall, GIS modelling plays a crucial role in understanding the spatial variation of air pollutants and allows for better decision-making and management of air quality (Abdul Qadeer Khan, 2022).

The changes and oscillations in the distribution of pollutants in the Earth's atmosphere across different geographic regions are referred to as spatial variation of air pollutants. The developing concerns to exposure on humans to the outdoor and indoor air pollution (Cheng, 2023). It is very essential to have both quantity and quality of air must be better. As people These pollutants are produced by natural processes or by human activity such as industrial emissions, automobile exhaust, and biomass combustion (Jie Chen, 2023) . They can have a negative impact on human health, ecosystems, and overall environmental quality. Emission sources, climatic circumstances, geography, and atmospheric processes all have an impact on the spatial variation of air pollutants. Pollutant concentrations are frequently greater in places with high emission sources, such as industrial zones or metropolitan centres, than in rural or isolated locations (Lian Xiong, 2023)

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Meteorological variables such as wind patterns, air stability, temperature inversions, and precipitation also impact pollution transport and dispersion (Lirong Yin, 2021). Mountains and valleys, for example, can impact the accumulation or blockage of pollutants, resulting in regional changes in pollutant concentrations.

Monitoring networks, satellite remote sensing, and atmospheric modelling are all useful techniques for investigating the geographic variation of air contaminants (Liu, 2023). These technologies give data on pollutant concentrations in various areas, allowing scientists and policymakers to identify pollution hotspots, evaluate the efficacy of emission control measures, and devise plans for improving air quality (Sirui Zhang, 2021). Understanding the geographical variation of air pollutants is critical for identifying locations with high pollution levels and susceptible populations, as well as assisting in the development of targeted mitigation plans and the implementation of public health interventions (Yiyong Xiao, 2020).

2. Methodology

The location for mapping the spatial variation is selected as Tamilnadu state and 12 districts are chosen for mapping. The data is been collected from the TNPCB website for 7 pollutants namely (PM 2.5, PM 10, NH_3, NO_2, SO_2, CO, O_3) for 30 days. The collected data is been given as the input for the spatial variation mapping in Arc GIS software (Naoum, 2002). Then the spatial variation for 12 districts is been mapped. The highly polluted district is found and the reasons are given for the polluted area.

3. Location

The location points are:

Ariyalur	Keelapalur
Chennai	1. Alandur bus depot
	2. Arumbakkam
	3. Kodungaiyur
	4. Manali
	5. Perungudi
	6. Royapuram
	7. Velachery Res. Area
Coimbatore	1. PSG college of arts and science
	2. SIDCO Kurichi
Cuddalore	Semmandalam
Dindigul	Mendonsa colony
Kanchipuram	Kilambi
Ooty	Bombay Castel
Ramanathapuram	Chalai Bazaar
Salem	Sona college of Technology
Thoothukudi	Meelavittan
Tirupur	Kumaran college
Vellore	Vasanthapuram

These are the 12 districts selected for mapping the spatial variation (Figure 1).

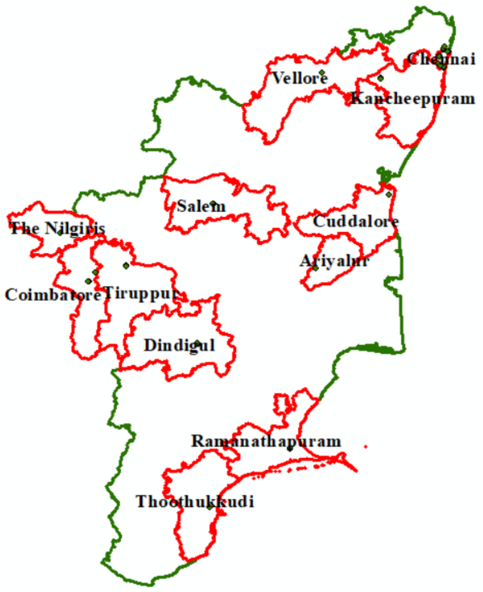

Figure 1. Tamil Nadu map

4. Data

The data which is available in TNPCB website is been collected for 30 days (01.04.2023 – 30.04.2023) at the peak hour 9.00 AM. 7 pollutants are considered and about 570 data has been collected for each pollutant and each location (Table 1). For example:

Location: Coimbatore

Date: 01.04.2023

Time: 9.00 AM

Table 1. Sample Data

Pollutant	Avg	Min	Max
PM 2.5	53	1	86
PM 10	-	-	-
NO_2	16	2	106
NH_3	2	1	25
SO_2	17	17	18
CO	99	14	102
OZONE	6	4	16

5. Results and discussion

5.1. PM 2.5

Because of a variety of causes, the Nilgiris district, famed for its scenic beauty and natural environment, is prone to increased PM 2.5 levels. The Concentration in Nilgiris is currently 12.8 times the WHO annual air quality guideline value. The the PM2.5 concentration was 64 $\mu g/m^3$. Geography, terrain, tourism, population density, agricultural practises, industrial pollutants, and transportation are among them (Mehdi Mokhtari, 2015). The bowl-like form of the valley absorbs pollutants and prevents them from dispersing, while stagnant air in the valleys leads to greater pollution levels. Higher PM 2.5 levels are also caused by tourism-related activities such as motor traffic, construction, and energy use. Higher PM 2.5 levels are also caused by agricultural practises such as crop residue burning, fertiliser usage, and pesticide use.

Industrial emissions, particularly combustion processes, also contribute to greater levels of pollution in the surrounding environment. Transport emissions can also contribute to air pollution in the Nilgiris district, especially during tourist seasons (Figure 2).

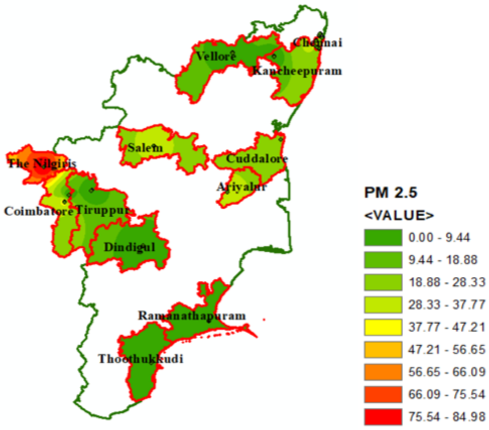

Figure 2. PM 2.5 results

5.2. PM 10

The Nilgiris district, including Ooty, may experience higher levels of PM 10 from 77 µg/m^3 to 80µg/m3 due to various factors. Natural factors, such as forests and vegetation, can contribute to higher levels of PM 10 in the air (Mehdi Mokhtari, 2015). The topography of the Nilgiris district, with its valleys and hills, can trap pollutants, acting as sink areas and accumulating particulate matter. Wind patterns can also influence the transport and dispersion of pollutants, potentially leading to higher concentrations in certain areas.

Agricultural activities, such as ploughing, tilling, and harvesting, can generate dust, contributing to higher PM 10 levels in the air. Urbanization and development activities, such as construction projects, can generate dust from excavation, demolition, and transportation of materials. Industrial emissions, such as combustion, material handling, and emissions from chimneys, can also contribute to PM 10 levels.

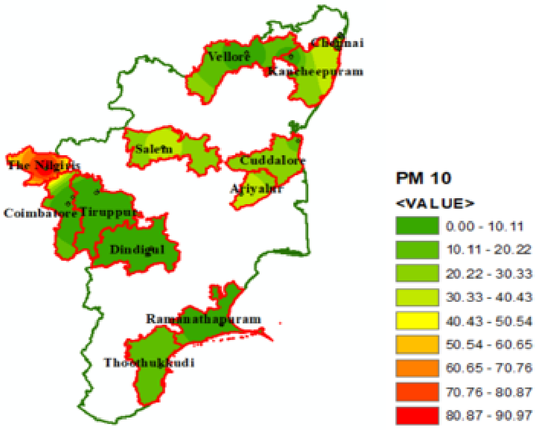

Figure 3. PM 10 Results

Vehicular emissions, particularly during peak tourist seasons, can result in higher levels of PM 10 due to exhaust emissions, tire and brake wear, and road dust resuspension. The narrow roads and congested areas in some parts of the Nilgiris district may exacerbate these effects (Figure 3).

5.3. NO_2

Ariyalur, a city known for its cement production and related industries, can have higher NO_2 levels due to various factors (Weilian Li, 2020). The highest level of NO_2 recoded was 25.33 µg/m^3 Industrial emissions, such as chimneys and combustion processes, contribute to elevated levels of NO_2 in the local air. Vehicle traffic, especially in congested areas, increases NO_2 emissions from vehicle exhaust, especially diesel engines. Heavy-duty vehicles, such as trucks, also contribute to NO_2 levels. Power generation plants, which produce fossil fuels like coal or natural gas, can also contribute to NO_2 emissions.

Agricultural practices, such as excessive use of nitrogen-based fertilizers or improper waste management, can also contribute to increased NO_2 levels. Geography and meteorology also play a role in NO_2 levels in Ariyalur. The presence of hills or valleys, wind patterns, and weather conditions can affect the dispersion and accumulation of NO_2 (Figure 4).

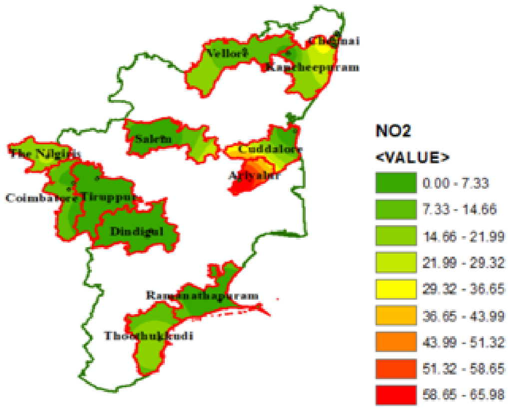

Figure 4. NO2 Results

5.4. NH_3

Ammonia levels in Chennai can be higher due to various factors, including agricultural activities, industrial emissions, waste management, traffic, and atmospheric chemistry (Jane E Clougherty, 2008). It is also varying from 9.51 to 23.1 µg/m^3. Agricultural practices, such as the use of ammonia-based fertilizers and animal husbandry operations, can release ammonia into the air, causing elevated levels. Industrial processes, such as chemical manufacturing, petrochemicals, and fertilizer production, also contribute to ammonia emissions. Improper waste management practices, such as inadequate sewage treatment or landfill decomposition, can also lead to ammonia release. Traffic, particularly in congested areas, can contribute to ammonia levels due to reactions between nitrogen oxides (NOx) and other atmospheric components.

Chemical reactions in the atmosphere can also play a role in the presence of ammonia, with emissions from various sources, including agricultural and industrial activities, undergoing atmospheric transformations. The reasons for higher NH^3 levels in Chennai may vary based on local sources, meteorological conditions, and prevailing factors (Figure 5).

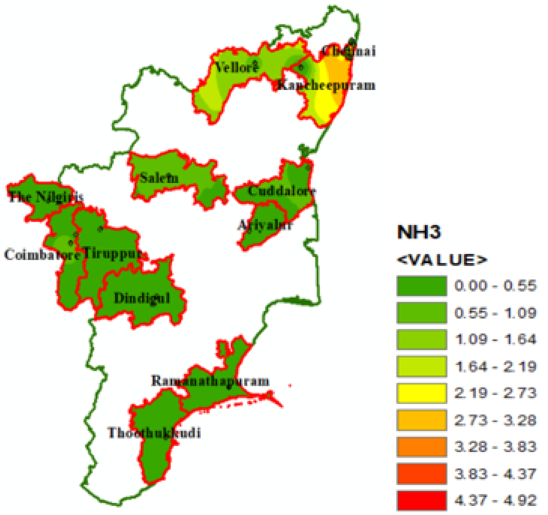

Figure 5. NH3 Results

5.5. SO$_2$

Salem, an industrial city, is susceptible to higher levels of sulfur dioxide (SO$_2$) from 26.5 to 42.28 µg/m^3 due to various factors. Industrial emissions, such as chemical plants, steel mills, and thermal power plants, often use fossil fuels like coal or oil, which can release sulfur dioxide when the fuel contains sulfur impurities (Liu, 2023). Inefficient emission control measures can result in higher SO$_2$ levels in the area. Power generation, particularly coal-fired power plants, can also contribute to SO$_2$ emissions, especially if they lack efficient emission control technologies. Transportation also contributes to SO$_2$ levels, with vehicle emissions being a primary source. However, high volumes of diesel vehicles or older vehicles with inefficient emissions control systems can also release sulfur dioxide into the atmosphere.

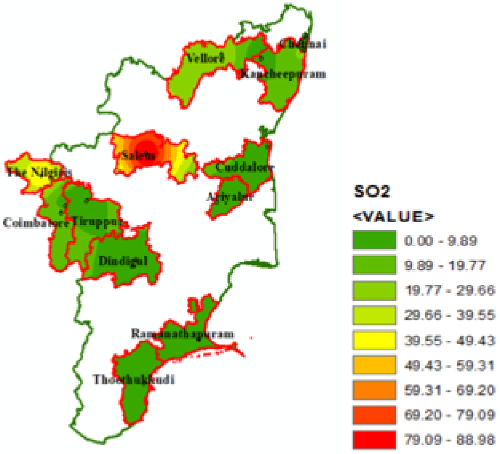

Figure 6. SO$_2$ Results

Natural sources, such as volcanic activity or geothermal vents, can also contribute to SO$_2$ levels. Meteorological factors, such as wind patterns and atmospheric conditions, can influence the dispersion and concentration of SO$_2$ in a particular area. Local geography and topography can also contribute to elevated SO$_2$ concentrations (Figure 6).

5.6. CO

Carbon monoxide (CO) levels in Chennai varies from 2 to 26 mg/m^3 which can be higher due to various factors, including vehicular emissions, industrial emissions, solid waste management, biomass burning, meteorological conditions, and agricultural practices. High traffic volumes and congestion in urban areas contribute to increased CO levels, as incomplete combustion of fossil fuels in vehicles and poorly maintained emission control systems can release CO into the air (Lian Xiong, 2023). Industrial activities, such as manufacturing plants, power plants, and refineries, can also emit CO as a by-product of combustion processes. Inadequate waste management practices, especially in densely populated areas, can also contribute to elevated CO levels in Chennai. Biomass burning, particularly during specific seasons, can also release CO into the air.

Local weather conditions can also impact the dispersion and accumulation of pollutants, including CO, resulting in higher concentrations in certain areas (Figure 7).

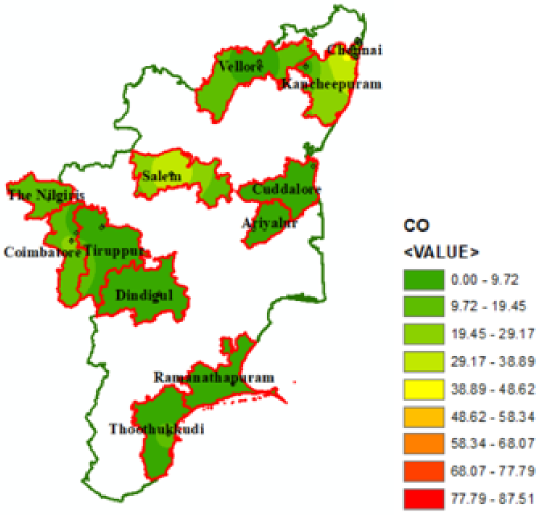

Figure 7. CO Results

5.7. OZONE

Thoothukudi, a coastal city in Tamil Nadu, may experience higher levels of ozone which varies from 6.68 to 30.80 µg/m^3. Photochemical reactions, industrial emissions, sunlight, and temperature are all contributing factors to the formation of ozone (Gemitzi A. 2011). Industrial activities, vehicle exhaust, and other anthropogenic sources can contribute to the formation of O$_3$ under favourable meteorological and chemical conditions. Thoothukudi's industrial hub, with thermal power plants, chemical plants, and metal processing industries, can release NOx and VOCs, which are key ingredients in ozone formation. If these emissions are not adequately controlled or the area experiences unfavourable meteorological conditions, O$_3$ levels can be higher.

Sunlight and temperature also play a role in ozone formation, with Thoothukudi experiencing high temperatures and abundant sunlight during certain seasons. Atmospheric stability, influenced by meteorological factors, can impact the accumulation of pollutants, including ozone (Helen Crabbe, 2000). Longrange transport, which involves ozone transported over long distances by wind patterns, may also influence O_3 levels in Thoothukudi. The specific reasons for higher O_3 levels in Thoothukudi may vary based on local sources, meteorological conditions, and prevailing factors (Figure 8).

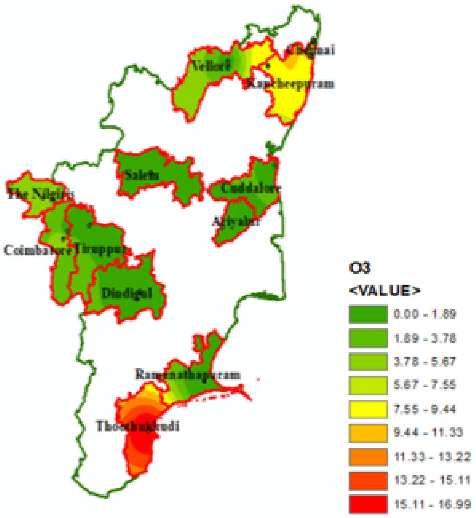

Figure 8. Ozone Results

5.8. *Highly polluted Area*

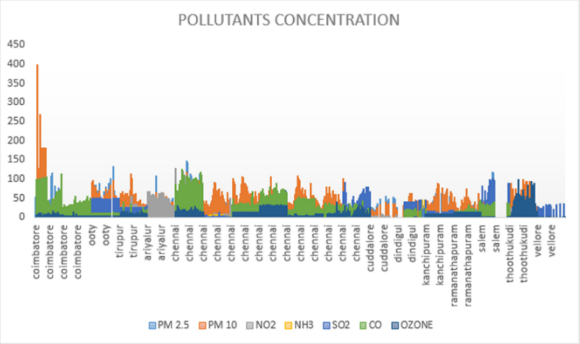

Figure 9. Graph of highly polluted area

PM 2.5 – Nilgiris, PM 10 – Nilgiris, NO_2 – Ariyalur, NH_3 – Chennai, SO_2 – Salem, CO – Chennai, O_3 – Thoothukudi (Figure 9).

6. Mitigative measures

- Strengthen emission standards: Implement and enforce stricter emission limits for businesses, power plants, cars, and other sources of pollution. To ensure emissions are below allowable limits, compliance with these criteria must be consistently monitored and enforced.
- Promote clean energy sources: To lessen reliance on fossil fuels and cut emissions, encourage energy efficiency measures and the use of renewable energy sources, such as solar and wind energy.
- Improve transportation infrastructure: To cut down on the amount of private automobiles on the road, make investments in public transit systems like trains and buses. To encourage non-motorized transportation choices, provide bicycle lanes and pedestrian-friendly infrastructure.
- Upgrade vehicle emissions standards: Implement and enforce stricter vehicle emissions regulations, especially for diesel trucks and buses and other vehicles that contribute considerably to air pollution. Inspect and maintain cars often to make sure they adhere to emission standards.
- Encourage electric mobility: Give electric car owners incentives, such as tax breaks, the construction of charging infrastructure, and subsidies. Encourage the use of electric cars for both personal and public transportation.
- Enhance waste management: Adopt sound waste management techniques, such as proper garbage collection, segregation, recycling, and disposal. To reduce the discharge of pollutants from landfills, promote composting and waste-to-energy initiatives.
- Promote sustainable agriculture: Encourage organic agricultural methods while minimising the use of pesticides and fertilisers that include chemicals. Encourage appropriate agricultural waste management practises and discourage open burning of agricultural garbage.
- Strengthen industrial emission controls: Employ more stringent laws and cutting-edge emission control technology in industrial sectors with high pollution potential. Emissions from industries, power plants, and other industrial sources should be monitored and controlled.
- Strengthen air quality monitoring: To provide real-time information on pollution levels, establish and extend air quality monitoring networks throughout Tamil Nadu. Make informed judgements about public policy and create specialised pollution control plans using the data.

7. Conclusion

The examination of air pollution's spatial fluctuation is a complex matter that necessitates attention. The data acquired from this investigation demonstrates the significance and need for conducting health risk assessments and implementing control measures. In this study, the utilization of GIS modeling aids in comprehending the distribution, causes, and impacts of air pollution in various geographical areas. Through GIS modeling, the results visually represent and analyze geographical patterns of air pollution by integrating diverse datasets, including air quality measurements, meteorological data, emission inventories, and land use information. This facilitates the identification of hotspots, areas with high pollution levels, and variables that contribute to fluctuations in pollutant concentration. Understanding the geographical disparity of air pollutants is crucial for implementing tailored pollution reduction methods and regulations in specific locations. Notably, the Nilgiris region has recorded a PM2.5 concentration of 64 $\mu g/m^3$.

The spatial variation of air pollutants is mapped using the Arc GIS software. The data is collected from the TNPCB website over a period of 30 days (01.04.2023 – 30.04.2023) during the peak hour of 9.00 AM. The pollutants considered include PM 2.5, PM 10, NO_2, NH_3, SO_2, CO, and O_3, and mapping is conducted for 12 districts in Tamil Nadu. A total of approximately 570 data points are collected for each pollutant at each location. The concentration of pollutants, such as PM 2.5, is segregated and inputted into the Arc GIS software for mapping purposes. The district with the highest pollution level for each pollutant is identified, and the reasons for the elevated pollution in that particular district are provided.

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