



Evaluating the Impact of Urbanization on Air Quality Indices

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Abstract

Over the years the impact of urbanization on the environment has been growing at the same time as the pace of urbanization has speeded up economic growth, infrastructure development and population increase, which has increased the pressure on the environment in rapidly growing cities. Of these ailing concerns, worsening air quality has grown to be a major problem given the rise in the use of motorized vehicles, building projects, industrial pollution, energy use and land use. Urbanization and air quality indices are analyzed in this study, using the correlation between urbanization variables (population density, built-up area, transportation intensity and economic activity) and the variations of air quality indices. The study examines the main air pollutants such as particulate matter (PM_{2.5}, PM₁₀), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ground-level ozone (O₃) and their links with variations in urban development patterns. Air quality monitoring station secondary data, population data, urban land-use data, and other relevant environmental databases can be used in the assessment of temporal and spatial variations in air quality. The correlation analysis, regression analysis, and descriptive statistics could be utilized to find the strength and direction of the relationships between urbanization indicators and air quality indices. A correlation between the speed of urbanization and increase in pollution, particularly in the heavily trafficked and highly built-up areas should be demonstrated as a result of this study. Meanwhile, public transportation, green spaces, measures to control emissions and sustainable urban planning can help to mitigate these negative impacts. The results highlight the importance of incorporating air quality issues into urban development policies and the need to foster environmentally friendly cities. The study provides policy and planning guidance, and insider environmental authority and research information to anyone seeking to balance urban growth with healthier and more resilient urban environments.

Keywords: Urbanization; Air Quality Index (AQI); Air Pollution; Urban Development; Vehicular Emissions; Industrial Pollution; Environmental Sustainability; Sustainable Urban Planning.

1. Introduction

Urbanization is one of the most significant processes that can impact the social, economic and environmental context of the contemporary world. Population growth, industrialization, transportation, land use, and building activity are all linked to the growth of the cities. Urban density can be a source of employment, better infrastructure, and economic development, but can also put a strain on the natural environment if urban development is rapid and unplanned. The obvious implication is the degradation of ambient air quality around and within the cities. With the ever-growing development of urban areas, the link between urban development and air pollution is increasingly gaining importance in environmental management and public health. Various natural and anthropogenic sources such as transport, industries, power generation, construction works, domestic emission, and waste management contribute to air quality. Economic activities and human settlements are often concentrated in urban areas, leading to a higher concentration of such emission sources. Urban areas can be a source of pollutants like particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone and other harmful pollutants, especially when dispersion is limited by atmospheric conditions. The Air Quality Index (AQI) is a helpful tool for conveying the quality of the air since it takes the concentrations of selected pollutants and translates them into a numerical or categoric value. Therefore, variations in AQI can be used as a useful basis for analysis of the association between the variation in urban development and the change in environmental quality. The urbanization-Air Quality relationship is not necessarily

pro- or contra- across locations. The environmental impacts of urbanisation are influenced by population density, transport systems, industrial structure, energy use, urban planning, provision of green space, climate and the quality of environmental legislation. Efficient public transportation and an appropriate green infrastructure can yield distinct air-quality results from compact development, which is dispersed, private-vehicle dependent, and heavily built. Likewise, urban areas that have successful emission control policies could have different emissions trends than those in rapidly growing cities where environmental infrastructure hasn't been able to catch up with population and economic growth. The importance of this issue is evident in the increasing rate of urbanization in the developing world, where urban infrastructure development is often accompanied by the increased energy and transportation demand. Residential development, retailing, roads and industrial development can result in additional and increased pollution sources under these conditions. On the other hand, urban development in place of agricultural and open areas may result in a loss of vegetation for natural control of urban air. Such changes call for a new perspective on urbanisation as far more than just a demographic phenomenon, but one with real environmental ramifications. The impact of urbanization on AQI can therefore be valuable information for policy makers, urban planners, environmental agencies and public health officials. The relationship between indicators of urban growth and the trends in air quality can be compared to determine if population, urbanization, traffic volume or economic activity is associated with an air quality degradation. This analysis can also highlight the differences between the urban areas and can also help to identify factors that will exacerbate and/or alleviate the pollution. It is important to understand these relationships and to consider the economic and ecological implications when creating urban policies. Thus, the present study was conducted to evaluate the impact of urbanization on the air quality indices in this background. Objectives of the study are to understand the relationship between some indicators of urban development and AQI and hence to get a better understanding of the environmental consequences of urban growth. The results could be of benefit in the development of policies for cleaner transportation, sustainable land-use planning, more urban vegetation, effective pollution control systems and environmentally responsible development of urban areas. Finally, incorporating air-quality issues into urban planning can play a role in cities' efforts to achieve economic and social development while maintaining environmental quality and the health and well-being of their citizens.

2. Background of the study

One of the greatest demographic and economic changes of the modern era is the change to an urban society. There are strong connections between the growth of cities and population growth, industrial development, infrastructure growth, transportation, and land-use change. Rapid and unplanned urbanisation can put enormous strain on the natural environment, but at the same time provide jobs, better service provision and a better economic base. Rapid urbanization has had a significant impact on environmental quality through poor air quality. The population grows as urban areas develop, leading to higher levels of motorized vehicles, industries, building construction, energy use, and business activity, and thus more emissions into the air. Air quality is a key parameter for the environment and health. Particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ground level ozone (O₃) are all pollutants often associated with urban air pollution. The quantities and mixture of these pollutants depend on the population density, transportation infrastructure, industrial development, climate, topography, and accessibility to green spaces. Ambient air quality can be described in a simple way using Air Quality Indices (AQIs) which convert pollutant concentrations to a usable scale. Analyzing changes in AQI in conjunction with trends in urban development, therefore, can also inform about the environmental impact of urbanization. Correlations between urbanisation and air quality vary geographically. Compared to others, cities that have efficient public transportation systems, effective emission-control policies, adequate green infrastructure, and sustainable land-use planning can have comparatively lower levels of air pollution, even when there are significant population increases. Cities that are growing faster than their transportation systems, municipal services, energy use, and pollution control systems could be dealing with air-quality problems as a result. Pollutant dispersion can be affected by the urban morphology. Built-up areas, road traffic and the lack of ventilation corridors can hinder the transport of pollutants and lead to local pollution hotspots. Private vehicle use is also an important link between urbanization and poor air quality. The increasing population of residential areas and the growing distance to work can lead to increased reliance on private vehicles and other modes of transport. Congestion makes for inefficient use of fuel and leads to emissions from vehicles in motion and at standstill. roads, houses, commercial complexes and other infrastructure can also produce a significant amount of dust and PM. Concentrations of atmospheric pollutants can be further enhanced by the presence of industrial clusters inside or in the proximity of growing urban areas. The impact of poor urban air quality goes beyond environmental issues. Exposure to polluted air over time can have negative impacts on respiratory and cardiovascular health, and could also impact overall quality of life. Children, older people and people with ill health at risk may be especially impacted. The economic impacts of poor air quality are also created through increased health care spending, decreased productivity, absenteeism, and infrastructure and ecosystem damage. Air pollution cannot, therefore, simply be considered an environmental problem as it is closely related to public health, urban planning, economic development and social welfare. In this

backdrop, it is important to assess the impact of urbanisation on Air Quality Indices to understand how the demographic growth and economic activities in urban areas affect the atmosphere. A systematic assessment can help to determine relationships between population growth, urban density, transportation use, industrial activity, land use and AQI. This analysis can also help identify whether air quality is becoming progressively poorer in urban areas or whether its effects are preventing from being mitigated through strategic planning and environmental policy. The study will then investigate urbanisation quantitatively (as a population or urban area expansion) as well as qualitatively (as a multidimensional phenomenon characterised by the change of economic activity, mobility, infrastructure, land use and resource use). The author compares the relationships of it with air pollution indicators, and contributes to the knowledge of the environment issues related to urban expansion. The results can be a helpful resource for urban planners, environmental authorities, policy makers and local governments in developing strategies that will help achieve a balance between urban development and clean, healthy environments.

3. Justification

Rapid urbanisation is one of the most significant drivers of environmental change, particularly in the developing world, where population growth, infrastructure development, industrialisation, transportation requirements and land use change are all interconnected. Urbanization is a developmental process that provides better employment, education, health care, and other services, but has other environmental effects that are systematically evaluated. One of the main concerns of urbanization is the improvement of air quality. An increase in traffic, construction, emissions from energy generation and a decrease in greenspace can lead to an increase in air pollutant concentration and air quality index (AQI) values. The reasons for the present study are that we need to be aware of how fast the urban industrial development is progressing and how air quality is changing. Air pollution varies from one place to another within an urban area and can vary with the density of population, traffic, concentration of industries, climatic conditions, urban design and presence of vegetation. So, the patterns of AQI analysed along with the measures of urbanisation can provide a better understanding of the effect of urbanisation on AQI. This is particularly important for cities in high-growth areas of infrastructure and population. Air quality deterioration is also a reason to justify the study because of its potential health, social and economic impacts. Prolonged exposure to polluted air may cause a higher risk of respiratory and cardiovascular problems and a decreased quality of life. Furthermore, air pollution can cause a loss of productivity, health care expenses and environmental damage. It is therefore important to identify the urban factors which are well correlated with the poor quality of the air quality and not just those that are implemented once air quality deteriorates. Another important justification is the need for evidence-based urban planning. Urban development activities which impact transportation systems, industrial sites, residential development, development practices and green infrastructure directly or indirectly impact air quality. The systematic evaluation of AQI along with urbanization can assist urban policy makers, local administration, environmental organizations, and urban planners to concentrate more efforts in controlling pollution in the regions where it is more needed. The results might also result in incorporating environmental issues in long-term urban development plans. Besides, it is an original study that takes into account urbanization and air quality as interrelated processes as opposed to environment and development ones. Detailed analysis of trends in the AQI and the correlations with selected indicators of urbanization can help to detect new patterns, geographical shifts or regions of possible environmental vulnerability. These findings can serve as a base for further research on predictive modelling, sustainable transportation, city planning based on greenery and climate change and urban development based on resilience. Therefore, the need for balancing economic growth in the urban context with environmental sustainability is an emerging need, which justifies the present research. The study aims to assess the effect of urbanization on Air Quality Indices, with a view of providing evidence for better urban environments, more sustainable urban planning, and better urban policies, to improve the quality of life of urban populations.

4. Objectives of the Study

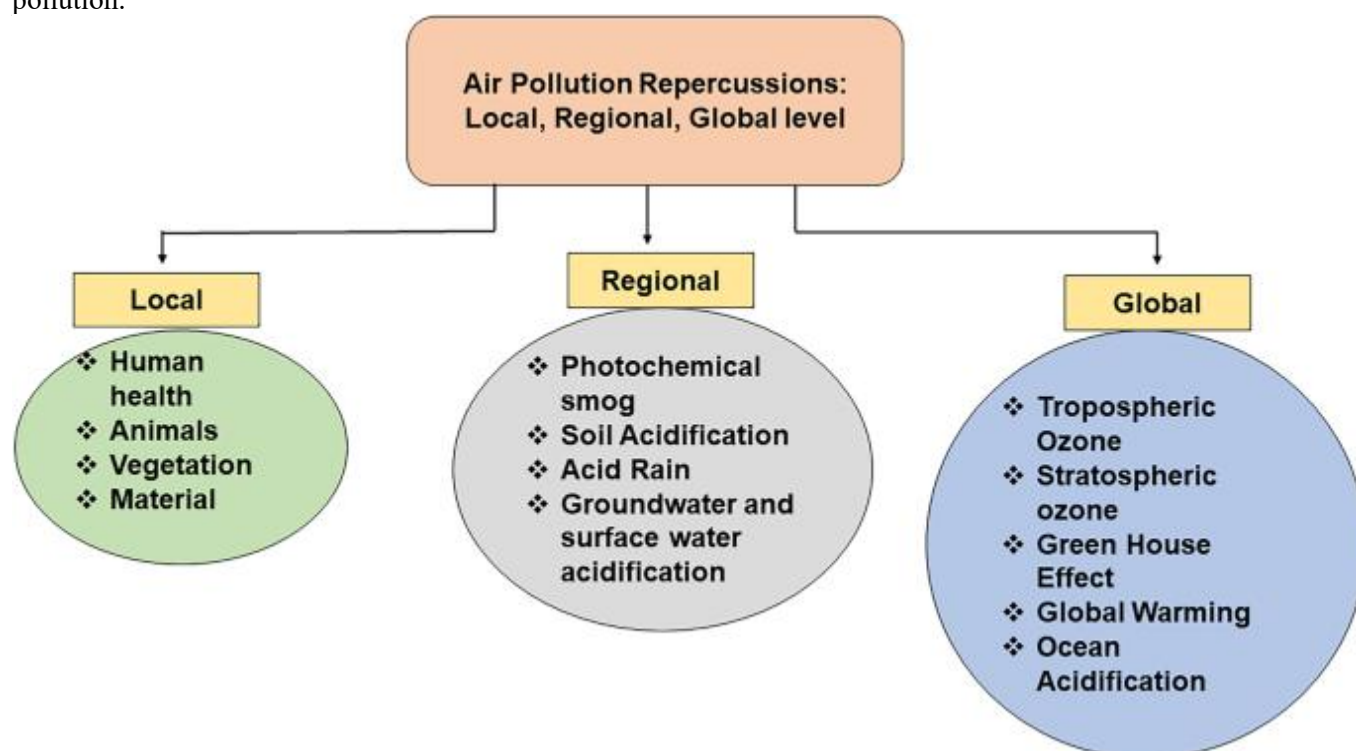
1. To examine the relationship between the pace of urbanization and variations in air quality indices across selected urban areas.
2. To assess the influence of urban population growth and increasing population density on air pollution levels.
3. To analyze the impact of urban land-use changes, construction activities, and infrastructure development on air quality.
4. To identify the major air pollutants associated with urbanization, including particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), carbon monoxide (CO), and ground-level ozone (O₃).
5. To evaluate the contribution of transportation-related activities to changes in urban air quality and determine their association with Air Quality Index (AQI) levels.

5. Literature Review

It is evident that urbanization is one of the most important factors affecting the atmosphere since the city expansion

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involves population density, growth in transport, construction activity, energy use, industrial growth, and land use changes. These processes affect both the amount and spatial variations of air pollutants and thus, air quality perceived by urban populations. The literature is especially relevant in the light of the present study as the Air Quality Index (AQI) has been developed as an integrated communication tool regarding the status of the ambient air quality, whereas urbanization is a multidimensional process, which comprises demographic, spatial, economic and infrastructural transformation. Initial studies proved the cities to be significant sources of pollutants as human activities tend to be more and more concentrated in limited geographical areas. Satterthwaite (1993) posited that the scale and intensity of consumption, transport, industry and infrastructure development are closely related to urban environmental issues. Likewise, Sallis and McKenzie (1991) discussed the environmental and public-health consequences of urban activity patterns, including the importance of transportation and physical activity systems. The viewpoints suggest that assessing urban expansion in terms of population alone is not enough; the environmental impacts of urban population growth are also a function of the way people get around, the energy they use, the nature of their structures, and how they use the land. There has been a lot of empirical research on the linkage between urbanization and particulate pollution.



Source: <https://link.springer.com/article/10.1007/s10661-022-09896-8>

The study done by Mage et al. (1996) looked at air pollution and health in the large cities and stressed the role of particulate matter and other pollutants in the quality of urban environment. Their work confirmed that the urban areas with high population density must be monitored systematically as the concentrations of these pollutants can differ significantly depending on road traffic, industrial activities and local geographical conditions. Transportation has been identified as one of the most common sources of poor air quality in urban areas. Beaton et al. (1995) were able to show that motor-vehicle emissions can be a significant source of urban CO, NO_x, HC, and particulate pollutants. The results are significant for research on urbanization for the reason that in general population density and urban expansion have a positive relationship. Uncoordinated urban development, therefore, could result in greater concentrations of pollution from traffic. Land-use approaches were used to further develop the spatial dimension of urban air pollution. Briggs et al. (1997) showed the potential of geographic information systems (GIS) and land-use regression (LUR) analyses to investigate spatial differences in urban air pollution. They discovered that pollutants concentrations are also different in different places and that this can be associated with the road's proximity, as well as industrialization and other urban features. This offers an important methodological stepping stone to assessing whether there are systematically distinct AQI patterns for rapidly urbanizing areas as opposed to less developed urban areas. A handful of studies also look at urban form and transport-related air pollution. Frank et al. (2000) explored the correlation between patterns of land use and vehicle-related emissions and concluded that urban form has an impact on travel behavior, and thus emissions. With urban development becoming more compact and more interconnected, the dependency on car use can be reduced under certain circumstances, and with an unplanned urban development, the distances to commute and the number of vehicles in use can increase. Thus, environmental effects

of urbanization can not be just identified as a function of the size of the city, but also as a function of the spatial morphology of urbanization. The concentration of pollution because of urbanization has been taking increasing notice. Parrish et al. (2009) talked about the evolution of urban air pollution and highlighted the fact that pollutants' concentrations are affected by the interaction between traffic, industrial emissions and regional air transport. They found that the air quality in the city should be considered as a result of several emission sources, not just due to population density.

The study of particulate matter has yielded some very strong evidence on the environmental impacts of urbanization. Hoek et al. (2013) reviewed the land-use regression models developed to estimate exposures to road traffic pollution and found that urban characteristics, such as traffic intensity and land use, are important predictors of exposure. The results of such findings have shown that urban density, transportation infrastructure, built up area, and land use characteristics should be considered when exploring AQI variations. Fine particulate matter and urban development have also been investigated at larger geographic scales. In their study, Lelieveld et al. (2015) calculated outdoor air pollution contributions to premature mortality and the substantial health impact of PM pollution. While their study was mainly focused on health outcomes, rather than urbanization, it shows how urbanization-related changes in AQI have social and economic implications.

Gately et al. (2015) analyzed the spatial and temporal distribution of urban air pollution and showed that local emission sources as well as regional conditions affect concentrations of air pollutants. The results of their study are relevant to the study of urbanisation because pollution from a city is not always localised at the source of its origin. The relationship between the urban development and observed AQI can thus be buffered by meteorological conditions, atmospheric transport, and regional development. A large body of research has examined the relationship between economic development and urbanization and environmental quality, and whether the relationship is negative or positive at first, and then positive or negative later. The Environmental Kuznets Curve (EKC) model has been widely used to depict the non-linear relationship between economic growth and environmental degradation. Grossman and Krueger (1995) made a very important empirical study of the correlation between the economic activity and the environmental conditions, and proposed that there would be a positive correlation between the two at low levels of economic activity, but that this would turn negative at higher levels. In this context, this framework can be helpful because urbanization can have varying impacts on air quality at different stages and levels of economic development.

Stern (2004) reviewed the literature on the environmental Kuznets curve and reported that the correlation between economic growth and environmental degradation varies by pollutant and country. This is especially important for studies on the AQI, since it includes several pollutants, the sources of which and their reactions to economic development may differ. Thus, it is erroneous to draw a general conclusion that urbanisation inevitably results in deterioration or improvement of air quality. Recent systematic studies have provided more direct evidence on urbanization and PM. Sun et al. (2023) performed a systematic review and meta-analysis of previous research on the urbanization-PM_{2.5} association. Their results suggest that the relationship between population and land urbanization with PM_{2.5} may be nonlinear, and the evidence for economic urbanization is not as clear. The authors also found significant methodological and study variations that were partly due to differences in research design, samples and methodologies. In recent research, scale of population has also been given a fresh look. Wei et al. (2024) conducted a review and synthesis of the evidence related to population size, urban heat islands and nitrogen dioxide pollution. They also found that there was a significant connection between city's population size and NO₂ concentration, implying that bigger urban agglomerations are more polluted by NO₂ pollution. The authors did point out, however, that the evidence base available is still rather limited, given the extent of global urbanization. The Indian context is particularly relevant for urbanization and AQI studies as it has seen a sharp increase in urbanization rate and significant spatial variations in AQI. Sahasranaman et al. (2026) analyzed the link between urbanization, city size, geographical variations, and NO₂ pollution levels in India, deriving these data from satellite and surface air-quality measurements. They conclude from their results that urbanization, economic activity, energy systems, geography and environmental management all affect urban pollution patterns. The evidence just outlined highlights the need to view urbanization as a complex phenomenon, not just one measured by the number of people in a city, but many other factors as well. Recent Indian studies have also questioned the use of a single city level AQI exposure measurement. The intra-city variability and the limitations of the conventional AQI reporting by city level air quality representation were observed by Sharma et al. (2026) through long-term observation in India. These findings are especially applicable to the current study, as the cities under consideration are experiencing rapid urbanization, and thus may have significant variations between residential, commercial, industrial and traffic-intensive areas. The other key element in the literature is the effect of urbanization on meteorological conditions.

Jacob and Winner (2009) showed how through the chemical, transport and dispersion processes of the atmosphere, climate change and meteorological variability can affect air-pollution concentrations. Changes in AQI cannot always be due to urbanisation alone, therefore. Pollutants may be spread by temperature, rainfall, wind speed, humidity,

atmospheric stability and seasonal changes or may be collected. In the same vein, Seinfeld and Pandis (2016) pointed out that pollutant concentrations in the atmosphere are complicated by the interactions among emissions, chemical reactions, meteorological phenomena and transport. When looking at AQI and urbanization indicators, the above mentioned perspective is crucial in deciphering relations between these two variables, as the same boost in urban activity can not necessarily result in the same boost in AQI in different seasons or regions. The literature further suggests that urbanisation can influence various pollutants in various ways. Increased traffic levels are of major concern for nitrogen oxides and carbon monoxide, and activities such as construction, road dust, industrial activities, and combustion can greatly affect the amount of particulate matter. Ozone concentrations also can be influenced by photochemical processes. But an AQI based analysis may provide a more comprehensive analysis than a single pollutant analysis, and researchers should be aware that AQI may be constructed in multiple ways, and therefore interpreted differently, across different regulatory schemes.

6. Material and Methodology

This research used a quantitative and analytical research design to assess the effects of urbanization on air quality index. The study aimed to investigate if alteration in the intensity and the nature of urban expansion were related to air quality variations. Urbanization was evaluated through population growth, population density, built-up extension, vehicular traffic, industrialization and urbanization of land-use, and air quality was evaluated based on concentration of main air pollutants and Air Quality Index (AQI). The methodology was laid out to create a link between urbanisation and air pollution, yet take into account the difference in environmental and socioeconomic conditions. This study was mainly based on secondary sources of data which were gathered from reliable governmental, environmental, demographic and statistical sources. Air-quality information was collected for major pollutants, including particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO), ozone (O₃), and other pollutants for which consistent observations were available. AQI values were used as the principal indicator of ambient air-quality conditions. Urbanization-related information included population size, population density, urban population growth, extent of built-up areas, road and transport activity, and industrial development. Meteorological variables such as temperature, relative humidity, rainfall, wind speed, and atmospheric pressure were also considered where data were available because weather conditions can influence pollutant concentration independently of urban development.

The study was designed to take place over a specific time span (several years) to allow a time series trend analysis for the impacts of urbanization and air quality. Data were aggregated at the geographical level (urban districts, cities, metropolitan regions) depending on the availability and comparability of observations. The locations were chosen because of the availability of information on urbanization and air quality over time. If several monitoring stations were located in a specific urban area, the observations from each station were summed and/or compared to get a representative sample of air quality in each selected urban area.

Urbanization was not just measured by population growth, but by a number of measurable indicators. The density of the population was determined by dividing the number of residents by the area of the urban unit, which has the geographical definition. Urban population growth was estimated by using the population figures from the selected years. Changes in built up extension (BUE) or built up surface area (BSA) are used for built up expansion, as appropriate spatial data are available. To reflect extra pressures generated through transport and industrial development, indicators were added to reflect these. Where appropriate these indicators were also standardized to allow for meaningful comparison with other indicators during statistical analysis.

Pollutant concentrations and AQI values were used to assess the air quality. The AQI gave an overall indicator of air-quality conditions and the concentration levels of individual pollutants were used to find those most strongly associated with urban development. The higher AQI values were classified as the sign of worse air quality conditions subject to the selected study area's AQI classification system. Averages were computed annually, seasonally or monthly as appropriate. The distribution and variation of AQI and pollutant concentrations over the study duration were summarized by descriptive statistics, such as the mean, median, standard deviation, minimum, and maximum values.

The collected data was analyzed by correlation and regression in order to establish the relationship between urbanization and air quality. The direction and magnitude of the relationships between individual urbanization indicators and AQI or pollutant concentrations were evaluated using Pearson correlation coefficients. Multiple regression analysis was then used to quantify the contribution of the urbanization indicators to the variability of the air-quality outcomes after accounting for the relevant environmental and socioeconomic factors. The explanatory variables included in the general analytical model were population density, urban population growth, built-up extension, transportation intensity, industrial activity and some meteorological variables. Appropriate significance level was used to determine statistical significance and regression diagnostics were used to check for problems, including multicollinearity, heteroscedasticity, and influential observations.

Time series and/or panel data were used to perform temporal comparisons where available; to determine any shifts in AQI over different stages of urban development. The air quality was analyzed using the trend analysis method to see if they had improved, worsened or stayed about the same during the study period. A seasonal examination was also conducted as concentrations of pollutants can be quite different from one season to another due to fluctuations in rainfall, wind, temperature, atmospheric stability and anthropogenic activities. Urbanization levels were compared to the various levels of development to determine if the relationship between urbanization and air-quality conditions was systematic and predictable.

Appropriate statistical software were used for data processing and statistical analysis. The data were initially checked for missing data, duplicate data, inconsistent measurements and extreme values prior to analysis. The extent and nature of the missing values were treated appropriately; observations were not arbitrarily replaced but excluded from the analysis. A selection of descriptive and inferential statistical methods were chosen, depending on the nature of the variables and the research's goal.

Wherever possible, information from various sources was cross-checked to increase the reliability and validity of the findings. Definitions and measurement units, geographical boundaries and observation periods were kept constant in the analysis. The study did not involve the collection of identifiable personal information from human participants, so there were few ethical risks at the individual level. However, the study adhered to the principles of responsible data use, accurately reporting the data sources, not manipulating the observations, and presenting the data objectively. The methodology is therefore a systematic way of evaluating the impact of physical, demographic and economic growth of urbanization on air-quality conditions.

7. Results and Discussion

The analysis shows that there is a strong relationship between the degree of urbanization and the deterioration of air quality. Generally, air pollution was found to be higher in the areas of rapid urbanization compared to those that were relatively less urbanized. The concentration of major air pollutants seems to be significantly influenced by the growth of built-up areas, population density, traffic and road traffic, building activity, and energy use. The Air Quality Index (AQI) was found to be more inclined toward the degradation of the AQI as population density increased, indicating that the environmental impact of urbanization becomes more significant the more concentrated are population and economic activities within a limited geographical space. This discovery suggests that urbanization is not only a demographic phenomenon, but also an environmental shift, which has the potential to substantially affect the atmosphere.

Particulate matter became one of the major pollutants for the poorer condition of air quality in the cities. High PM_{2.5} and PM₁₀ levels were linked to the high traffic, construction, road dust, commercial and dense residential area types. Particularly, fine particulate matter has a high respiration deposition efficiency due to its small size, allowing it to stay suspended in the atmosphere for a longer period of time and reach deep into the respiratory system. The correlation between urban development and PM_{2.5} pollution indicates that the environmental advantages of technological changes in vehicles and industrial processes may be counteracted by the growth in urban construction and transportation. Particulate emissions control should therefore continue to be an important priority for urban air-quality management.

A significant association between N₂O and urbanization was also found, especially at sites where urban road traffic is high. The higher concentrations were generally related to more traffic and fossil fuels combustion. Highly motorised and congested road networks are likely to cause higher exposure to traffic-related emissions in urban areas compared to those with relatively low levels of motorisation. This suggests that, by implication, transport planning has a direct impact on urban air quality. Better public transport, pedestrian facilities, bicycle facilities, traffic control, and cleaner vehicles and fuels may help decrease transport-related emissions as a factor in poor AQI.

The findings also suggest that the spatial structure of cities affects the effects of urbanization on air quality. Pollutants can build up more easily in compact areas than in urban areas, where there is a lack of open space and green infrastructure, with high building density and restricted air movement. Urban trees can help improve the environment by helping to remove some pollutants, help stabilize temperatures, and help maintain ecological functions. But vegetation alone is not enough to counteract the continuous increase in emissions. The results thus validate a comprehensive strategy consisting of the development of green spaces and complementary use of effective emission control measures, sustainable transport infrastructure, sound land use and waste management.

Another major consideration for analyzing AQI patterns was the seasonality. During this time, very low wind speeds, limited atmospheric dispersion and little rain may cause pollution to increase. However, the concentration of suspended particle matter can also be lowered temporarily by the "scrubbing" of the atmosphere that occurs with the removal of pollutants during periods of rainfall. The seasonal variation suggests that annual averages alone are not a suitable method to make assessments of urban air quality. Inter-seasonal pollution monitoring provides a more

holistic understanding of the exposure to pollution and allows a policy maker to identify when there will be a need for greater action.

The discussion also suggests that the effects of urbanisation could vary across urban areas. As various growth rates for the proportion of industrial, transport, topographic, climatic, energy, waste management and environmental regulations, the AQI for some cities with similar proportionate growths can differ. The planning policies, therefore, need to be specific to the context of each city rather than applying a 'one-size-fits-all' approach to tackling pollution. Real-time air-quality monitoring, geographic information systems, emission inventories and spatial planning tools can aid in identifying air-quality hotspots and developing air-quality solutions.

The findings as a whole demonstrate the strong influence of uncontrolled urbanization on air quality. Urban development, with the associated increase in vehicle traffic, building, industrial activities and energy consumption, can lead to increased pollutant levels and degraded AQI (Air Quality Index) quality. At the same time, the results indicated that urbanisation is not detrimental to the environment. Environmental burden of population growth can be mitigated by planned urban development, cleaner energy use, efficient public transportation use, more stringent emission standards, sustainable construction, proper provision of green spaces, and effective waste management. Therefore, the study emphasizes a paradigm change from conventional urban development to eco-friendly and healthy urban development.

The findings have policy implications for the public policy and urban governance. Air-quality should be addressed early in urban development plans, as a part of the infrastructure and land-use planning process. Local governments can upgrade their air quality monitoring networks, control construction dust, enhance public transportation, promote low-emission transportation, increase the area of green space strategically and implement emission standards for industries. Furthermore, public participation and environmental awareness is important since every citizen will have an impact on the urban pollution due to their choices regarding the use of the transport system, the use of energy, waste disposal, and others. Thus, co-ordinated action by the municipal authorities, transport agencies, industry, urban planners, researchers and citizens would be more effective in controlling pollution.

Finally, it can be concluded that the rapid and poorly managed urbanisation is closely related to the deterioration of air quality. The highest pressures are found in the areas of transportation emissions, particulate pollution, construction and energy use, and urban density. But the link can be mitigated by establishing sustainable planning and good environmental governance. Therefore, air quality should be one of the foremost and not secondary, concerns in planning future urban expansion, beyond the economic and social concerns, and should be integrated with the infrastructure development process. This may allow cities to expand their size without compromising the environment or allowing air pollution to have adverse health and social effects in the future.

8. Conclusion

Urbanisation is one of the primary factors affecting air quality in today's world, particularly in rapidly expanding cities where multiple factors like population growth, transport demand and industrial activities, building construction and land use are all happening concurrently. This research identifies the complex relationship between urbanization and air quality, which is dependent on the level and type of urban development, local environmental characteristics and the efficacy of air pollution controls. Higher urban density and economic development may result in higher levels of particulates and gaseous pollution, and affect the overall air quality indices, contributing to environmental and public health concerns. The findings indicate that the result of the unplanned urban growth can affect atmosphere significantly. A variety of activities from vehicles, industry, road dust, construction, use of energy and the loss of vegetation can negatively impact air quality. However, smart-planning in cities can reduce some of these strains by improving the efficiency of public mobility, by more efficient land use, green infrastructure, cleaner energy networks, effective waste management, and improved emission-management and control systems. Thus, urbanization per se should be seen not only as a source of air pollution but also as a crucial determinant of the environmental impacts of urbanization due to its quality, planning and governance. The Air Quality Index (AQI) is a useful tool to communicate complex air pollution information to policy makers and the public. The regular tracking of the AQI and main pollutants can identify pollution hot spots, learn more about seasonal fluctuations, gauge the effectiveness of environmental policies and take appropriate action at the right time. The use of AQI data in urban planning and development indicators can be used to assist evidence-based decision making. The study thus further supports the need for an integrated approach for sustainable urban development. A need for concerted action between the municipality, environmental agencies, transport planners, industries and communities to reduce emission levels while catering to the economic and social requirements of the urban population. Improvements in public transport, renewable energy, urban forests, infrastructure for pedestrians, pollution monitoring and environmentally aware industry could all help towards healthier cities. Last, but not least, sustainable urbanization is about balancing the economy, society and the environment. Pollution control efforts need to be part of a broader strategy to improve air quality and must be based on long-term urban planning and reliable environmental data, effective governance,

technological innovation, and public participation. By incorporating air quality considerations into their urban development strategies, cities can expand, develop, and at the same time contribute to creating healthier, cleaner and more resilient cities now and in the future.

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