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Spatial distribution map of air pollutants and its impact on human health for Tiruchirappalli City using GIS techniques

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Abstract

Air pollution poses a serious challenge for urban areas, particularly in developing cities like Tiruchirappalli. This study assess the ambient air quality and prepare the maps for Tiruchirappalli using geospatial techniques and focused on air pollutants such as Nitrogen Oxides (NOx), Sulfur dioxide (SO_2), Particulate Matter (PM_{10} and $PM_{2.5}$), Total Suspended Particulate Matter (TSPM) and Carbon Monoxide (CO), which are primarily responsible for the poor air quality in the city. Data for these pollutants were collected from 13 different sampling locations within the city. Spatial interpolation techniques, specifically Inverse Distance Weighting (IDW), were applied to represent the distribution of air quality across the study area during the summer months from January to March 2024. This period was chosen due to the high dispersion characteristics of air pollutants. The generated spatial distribution maps identified potential air pollution hotspots within the city, particularly in the areas with high traffic density where elevated levels of NOx and CO were observed. The outcomes of this study hold significant implications for urban planning, management and public health strategies in Tiruchirappalli city, emphasizing the need for targeted interventions to mitigate air pollution in identified polluted areas.

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Introduction

Air pollution involves the release of harmful substances, including particulates, gases, and biological molecules, into the atmosphere, posing risks to human health and the environment.

Major sources include automobile emissions, biomass burning, urbanization, industrial activities, construction, and natural events such as volcanic eruptions and wildfires. Key pollutants include Nitrogen Oxides (NOx), Sulfur dioxide (SO_2), Particulate Matter (PM_{10} and $PM_{2.5}$), Total Suspended Particulate Matter (TSPM), and Carbon Monoxide (CO) (Balakrishnan *et al.*, 2014). These pollutants are associated with various adverse effects, such as acid rain, ozone layer depletion, and damage to wildlife, ecosystems and also respiratory and cardiovascular diseases in humans (Yin *et al.*, 2024). Based on data collected for 2021, Delhi ranked the most polluted capital city, and another 62 Indian cities are in the top 100 most polluted cities list (https://www.iqair.com). Studies have shown that major cities of India like Delhi, Raipur, Gwalior, and Lucknow are listed among the world's top 10 polluted cities and altogether 37 Indian cities feature in a list of 100 most polluted cities globally, with highest PM10. In 2016, WHO released a global urban air pollution ranking that identified Chennai as the most polluted city in Tamil Nadu, with a global ranking of 314. Trichy and Coimbatore were also highlighted, ranking 370 and 410, respectively (Kamboj *et al.*, 2022). These statistics highlight the urgent need for comprehensive air quality monitoring and management strategies in such a city. However, establishing an extensive network of monitoring stations is challenging due to high costs and logistical constraints. To address this, spatial interpolation techniques offer a practical solution by estimating pollutant levels at unmonitored locations using data from existing monitoring stations (Shukla *et al.*, 2020) GIS techniques have been applied by various researchers primarily to analyse the spatial and temporal distribution of pollutants. Interpolation, a mathematical method of numerical analysis, allows for the creation of continuous surface maps that depict the spatial distribution of air pollutants. These techniques are crucial for assessing air quality over large areas where direct measurements are unavailable (Jha *et al.*, 2011). Geographic Information System (GIS) tools significantly enhance the efficiency and accuracy of spatial interpolation, making it a dominant tool for modeling spatial variations in environmental systems. The findings will aid environmental engineers and scientists in making informed decisions and developing targeted interventions to improve air quality in the highly polluted area (Gupta, 2013).

Health impacts

Air pollutants irritate the airways, leading to inflammation and a reduction in lung function. This can result in severe health problems including as heart attack, worsened asthma symptoms, and reduced lung function (WHO, 2021). Chronic exposure to $PM_{2.5}$ and other airborne toxins can result in respiratory diseases like COPD. Fine particulate matter and gaseous pollutants such as nitrogen dioxide (NO_2) can penetrate the bloodstream, triggering systemic inflammation, oxidative stress, and the buildup of plaque in arteries. This contributes to atherosclerosis and other cardiovascular complications (Pandey *et al.*, 2021).

Individuals exposed to these pollutants may experience symptoms like coughing, sneezing, nasal congestion, and itchy eyes. These reactions are particularly common in urban areas with high levels of particulate matter and pollutants (Renzi *et al.*, 2022). Prolonged exposure to elevated CO levels can have serious health consequences, particularly for vulnerable populations such as children, the elderly, and those with pre-existing health conditions. CO reduces the blood ability to carry oxygen, leading to symptoms like headaches, dizziness, and fatigue at lower exposure levels. At higher concentrations, it can cause impaired vision, confusion, unconsciousness, and even death.

Materials and methods

Study area

Tiruchirappalli city is the fourth largest corporation in Tamil Nadu state, India. It is situated on the banks of the river Cauvery at 10°00' to 11°30'N latitude and 77°45' to 78°50'E longitude. Total geographical area of the city is 163 km^2. The average annual rainfall recorded was 808 mm, mostly occurring during the monsoon season. The temperature in winter varies from 18.6°C to 23.1°C and in summer the range of 36.40°C to 44.10°C. There are 4 major highways such as NH 45, NH 67, NH 210 and NH 277 by way of the city.

Data collection

The samples were collected using advanced real-time continuous monitoring instrument of Aeroqual (AQM 65) for 8-hour duration. During the period of three month from January 29, 2024 to March 23, 2024, Samples were collected at 13 locations in the Tiruchirappalli City Corporation by random sampling method, broadly classified into Traffic Intersection Zone, Commercial Zone, Residential Zone, Mixed Zone as main categories. The details of the sampling sites are given on Table 1. All these locations are prominent places in the Tiruchirappalli City and are typical representatives of their respective categories. Sampling was carried out for Sulfur dioxide, Oxides of Nitrogen, Suspended particulate matter and PM_{10}, $PM_{2.5}$, TSPM and Carbon monoxide.

Software and tool

The study utilized the "Spatial Analyst" tool in ArcGIS 10.7.1 to assess spatial variability in air quality. Data for NOx, SO_2, PM_{10}, $PM_{2.5}$, TSPM and CO were collected from 13 sampling sites given in Table.1 The Inverse Distance Weighting (IDW) interpolation method was applied to estimate pollutant concentrations at unsampled locations, generating a comprehensive surface model. This spatial interpolation was visualized on maps to identify pollution hotspots. The ArcGIS platform enabled precise interpolation and mapping, providing a detailed spatial representation of air quality.

Table 1. Geographical location of sampling sites

Sampling site	Area category	Latitude	Longitude
Ariyamangalam	Mixed	10° 80'25" N	78° 70'55" E
K. K. Nagar	Residential	10° 77'02" N	78° 68'20" E
Kajamalai	Residential	10° 77'56" N	78° 69'01" E
Palpannai	Traffic	10° 48'46" N	78° 42'45" E
Palakarai	Traffic	10° 48'47" N	78° 42'45" E
Somarasampettai	Residential	10° 81'04" N	78° 63'20" E
Srirangam	Residential	10° 85'51" N	78° 69'51" E
Thiruvarambur	Mixed	10° 78'46" N	78° 76'02" E
TVS Tollgate	Traffic	10° 79'12" N	78° 69'43" E
Chatiram Bus Stand	Traffic	10° 49'59" N	78° 41'32" E
Woraiyur	Mixed	10° 49'39" N	78° 40'27" E
Salai Road	Traffic	10° 49'37" N	78° 41' 7" E
Melaputhur	Mixed	10° 48'05" N	78° 41' 12" E

Inverse distance weighting (IDW)

Interpolation aims to estimate values at unsampled locations using data from sampled points, producing continuous surface maps that represent spatial variations across an area. This technique is widely regarded as one of the most effective methods for modeling spatial changes in environmental systems (Li and Heap, 2014). Inverse Distance Weighting (IDW) is a deterministic interpolation method that predicts unknown values by calculating a weighted average of nearby known values, with weights inversely related to the distance between known and unknown points. This study used the IDW method to generate air pollution concentration maps for the study area. Utilizing data from sampling locations, the IDW algorithm estimated pollutant levels across the city, producing visual maps that highlight pollution hotspots and spatial patterns. These maps are crucial for assessing the potential impacts of air pollution on various communities and areas within the study area.

Results and discussion

The sampling period selected for this study was three months from January to March, 2024 and mean value was calculated for all the 13 locations (Table 2) and spatial distribution map were generated using ArcGIS as follows.

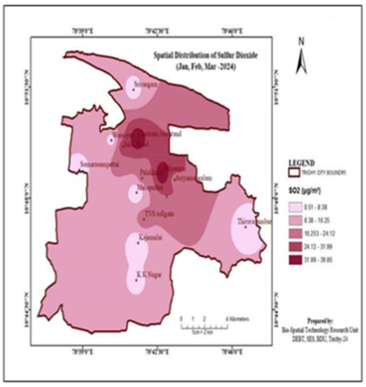

Fig. 1. Spatial distribution SO_2 (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

SO_2

Fig.1 shows that the concentration of SO_2 lies between the range from 0.50 µg/m³ to 39.89 µg/m³. The highest recorded concentration is 39.89 µg/m³ in Palpannai, followed by Chatiram bus stand 39.59 µg/m³ while the lowest concentration observed is 0.50 µg/m³ in Melaputhur.

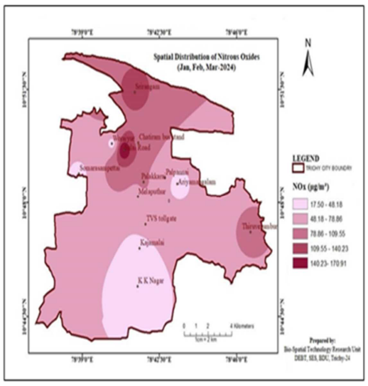

Fig. 2. Spatial distribution NOx (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

NOx

Fig. 2 shows that the concentration of NOx lies between the range 17.50 to 171.09 µg/m³. The maximum concentration (171.09 µg/m³) was observed at Salai road, followed by Srirangam (123.66 µg/m³) and Chatiram bus stand (107.90 µg/m³). The minimal was observed (17.50 µg/m³) at the Kajamalai. The NOx value is exceeds the permissible level of CPCB standard in many locations.

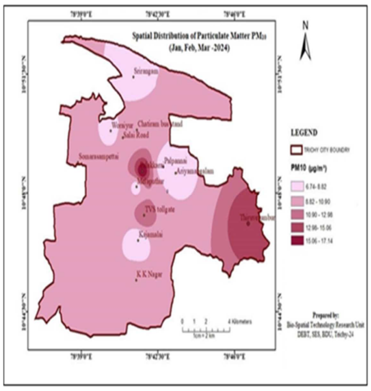

Fig. 3. Spatial distribution PM10 (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

PM_{10}

Fig. 3 shows that the concentration of PM_{10} lies between the range 6.74 µg/m³ to 17.17µg/m³. The highest recorded concentration is 17.17 µg/m³ in Palakkarai, followed by Thiruverumbur 15.08µg/m³ while the lowest concentration observed is 6.74µg/m³ in Kajamalai.

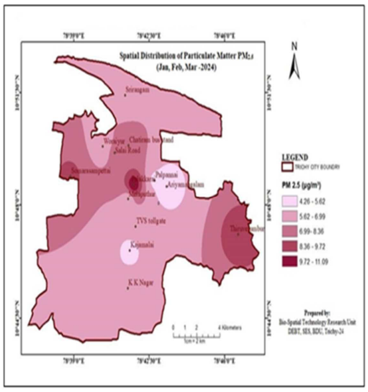

Fig. 4. Spatial distribution $PM_{2.5}$ (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

$PM_{2.5}$

Fig. 4 shows that the concentration of $PM_{2.5}$ lies between the range 4.26 µg/m³ to 11.11 µg/m³. The highest recorded concentration is 11.11µg/m³ in Palakkarai, followed by Thiruverumbur 9.162µg/m³ while the lowest concentration observed is 4.26µg/m³ in Ariyamangalam.

Table 2. Concentration of air pollutants from January – March, 2024

Locations	SO_2 (µg/m³)	NOx (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	TSPM (µg/m³)	CO (ppm)
Ariyamangalam	22.72	32.04	6.88	4.26	15.22	1.51
Chatram Bus Stand	39.59	107.90	9.86	7.84	13.62	2.57
K K Nagar	7.45	20.86	9.58	5.97	19.24	1.48
Kajamalai	2.55	17.50	6.74	5.14	9.67	1.30
Melaputhur	0.50	71.39	7.64	6.07	10.72	3.03
Palakarai	17.91	81.55	17.17	11.11	36.35	2.42
Palpannai	39.89	60.74	7.34	5.33	11.42	1.87
Salai Road	27.17	171.09	9.06	7.23	14.93	2.85
Somarasam Pettai	5.51	42.04	10.54	8.85	15.05	1.72
Srirangam	5.48	123.66	7.45	6.00	10.90	2.07
Tiruverambur	5.56	82.33	15.08	9.16	38.82	1.35
TVS Tollgate	20.13	78.02	13.03	6.07	28.04	2.24
Woraiyur	6.09	40.30	8.01	6.20	12.62	2.16

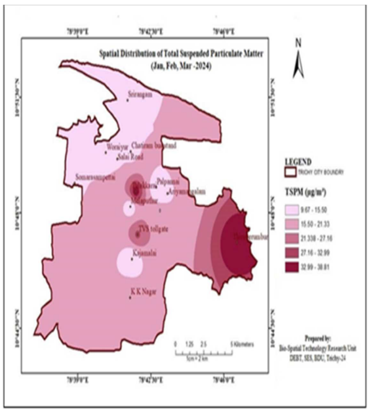

Fig. 5. Spatial distribution TSPM (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

TSPM

Fig. 5 shows that the concentration of TSPM lies between the range 9.67 µg/m³ to 38.82 µg/m³. The highest recorded concentration is 38.82µg/m³ in Thiruverumbur, followed by Palakkrai 36.35µg/m³ while the lowest concentration observed is 9.67µg/m³ in Kajamalai.

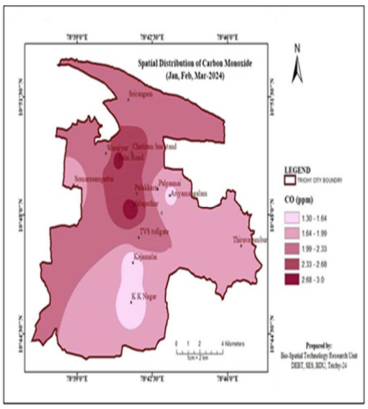

Fig. 6. Spatial distribution CO (µg/m³) of Tiruchirappalli City (Jan-Mar 2024)

CO

Fig. 6 shows that the concentration of CO lies between the ranges 1.30 ppm to 3.03 ppm. The highest recorded concentration is 3.03ppm in Melaputhur, followed by 2.57 ppm at Chatiram Bus Stand, 2.85 ppm at Salai Road, and 2.42 ppm at Palakarai. While the lowest concentration observed is 1.30 ppm in Kajamalai. The CO value is exceeds the permissible level of CPCB standard in many locations.

Hotspots of air pollution

Hotspots of air pollution were identified in several locations during the study, with notable increases in NOx and CO levels. These rises can be attributed to factors such as increased vehicular emissions, high population density, and other anthropogenic activities. The areas identified as pollution hotspots include Palakkarai, Woraiyur, Salai Road, Srirangam, TVS Tollgate, Palpannai, Chatiram Bus Stand, and Thiruverumbur, all of which recorded high levels of air pollutants. These findings underscore the urgent need for enhanced monitoring, stricter regulations, and more effective pollution control measures to mitigate the impact on public health and the environment.

Tiruchirappalli city experiences moderate air pollution levels, particularly with sulfur dioxide (SO_2), PM10, PM2.5, and total suspended particulate matter (TSPM), which consistently remains within National Ambient Air Quality Standards (NAAQS). However, pollutants like Nitrogen Oxides (Nox) And Carbon Monoxide (CO) exceed permissible limits in specific areas such as Salai Road, Kajamalai, Palpannai, Woraiyur, and Palakkarai.

The reduced levels of SO_2 in the city are largely attributed to the use of low-sulfur fuel in vehicles, helping to curb emissions.

However, medium levels of PM_{10} and $PM_{2.5}$ are observed in areas like Palakkarai, TVS Tollgate, Salai Road, Palpannai, and Somarasampettai, primarily due to heavy vehicular traffic and road dust disturbances. The rising number of vehicles, especially diesel-powered ones, contributes significantly to Particulate Matter and Nitrogen Oxides. Without proper management, the situation regarding particulate matter could deteriorate further.

The growing levels of Carbon Monoxide (CO) in high-traffic areas such as Palakarai, Woraiyur, and Salai Road have become a serious concern, with CO concentrations exceeding NAAQS standards, posing significant health risks. The primary source of CO is the incomplete combustion of fossil fuels, particularly in vehicles. To address this, it is critical to implement measures like adopting cleaner vehicle technologies, stricter emission controls, and better traffic management. Public awareness campaigns promoting reduced vehicular use and improved public transportation could also help mitigate CO levels and protect public health.

Conclusion

It is concluded that, the air quality in Tiruchirappalli city is significantly increased by vehicle emissions. A multi-pronged approach, involving both government initiatives and active public participation, is essential to address these issues. While some progress has been made in reducing pollutants like SO_2, PM_{10}, and $PM_{2.5}$, concerning trends in NOx and CO levels, particularly at traffic intersections, highlight the need for further action. Spatial interpolation methods like Inverse Distance Weighting (IDW) proved valuable in predicting pollutant levels within the study area, helping to identify pollution hotspots. These techniques enhance the overall assessment by allowing a more detailed spatial understanding of air quality across the city. To avoid the health impacts management strategies should be followed. Implementing stringent vehicle emission standards, promoting cleaner fuels, enforcing regulations on fuel adulteration, and regularly monitoring vehicle inspection and maintenance practices are crucial measures to mitigate air pollution and ensure compliance.

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