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The Influence Of Urban Growth On Air Quality Of Panaji City In A Geographical Perspective

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Abstract:

The degradation of air quality in many urban areas has been mostly caused by rapid urbanization, population growth, increasing vehicle movement, and shifting land-use patterns. Coastal cities are also not completely free from pollution. In this context, the study examines the air quality status of Panaji city, the capital of Goa, over a period of three years from April 2022 to March 2025. Secondary data were collected from the Central Pollution Control Board (CPCB) for Panaji city. Annual average concentrations of each pollutant were calculated and compared with the National Ambient Air Quality Standards (NAAQS, 2009) to evaluate whether pollution levels were within safe limits. The findings show that PM10 levels were slightly higher than the national standard in all three years, although a slow decreasing trend was observed. This indicates that coarse dust particles remain the main air quality concern in Panaji city. PM10 pollution is mainly linked to vehicular traffic, road dust resuspension, construction activities, and increased tourism-related movement. On the other hand, PM2.5 concentrations remained well within permissible limits throughout the study period, suggesting low levels of fine particulate pollution. The gaseous pollutants SO2 and NO2 were recorded at very low concentrations, reflecting the absence of major industries and controlled vehicular emissions in the city. Overall, Panaji experiences moderate air pollution, with particulate matter especially PM10 being the dominant pollutant. Natural factors such as coastal winds, high rainfall, and atmospheric dispersion play role in reducing pollution levels and maintaining relatively better air quality. Therefore, effective measures such as better traffic management, control of road dust, and planned urban development are necessary to further improve air quality. The study highlights the importance of monitoring and managing air pollution in small coastal cities to ensure a healthy urban environment.

Keywords: Air Pollution, Urbanization, Particulate Matter, Coastal City, National Ambient Air Quality Standards (NAAQS)

Introduction:

Air pollution is a global concern and due to its adverse impacts on both the environment and human health. As cities grow due to increasing population and economic activities, more pollutants are released into the air from vehicles, industries, and daily human activities. This rise in pollution reduces air quality and negatively affects people's health. The degradation of air quality in many urban areas has been mostly caused by rapid urbanization, population growth, increasing vehicle movement, and shifting land-use patterns. In developing countries like India, infrastructure development, and increased transportation demand have emerged as key drivers of urban air pollution. However, Panjim has seen a rise in tourism-related activities, infrastructure development,

urbanization, and vehicle traffic in recent years, all of which could have an impact on the region's air quality.

Study Area:

Goa's capital, Panaji, is situated on India's western coast, overlooking the Arabian Sea, along the banks of the Mandovi River. The city is strategically located along the coast on the western edge of the Indian Peninsula, at roughly 15.49° N latitude and 73.82° E longitude. Panaji is physiographically a part of the coastal plain region, which is distinguished by gently sloping, low-lying terrain. Rainfall is mostly obtained during the southwest monsoon (June–September), with an average of 3000 mm per year. High rainfall and coastal winds help reduce air pollution by washing out and dispersing airborne particles. Panaji is mostly an urban area with a modest population density, especially in commercial centres like Patto Plaza. As per census 2011, the population of panjim city is 70,991 The main causes of air pollution in Panaji include urban activities like traffic, construction, and road dust resuspension.

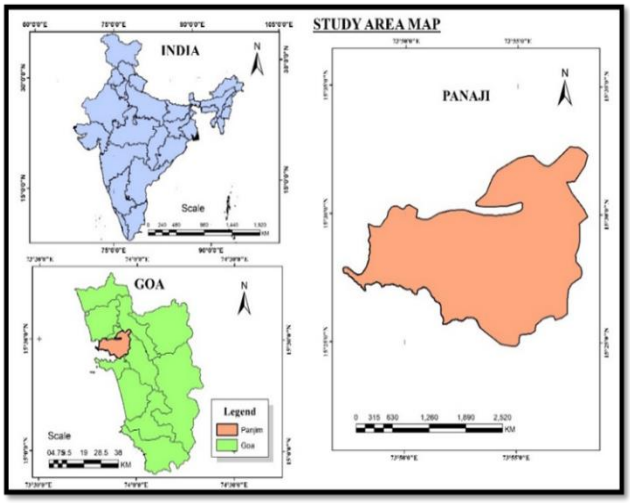

Figure 1 Study Area Map of Panjim Goa
Source: Prepared by Author using SoI Toposheet in QGIS.

Data Source:

The current study's data on air quality was gathered from secondary sources. The data were obtained from the Central Pollution Control Board (CPCB). The air quality monitoring station under consideration for this study is situated close to Dempo Tower Patto Plaza, Panjim City Goa, which is a significant metropolitan center with traffic and commercial activity. The study focuses on four major air pollutants, namely Particulate Matter (PM_{10}), Particulate Matter ($PM_{2.5}$), Sulphur Dioxide (SO_2), and Nitrogen Dioxide (NO_2). These pollutants were selected because they are commonly used indicators to assess urban air quality and potential health impacts. The data cover a period of three years from April 2022 to March 2025 reported by CPCB.

Objectives:

1. To analyse the annual variation of major air pollutants in Panaji city and assess its air quality status by comparing observed values with National Ambient Air Quality Standards (NAAQS).
2. To examine the relationship between urbanization and air quality trends in Panaji city.

Methodology:

The collected air quality data were organized and processed on a year-wise basis. Then Annual average concentrations of each pollutant were calculated for each year of the study period. After this, the calculated annual average values were compared with the National Ambient Air Quality Standards (NAAQS, 2009) prescribed by the Government of India. Year-to-year variations in pollutant concentrations were analysed to observe increasing or decreasing trends in air pollution levels. The observed pollution trends were interpreted in relation to urban activities such as vehicular traffic, road

dust resuspension, construction work, and local environmental conditions, including coastal influence and rainfall patterns. Based on pollutant levels and their comparison with national standards, the overall air quality status of Panjim city was assessed.

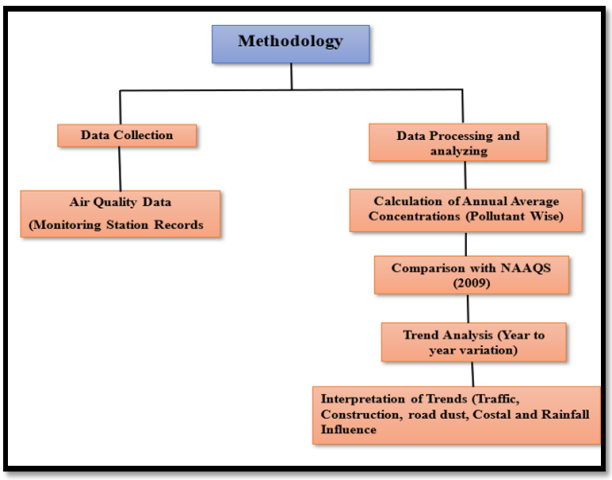

Figure 2 Methodology Chart

Review of Literature:

The study titled "Influence of Urban Air Pollution on the Population in the Klang Valley, Malaysia: A Spatial Approach" by Siti Haslina Mohd Shafie et al. (2022) looked at the spatial distribution of PM_{10} air pollution and how it affected urban populations' health. The study used population census data from 2000 to 2009 and $PM_{2.5}$ data from five air quality monitoring stations. GIS-based techniques were used, such as the Air Quality health risk model, spatial clustering analysis, and IDW interpolation. The results demonstrated that $PM_{2.5}$ levels were greater in highly urbanized and industrial locations, surpassing both national and WHO norms and creating serious threats to the population's respiratory health.

The study titled "Assessing the Air Pollution Tolerance Index of Urban Plantation: A Case Study Conducted along High-Traffic Roadways" by Asif and Ma (2024) focuses on determining how tolerant roadside plants are to air pollution. Assessing the Air Pollution Tolerance Index (APTI) of particular plant species growing alongside busy roadways in Lahore, Pakistan, was the primary goal. Traffic count data and primary data from leaf samples of four different plant species were taken. The main conclusions showed that choosing appropriate plants for urban pollution mitigation is necessary.

Okolie et al. (2023) carried out a study named "Spatio-Temporal Variability of Air Quality and Relationship with Meteorological Parameters in Cape Town, South Africa." The paper studies NO_2, SO_2, and PM_{10}. for the years 2020–2021, the study included meteorological data from NASA and satellite sources as well as air quality data from five monitoring stations. Correlation analysis, IDW interpolation, and GIS methods were used.

The paper "Impact of Urbanization on Air Quality in Kenya" by Jack Odhiambo (2021). Studies how urbanization affects pollutants like CO_2 and $PM_{2.5}$. Secondary data was gathered for the study via reports, online databases, and published papers. The results demonstrated that urbanization has greatly increased air pollution, particularly in cities like Nairobi, mostly as a result of industrial activity, traffic congestion, and the usage of fossil fuels, posing major hazards to public health.

Another paper "Assessing the Air Pollution Tolerance Index of Urban Plantation: A Case Study Conducted along High-Traffic Roadways," by Asif (2024) focuses on determining how tolerant roadside plants are to air pollution. Evaluating the Air Pollution Tolerance Index (APTI) of particular plant species growing beside busy roadways was the primary goal. The results showed that different species had different levels of plant tolerance, and choosing plants that can withstand pollution can assist lower urban air pollution

Discussion and Results:

1. **Annual Average of AAQM Data for Panaji City (April 2022 to March 2023)**

Table 1 1.Annual Average of AAQM Data for Panaji City (April 2022 to March 2023)

Year	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)
April 2022 – March 2023	68	30	3	17
April 2023 – March 2024	65	19	3	12
April 2024 to March 2025	62	28	8	14

During 2022-23 Panjim city had higher levels of particulate matter than in the years that followed. The average yearly levels of PM_{10} and $PM_{2.5}$ were 68 µg/m³ and 30 µg/m³, which means that the city had moderate levels of particulate pollution. The main reasons for these higher values are more vehicular traffic, traffic jams, construction work, and business activity in the center of Panjim. The concentration of SO_2 was low at 3 µg/m³, since there are no much industries present in the city. Similarly, NO_2 content was 17 µg/m³, indicating emissions primarily from vehicle exhausts.

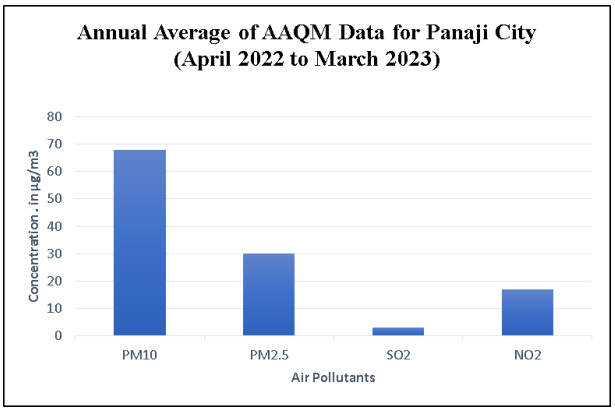

Figure 3 Annual Average of AAQM Data for Panaji City (April 2022 to March 2023)

Source: Compiled by the Authors

In comparison to the prior year, Panjim City's air quality improved somewhat in 2023–2024. The amount of PM_{10} decreased to 65 µg/m³, and $PM_{2.5}$ reduced significantly to 19 µg/m³. This indicates that the number of tiny particles and dust in the air declined throughout this time. Higher rainfall, which helps remove dust and pollutants from the air, lowered construction work in certain months, and improved traffic management are the main causes of this improvement. Rainfall plays an important role in cleaning the atmosphere by settling airborne particles. The SO_2 level stayed low at 3 µg/m³, indicating that industrial pollution is not a major problem in Panjim. Additionally, the NO_2 level dropped to 12 µg/m³, indicating less vehicle pollution possibly as a result of improved and smoother traffic flow and implementation of better traffic management.

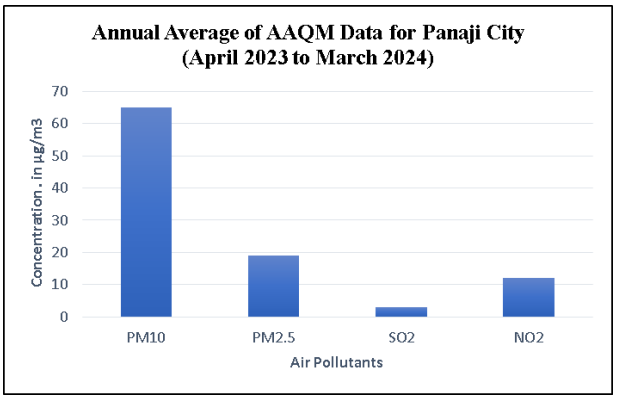

Figure 4 Annual Average of AAQM Data for Panaji City (April 2023 to March 2024)

During 2024–25, the air quality of Panjim city showed mixed trends. The annual average PM_{10} further declined to 62 µg/m³, indicating a gradual improvement in coarse particulate pollution. Nevertheless, $PM_{2.5}$ increased again to 28 µg/m³, suggesting a rise in fine particulate pollution. Renewed construction, more cars, more tourists, and urban growth are all contributing factors to this increase, which produces finer particles that stay suspended in the atmosphere for longer. A noticeable increase in SO_2 concentration to 8 µg/m³ was observed during this

year. Although still within permissible limits, this rise is due to higher fuel consumption, increased traffic, and commercial energy use. The NO_2 concentration increased slightly to 14 µg/m³, reflecting growing vehicular emissions due to population growth and urban development. This year clearly shows the emerging early signs of environmental stress caused by continued urbanisation in Panjim city.

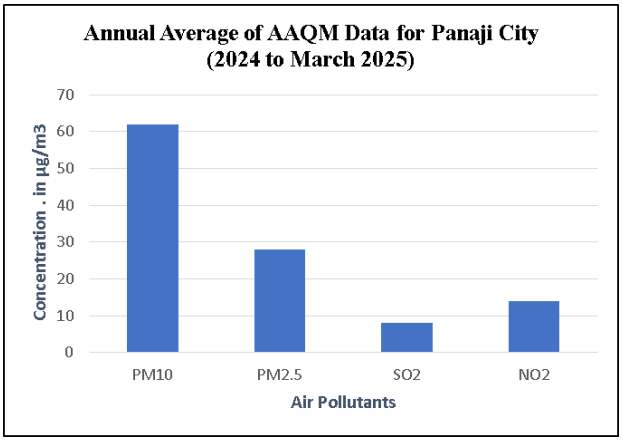

Figure 5 Annual Average of AAQM Data for Panaji City (April 2024 to March 2025)

2. Trend of Annual Average Air Pollutant Concentration in Panjim City (2022-2025) and Compliance with AQI Standards.

National Embient Air Quality Standards (2009)

- **PM10: 60 µg/m3**
- **PM 2.5: 40 µg/m3**
- **SO2: 50 µg/m3**
- **NO2: 40 µg/m3**

The study analysed the variation of four major pollutants. The results show a unique variation between gaseous and particle contaminants, when compared to the National Ambient Air Quality Standards. Among all pollutants, PM_{10} consistently remains slightly above the national permissible limit, even though a gradual declining trend is observed over the study period. This suggests that the city's coarse dust pollution is still a serious problem. Urban activities like road dust, increased vehicle traffic, construction, and tourism-related activities are the primary causes of the higher PM_{10} levels. Frequent rainfall, coastal winds, and pollution control efforts that assist reduce and disperse dust particles in the air could be the cause of the slow decline in $PM_{2.5}$ levels.

On the other hand, $PM_{2.5}$ levels show comparatively low fine particulate pollution throughout the research period, staying within national requirements. This implies that seasonal rains, adequate air circulation, and Panaji's low industrial activity plays an important role in maintaining acceptable air quality. Similarly, SO_2 concentrations are still far below the recommended levels and NO_2 levels also remain within safe bounds, reflecting regulated vehicle emissions.

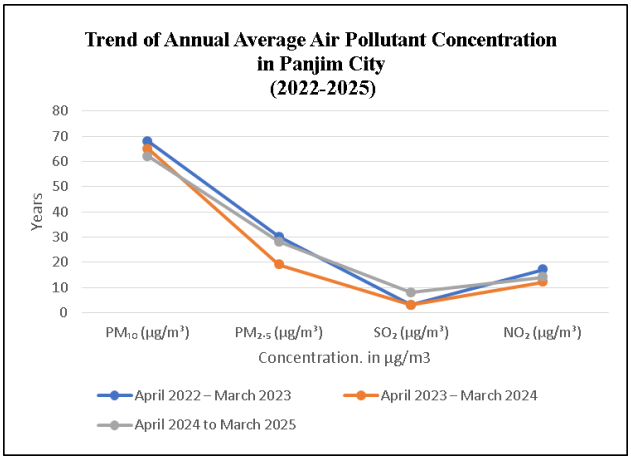

Figure 6 Trend of Annual Average Air Pollutant Concentration in Panjim City (April 2022 to March 2025)

Major Findings:

1 The primary air pollutant in Panaji city was PM_{10}, which gradually decreased from 68 µg/m³ in 2022–2023 to 62 µg/m³ in 2024–2025, suggesting a decrease in coarse particle pollution.

2 Throughout the study period, $PM_{2.5}$ concentrations stayed below allowable bounds, with the lowest levels noted in 2023–2024 as a result of increased rainfall and decreased construction activity.

3 Because there were no significant industrial sources and little fossil fuel combustion in the city, SO_2 levels were consistently quite low.
4 Despite an increase in vehicle traffic, NO_2 concentrations remained within safe levels, indicating relatively controlled transport-related emissions.
5 Despite early indications of urbanization-related stress, Panaji's air quality is still quite acceptable overall due to natural factors like heavy rainfall, coastal winds, and adequate atmospheric dispersion.

Suggestions and Recommendations:

1 To reduce PM_{10} pollution, regular road sweeping and dust suppression techniques should be used.
2 Better traffic management is needed, especially in commercial areas like Patto Plaza, to reduce vehicle emissions.
3 Construction activities should be strictly monitored, with mandated dust control measures in place on construction sites.
4 To lessen traffic, public transportation and non-motorized modes of transportation like walking and cycling should be promoted.
5 To capture dust particles and enhance air quality, there should be more roadside plants and green buffers.

Conclusion:

According to this study, Panaji is at a transitional stage of environmental stress, where urbanization is starting to have an impact on the quality of the environment but has not yet reached dangerous proportions. The results indicate that although pollution levels are generally controllable at the moment, future hazards could arise from unregulated urban growth, more tourism, and rising automobile use. Although Panaji's natural advantages such as its seaside location and climate offer protection, they shouldn't be viewed as long-term fixes. To protect environmental quality, proactive planning, prompt regulation, and careful urban management are crucial. Panaji will grow in a balanced and sustainable way without affecting the health of the general public or the environment due to ongoing monitoring and preventative measures. Although Panaji's air quality is generally better than that of many Indian cities, long-term environmental sustainability calls for consistent efforts.

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