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Geographical Assessment of Ozone Pollution Trends across Mumbai Monitoring Stations

Dr. Ravindra Sudam Bhagat

Abstract

Ground-level ozone (O_3) is a secondary pollutant formed through photochemical reactions of NO_x and VOCs under solar radiation and is a major component of urban smog (Seinfeld & Pandis, 2016). The World Health Organization identifies ozone exposure as a significant risk to respiratory health and premature mortality (WHO, 2021). In rapidly urbanizing Indian megacities, increasing vehicular and industrial emissions have intensified ozone formation. This study assesses spatial and temporal trends of O_3 across major monitoring stations in Mumbai, Maharashtra, during 2016–2024. Annual average ozone data were analyzed using the non-parametric Mann–Kendall test to detect monotonic trends (Hirsch et al., 1982). Results reveal spatial variability in ozone concentration across southern, central, western, northern, and eastern zones of the city. Among nine stations, only Bhandup shows a statistically significant decreasing trend at the 5% level. Other stations exhibit weak increasing or decreasing tendencies that are not statistically significant. The findings reflect the influence of coastal meteorology, emission intensity, and land-use patterns on ozone dynamics. The study provides scientific evidence to support urban air quality management and policy planning in Mumbai.

Keywords: *Air Pollution, Coastal Megacity, Ground-level Ozone (O_3), Photochemical Pollution*

Introduction

Tropospheric ozone (O_3) is a secondary air pollutant formed by photochemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) under sunlight. It is widely recognized as a major component of urban smog and poses significant risks to human health, vegetation, and climate systems (Seinfeld & Pandis, 2016). The World Health Organization identifies ground-level ozone as a serious public health concern linked to respiratory diseases and premature mortality (WHO, 2021). Additionally, the Intergovernmental Panel on Climate Change highlights ozone as a short-lived climate pollutant contributing to radiative forcing and global warming (IPCC, 2021). In India, rapid urbanization and vehicular growth have intensified photochemical pollution in metropolitan regions. The Central Pollution Control Board reports increasing ozone episodes in several major cities, including coastal megacities. Mumbai, characterized by dense traffic, industrial activities, and sea-breeze circulation, presents complex spatial variability in ozone concentration. While particulate pollution has been extensively studied, long-term ozone trend assessment remains limited. Therefore, this study conducts a geographical assessment of ozone pollution trends across Mumbai monitoring stations for the period 2016–2024 using the Mann–Kendall non-parametric test (Hirsch et al., 1982). The analysis aims to identify spatial differences and statistical significance of ozone trends to support urban air quality management strategies.

Study Area:

Mumbai, located in Maharashtra on the western coast of India, lies between 18°53′–19°16′ N and 72°48′–72°59′ E along the Arabian Sea. The city is governed by the Brihanmumbai Municipal Corporation and is characterized by a tropical coastal climate with strong sea-breeze influence. The study includes major air quality monitoring stations located in different geographical zones—Colaba and Worli (south), Mazgaon and BKC (central), Andheri and Malad (west), Bhandup and Borivali (north), and Nerul (east).

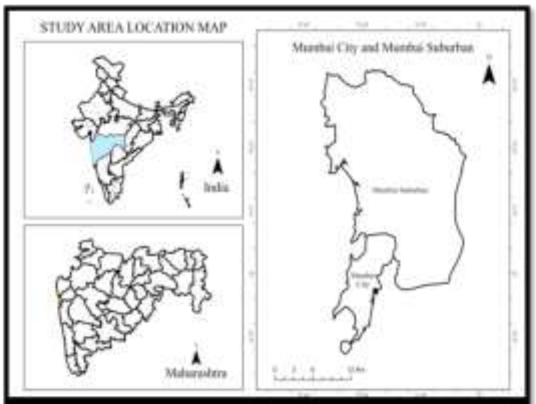

Fig- Location Map of Study Area

These stations represent diverse land-use patterns and emission characteristics, making Mumbai suitable for assessing spatial and temporal trends of ozone concentration during 2016–2024.

Objectives of the Study

1. To analyze the temporal trends of ground-level ozone (O_3) concentrations across different monitoring stations in Mumbai over a selected time period.
2. To identify the areas with higher ozone concentration levels and assess their possible environmental and urban influences.
3. To study the annual average variation of ozone levels (summer, monsoon, and winter) across Mumbai monitoring stations.
4. To Study the spatio temporal analysis of Ozone Concentration

Methodology

The data for this study were collected from the Indian Institute of Tropical Meteorology (IITM) and the System of Air Quality and Weather Forecasting and Research (SAFAR). The ozone (O_3) concentration data from different monitoring stations were organized and processed using Microsoft Excel. To identify trends in the data, the Mann–Kendall trend analysis method was applied. In this method, the S value and Z value were calculated to determine increasing, decreasing, or no trend in ozone concentration at a 5% significance level. The spatial distribution of ozone concentration was further analyzed using ArcGIS software. GIS techniques were used to prepare maps and examine spatial patterns across different locations. Finally, the results from statistical analysis and GIS mapping were interpreted to draw the conclusions of the study.

Statistical Analysis of Study Area:

The Mann–Kendall (MK) method is a non-parametric statistical test used to detect monotonic (increasing or decreasing) trends in time-series data. It was developed by Mann (1945) and Kendall (1975) and is widely applied in environmental and climatological studies. The method does not require the data to follow a normal distribution and is less sensitive to outliers, making it highly suitable for air quality and hydro-meteorological datasets.

Table 1 - Annual Average Ozone (O_3) Concentrations

Station	S Value	Z Value	Trend	Significance (5%)
Bhandup	-23	-2.29	Decreasing	Significant
BKC	-1	0	No trend	Not Significant
Colaba	5	0.42	Slight Increase	Not Significant
Andheri	-4	-0.31	Slight Decrease	Not Significant
Malad	-1	0	No trend	Not Significant
Mazgaon	-6	-0.52	Slight Decrease	Not Significant
Worli	-11	-1.04	Decreasing	Not Significant
Borivali	-10	-0.94	Decreasing	Not Significant
Nerul	2	0.1	Slight Increase	Not Significant
Source – Computed by Researcher				

Table 1 presents the results of the Mann–Kendall trend analysis applied to annual average ozone (O_3) concentrations recorded at nine monitoring stations across Mumbai for the period 2016–2024. The analysis evaluates the direction and statistical significance of monotonic trends using the Mann–Kendall S statistic and corresponding Z values. The stations included in the study represent different geographical zones of the city, namely Bhandup, BKC, Colaba, Andheri, Malad, Mazgaon, Worli, Borivali, and Nerul. The table summarizes the calculated S values, Z statistics, trend direction (increasing or decreasing), and their significance at the 5% level.

The results indicate that among the nine stations, only Bhandup exhibits a statistically significant decreasing trend in ozone concentration ($Z = -2.29$), as its absolute Z value exceeds the critical value of 1.96 at the 5% significance level. All other stations show either weak increasing or decreasing tendencies; however, their Z values remain within ±1.96, indicating that these trends are not statistically significant. Stations such as Worli and Borivali show moderate negative S values, suggesting a decreasing tendency, while Colaba and Nerul exhibit slight increasing trends. Overall, the findings reveal spatial variability in ozone behavior across Mumbai, but no widespread statistically significant trend except at Bhandup, highlighting localized influences of emission patterns and meteorological conditions.

Spatio-Temporal Analysis of Ozone Concentration:

O_3 Concentation in 2016

The 2016 ozone (O_3) map of Mumbai shows clear spatial variation in ozone concentration across major monitoring locations such as Chembur, Bhandup, Bandra Kurla Complex, Colaba, Andheri, Malad, Mazgaon, Worli, Borivali and Nerul. The highest concentration (29.92–33.77) occurs in the southern tip of the city around Colaba and Worli, while high values (27–29) are found in the southern and eastern coastal areas such as Mazgaon and Nerul. Moderate levels (23–26) dominate the northern and eastern regions including Chembur, BKC and Andheri, whereas the central-western part records the lowest values (12.5–19) in areas like Bhandup, Malad and Borivali. This pattern suggests that southern coastal areas experience higher ozone formation due to traffic, port activities, and industrial emissions, while central urban areas show lower ozone levels due to dense urban conditions and higher NO emissions.

O_3 Concentation in 2020

The 2020 map indicates a general decrease in ozone concentration compared to 2016 across locations in Mumbai such as Chembur, Bhandup, BKC, Colaba, Andheri, Malad, Mazgaon, Worli, Borivali and Nerul. The highest values (30.29–33.04) remain in the southern tip around Colaba and Worli, while moderate concentrations (22–27) occur in the eastern and southern regions including Chembur, Mazgaon and Nerul. The central and northern parts such as Bhandup, Malad, Borivali and Andheri show lower values (5.44–16). This suggests that central Mumbai has the lowest ozone levels, while southern coastal areas continue to act as ozone hotspots, though overall ozone levels have reduced in several regions.

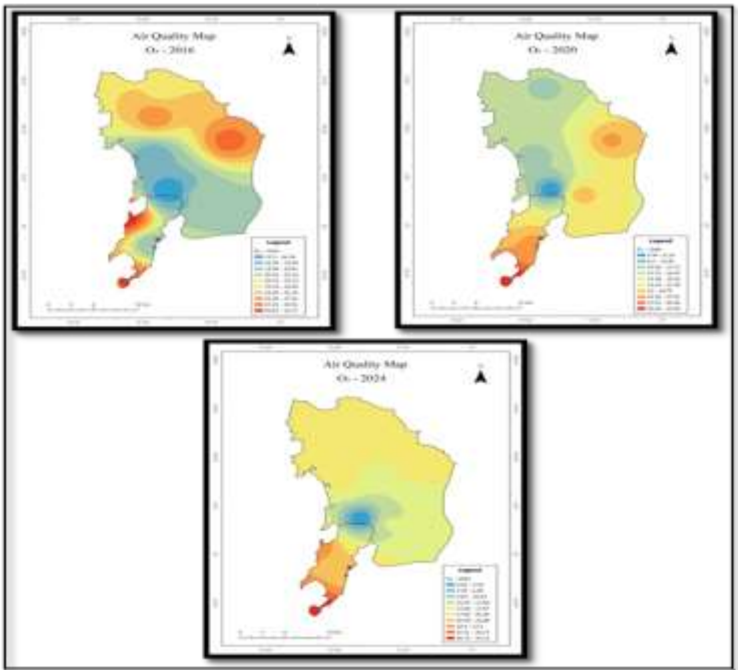

Fig 2- Temporal O3 Concentration in Mumbai and Suburban Area

O_3 Concentation in 2024

The 2024 map shows a further decline in ozone concentration across most parts of Mumbai, particularly in locations such as Bhandup, Andheri, Malad and Borivali. The central region records very low values (0.02–10), while moderate levels (13–20) appear in northern and eastern areas including Chembur, BKC and Nerul. However, higher concentrations (27–34) still occur in the southern coastal zone around Colaba, Worli and Mazgaon. This indicates that central Mumbai remains a low-ozone zone, while the southern region continues to be a persistent hotspot, although overall ozone levels have decreased compared to previous years.

O_3 distribution maps for 2016, 2020, and 2024 in Mumbai shows a gradual decrease in ozone concentration over time. In 2016, higher ozone levels were observed mainly in the southern coastal region, while moderate to low levels occurred in other parts of the city. In 2020, overall ozone concentration slightly declined, but the southern region remained a major hotspot. By 2024, ozone levels further decreased, especially in the central region, though the southern coastal belt continued to show comparatively higher concentrations. Overall, the spatial pattern remains similar, indicating that while ozone levels are reducing, certain areas still require focused pollution control measures.

Conclusion:

The study analyzes ozone (O_3) trends at nine monitoring stations in Mumbai—Bhandup, BKC, Colaba, Andheri, Malad, Mazgaon, Worli, Borivali, and Nerul during 2016–2024. The Mann–Kendall analysis shows that most stations have weak increasing or decreasing trends that are not statistically significant. Only Bhandup shows a significant decreasing trend at the 5% level. Spatial analysis indicates higher ozone concentration in southern coastal stations such as Colaba and Worli, while central areas show lower values. Overall, ozone levels show a slight decline over time, but some coastal areas still remain hotspots requiring continuous monitoring and control measures.

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Nil.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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