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Exploring the Impact of Population Growth on Air Quality: A Case Study of Shiraz, Iran

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Abstract

This study explores the relationship between population growth, urbanization, and air quality in Shiraz, Iran, from 2020 to 2025. Using a quantitative approach, the study analyzes the correlation between the Air Quality Index, particulate matter less than 2.5 µm (PM2.5), particulate matter less than 10 µm (PM10), and population density. Data was collected from government sources, focusing on changes in pollution levels and urban development. The findings reveal a moderate positive correlation between AQI and both PM2.5 and PM10, indicating that particulate matter significantly impacts air quality. However, the correlation between AQI and population density is weak, suggesting that factors like infrastructure and urban planning may mitigate the effects of population growth. The study highlights the complex interactions between urban expansion, air pollution, and public health, emphasizing the need for sustainable urban policies.

Keywords: Air quality index, particulate matter (PM2.5, PM10), population density, urbanization, Shiraz

1 Introduction

Air quality is a critical determinant of environmental and public health, influencing both short-term respiratory conditions and long-term cardiovascular diseases (1). Among the various factors contributing to air quality degradation, particulate matters such as PM2.5 and PM10 plays a significant role (2). These pollutants, defined by their aerodynamic diameters, are associated with various adverse health effects due to their ability to penetrate the respiratory system and, in some cases, enter the bloodstream. PM2.5, being finer, poses more severe risks compared to PM10 as it can reach the alveolar regions of the lungs and is linked to chronic diseases such as asthma, bronchitis, and even premature mortality (3). Understanding the dynamics of particulate matter and its correlation with air quality is essential for devising effective mitigation strategies, particularly in urban settings where pollution levels tend to be high (4).

Urbanization and population growth have changed cities worldwide, increasing air pollution from more vehicles, industries, and energy use (5). The link between population density and air pollution in crowded areas is a major concern. Higher population densities often mean more emissions from sources like vehicles and home heating, increasing PM2.5 and PM10 levels. However, the exact relationship between population density and air quality can be complex, influenced by factors such as urban planning, infrastructure development, and government policies on pollution control. Therefore, Exploring the link between population density, particulate matter, and AQI can offer useful insights for managing urban environments.

Shiraz, one of Iran's largest cities, is an ideal case for studying these relationships.In the past decade, Shiraz has grown quickly, with more people and major changes in infrastructure and transportation (6). For instance, the completion of Shiraz Metro Line 2 has enhanced public transportation, potentially reducing vehicular emissions (7). At the same time, Shiraz has expanded, adding new residential and industrial areas to support its growing population (8). These changes affect air quality, as urban sprawl usually increases energy use and emissions from both fixed and moving sources.

Despite these developments, there remains a gap in understanding the precise impact of urban growth on air quality in Shiraz. While studies have explored the role of industrial activities and transportation in air pollution, the relationship between population density, particulate matter, and air quality index (AQI) remains underexplored. This paper seeks to address this gap by analyzing recent data on AQI, PM2.5, PM10, and population density in Shiraz from 2020 to 2025. The study aims to identify correlations among these variables and provide a basis for future urban planning and environmental policies. Moreover, the study's focus on particulate matter is particularly relevant given its widespread impact on public health. According to the World Health Organization (WHO), PM2.5 is among the most dangerous pollutants due to its ability to bypass the body's natural defense mechanisms and directly affect the cardiovascular and respiratory systems. In Iran, air pollution is a significant health burden, with PM2.5 concentrations in many urban areas exceeding WHO guidelines. Understanding how population density and urbanization influence these pollutants can help policymakers develop targeted interventions to protect public health.

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This paper also considers the broader implications of urban sprawl and infrastructure development. While these factors can exacerbate air pollution through increased energy demands and vehicular traffic, they can also offer solutions. For instance, improved public transportation systems, like metro lines, can reduce reliance on personal vehicles and, consequently, emissions. Similarly, urban planning strategies that prioritize green spaces and energy-efficient buildings can mitigate the adverse effects of urban growth. By examining the trends in Shiraz, this study aims to contribute to a more nuanced understanding of how urban development interacts with environmental quality.

2 Research Methodology

This study adopts a quantitative research approach to examine the correlations between AQI, PM2.5, and PM10, and population density in Shiraz from 2020 to 2025. The methodology encompasses data collection, analysis, and interpretation, structured to provide insights into the interrelationships between these variables and their implications for urban environmental management.

2.1 Data Collection

Data on AQI, PM2.5, and PM10 were obtained from (9) and (10). These datasets included monthly and annual averages for each year from 2020 to 2025. Also, population and area data were sourced from (11). Population density was calculated by dividing the total population by the urban area (in square kilometers). Qualitative information on urban development, including transportation and sprawl trends, was gathered from government reports and urban planning documents. The study focuses on six years (2020 to 2025) to capture trends and variations influenced by urbanization and policy implementations, such as the expansion of public transportation systems and infrastructure development.

2.2 Data Analysis

To examine the relationships between variables, the following statistical analyses including Pearson correlation coefficients and trend analysis were performed. The strength and direction of linear relationships between AQI, PM2.5, PM10, and population density were quantified. Pearson's correlation coefficient (ρ) was calculated for each pair of variables. Changes in AQI, PM2.5, and PM10 levels over time were analyzed to identify patterns that may correlate with population growth and urban expansion. The correlations were interpreted in terms of strength (e.g., weak, moderate, or strong) and direction (positive or negative). This analysis aimed to determine the extent to which population density and urban growth contribute to variations in AQI and particulate matter levels.

The analysis uses yearly averages, which might hide short-term changes in AQI and particulate matter caused by seasonal shifts or occasional pollution events. The study looks at the entire urban area of Shiraz without considering differences in pollution levels and population density within the city. The study examines all of Shiraz without considering variations in pollution levels and population density within different parts of the city. Although reliable and official data sources were used, errors in reported values or changes in measurement methods over time could impact the results. All data used in this study were sourced from publicly available or authorized government databases. No personal or sensitive information was collected, ensuring compliance with ethical research standards.

3 Results and Discussion

The collected data of AQI, PM2.5, PM10, and population density in Shiraz, Iran is presented in Table 1. In this study the area of Shiraz was considered as 240 Km^2.

PM2.5 and PM10 remain constant except for 2025, where there is a noticeable increase in PM2.5 (from 20 to 26 µg/m³) and a slight increase in PM10 (from 62 to 65 µg/m³). Population density increases steadily due to population growth while the area remains constant. AQI fluctuates, with no direct relationship visible at first glance. The correlation coefficients to determine the relationships quantitatively were calculated (see Table 2).

The analysis reveals a moderate positive correlation ($r = 0.51$) between AQI and PM2.5. This finding underscores the significant role that fine particulate matter plays in determining air quality. As PM2.5 concentrations rise, the AQI worsens, indicating a decline in air quality and potential health risks for the population. PM2.5 particles, being smaller and more penetrating, are known to cause respiratory and cardiovascular issues, making their contribution to AQI a critical concern for urban areas like Shiraz. The persistence of a moderate correlation suggests that while PM2.5 is a key pollutant, other factors also contribute to variations in AQI.

Table 1: Shiraz: A Snapshot of Air Quality, Demographics, and Urban Development (2020–2025)

Year	AQI (9)	PM2.5 (µg/m³) (10)	PM10 (µg/m³) (10)	Population (11)	Population Density (people/km²)	Urban Sprawl & Infrastructure Development
2020	72	20	62	1,651,000	6,879	Initiation of urban growth modeling to address healthcare service distribution (12).
2021	50	20	62	1,675,000	6,979	Ongoing urban development projects; concerns over preservation of historical architecture (13).
2022	73	20	62	1,699,000	7,079	Expansion of urban areas impacting rural settlements; emphasis on sustainable development (14).
2023	53	20	62	1,721,000	7,171	Completion of Shiraz Metro Line 2, enhancing public transportation (7).
2024	58	20	62	1,743,000	7,263	Continued urban expansion; focus on equitable distribution of healthcare services (15).
2025	75*	26	65	1,764,000*	7,350	Anticipated completion of major infrastructure projects; ongoing urban sprawl management efforts (16).

Notes:

- **N/A** indicates data not readily available or sourced.
- Population density is calculated as Density=Population/Area.
- *2025 data for AQI, PM2.5, PM10, NO_2, and CO are provisional estimates as of early 2025.
- Urban sprawl and infrastructure development information is based on available reports and studies.

Table 2: The correlation coefficients (r) between various variables

Variables	r	Description
AQI vs PM2.5	0.51	Moderate positive correlation, indicating AQI increases as PM2.5 rises.
AQI vs PM10	0.51	Moderate positive correlation, similar to PM2.5's impact on AQI.
AQI vs Population Density	0.08	Very weak positive correlation, suggesting minimal influence of population density on AQI.
PM2.5 vs PM10	1.00	Perfect positive correlation, as PM10 closely follows PM2.5 trends.
PM2.5/PM10 vs Population Density	0.64	Moderate positive correlation, indicating particulate levels rise with increasing population density.

Similarly, a moderate positive correlation (r = 0.51) is observed between AQI and PM10. This indicates that larger particulate matter (PM10) is another significant contributor to air pollution in Shiraz. Although the correlation strength is the same as with PM2.5, the impact of PM10 on air quality might be less severe because its larger particles tend to settle more quickly and affect the upper respiratory system. The combined influence of PM2.5 and PM10 suggests that particulate matter as a whole is a central component in the degradation of air quality, although their collective effect on AQI does not dominate entirely.

When examining the relationship between AQI and population density, the correlation coefficient (r = 0.08) reveals a very weak positive correlation. This indicates that, in this dataset, population density has a minimal direct influence on air quality. However, this weak correlation should not be interpreted as population density having no impact. Instead, it highlights that other urbanization factors, such as infrastructure development, transportation systems, energy consumption patterns, and industrial emissions, may play a more substantial role in shaping AQI trends. For example, Shiraz's efforts to expand its urban infrastructure, including metro systems and healthcare facilities, might mitigate some pollution impacts even as the population grows.

The relationship between PM2.5 and PM10, as expected, shows a perfect positive correlation (r = 1.00). This reflects their inherent interdependence as pollutants, where changes in PM2.5 levels invariably correspond to changes in PM10 levels. This is because PM2.5 is a subset of PM10, meaning that any increase or decrease in fine particulate matter will naturally affect the overall concentration of larger particles. This perfect correlation reinforces the importance of addressing both PM2.5 and PM10 when implementing air quality improvement measures

Finally, a moderate positive correlation (r = 0.64) exists between PM2.5/PM10 and population density. This suggests that particulate matter levels tend to rise as the number of people per square kilometer increases. The likely reasons for this relationship include increased vehicular emissions, industrial activities, and higher energy consumption in densely populated areas. The steady growth in Shiraz's population density, as seen in the dataset, could exacerbate particulate matter emissions unless mitigated by sustainable urban planning and stricter environmental regulations. This correlation underscores the importance of addressing population density's indirect impact on air quality through improved transportation systems, renewable energy initiatives, and stricter control over industrial emissions.

4 Conclusion

This research demonstrates the critical role of particulate matter, particularly PM2.5 and PM10, in influencing air quality in Shiraz. While population density shows a weak direct correlation with AQI, the study suggests that other urbanization factors such as transportation, infrastructure development, and industrial activities play a more significant role in shaping air quality trends. The findings emphasize the importance of adopting sustainable urban planning strategies, including improving public transportation and energy-efficient buildings, to mitigate the effects of urban sprawl and population growth on air quality. The study contributes valuable insights into the complex relationship between urbanization and environmental quality, offering a foundation for future policy development in Shiraz and similar urban areas.

Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

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