Impact of Population Growth on the Spatial Distribution of Particulate Matter ($Pm_{2.5}$) in the Niger Delta

Boyitie, Paul Odiyirin[1*], Enamuotor, Oghenekevwe[2], Ojoh, Collins Oghenekome[3]

[1,2]Nigeria Maritime University, Okerenkoko, Delta State, Nigeria

[3]Dennis Osadebay University, Asaba, Delta State, Nigeria

***Corresponding Author**

DOI: https://dx.doi.org/10.51584/IJRIAS.2025.101300004

Received: 02 October 2025; Accepted: 10 October 2025; Published: 06 November 2025

ABSTRACT

This study examines the impact of population growth on the spatial distribution of $PM_{2.5}$ in the Niger Delta, integrating satellite and ground-based data to assess pollution trends. Findings reveal a steady increase in $PM_{2.5}$ concentrations from 308 PPM (1990–2004) to 532.5 PPM (2015–2024), with urban centres like Imo, Abia, and Rivers experiencing the highest pollution levels due to rapid urbanization and industrial activities. A moderate association ($R = 0.570$) between $PM_{2.5}$ concentrations and population increase are confirmed by regression analysis. Significant differences in $PM_{2.5}$ pollution levels between states are highlighted by the study, with more industrialised areas showing higher $PM_{2.5}$ levels than locations with less urbanisation and more vegetation cover. The ANOVA results ($F = 284.473$, $p < 0.000$) indicate statistically significant differences in pollution levels, necessitating targeted interventions. Stricter emissions controls, better industrial waste management, and improved air quality monitoring systems are advised in order to reduce air pollution. Strengthening urban planning policies to balance development with environmental sustainability is also crucial. These measures are essential for safeguarding public health, as prolonged exposure to high $PM_{2.5}$ levels increases the risk of respiratory and cardiovascular diseases. The study highlights the need for proactive environmental policies and sustainable urban growth strategies to improve air quality and overall well-being in the Niger Delta.

Keywords: Urbanization, $PM_{2.5}$, Population Growth, Air Pollution, Environmental Sustainability

INTRODUCTION

The rapid increase in global population has significantly affected both natural and urban ecosystems. Air pollution, which offers major threats to public health, is one of the most important environmental issues linked to this increase (Maji et al., 2023). The Niger Delta, known for its expanding population, industrialization, and extensive crude oil extraction, has seen a sharp decline in air quality. Despite the severity of this issue, the relationship between population growth and the spatial distribution of fine particulate matter ($PM_{2.5}$) remains insufficiently explored, necessitating a deeper investigation into how demographic shifts influence pollution levels in this environmentally fragile region (Brida et al., 2024; Huang et al., 2024).

Urban expansion intensifies human activities, leading to increased pollution. Exposure to $PM_{2.5}$ has serious health effects, especially in areas with lax environmental laws and insufficient air quality monitoring. Long-term exposure to high pollution levels poses health dangers to people of the Niger Delta, where environmental rules are not consistently enforced (Abulude et al., 2024). The World Health Organisation (WHO) states that the average annual percentage of PM2.5 should not exceed 10 µg/m³ (2.3 PPM). The region's air quality is greatly impacted by oil spills, gas flaring, and industrial pollutants, all of which are important effects of petroleum extraction (Akinwumiju et al., 2020). Furthermore, the issue is made worse by uncontrolled transportation networks, biomass burning, and inadequate waste management (Nwadiaro et al., 2019; Zhang et al., 2024). Creating efficient pollution management plans for cities and their environs requires an understanding of how these variables interact with population increase.

Research on $PM_{2.5}$ exposure's geographical distribution in connection to population expansion is still rare, despite the well-established hazards to the environment and human health (Apte et al., 2018). According to Guo et al. (2016), most studies have focused on industrial pollution, neglecting the ways that increasing urbanisation, human settlements, and other anthropogenic activities raise $PM_{2.5}$ levels. This knowledge gap hinders the formulation of targeted policies aimed at improving air quality and protecting public health (Zambrano-Monserrate et al., 2024). This study intends to close the gap by examining how population growth influences the spatial distribution of $PM_{2.5}$ in the Niger Delta. Examining these patterns will provide crucial insights for public health policies, pollution mitigation measures, and sustainable urban planning. Analysing pollution levels across different population densities will generate critical data to inform environmental policies, helping to clarify the dynamics of air pollution in metropolitan areas that are expanding quickly and highlighting the significance of sustainable development.

Conceptual Issues and Empirical issues/literature

Environmental degradation, driven by rapid population growth, urbanization, and industrial expansion, remains a pressing concern in regions undergoing economic transformation. One of the most important effects of these is declining air quality, which is shown by an increase in fine particulate matter ($PM_{2.5}$) levels (Maji et al., 2023). While extensive research has explored the environmental impacts of human activities, the relationship between population growth and pollution levels requires further investigation. Air pollution, as a dimension of environmental degradation, has well-documented links to human health and urbanization (Gul & Das, 2023; Murano et al., 2023). Exposure to $PM_{2.5}$ is associated with respiratory diseases, cardiovascular conditions, and reduced life expectancy (Pryor et al., 2022). In the Niger Delta, rapid urban expansion has led to increased vehicular emissions, biomass combustion, and industrial discharges, exacerbating health risks (Numbery, 2020). The lack of effective pollution control measures has further intensified public health challenges, making air quality deterioration a critical issue (Ramayah et al., 2019).

Despite theoretical advancements in environmental studies, gaps remain in understanding the direct link between population growth and $PM_{2.5}$ distribution. While industrial pollution has been widely documented, the role of urbanization, migration, and human activities in shaping particulate matter concentrations is less explored. Addressing this gap is essential for formulating targeted policies that balance economic growth with environmental sustainability. This study builds on existing environmental degradation frameworks to investigate the impact of population expansion on the spatial distribution of $PM_{2.5}$. By integrating ecological theories with spatial analysis techniques, it seeks to provide a comprehensive understanding of pollution trends in the region. To lessen the negative consequences of population-driven pollution, the results will highlight the necessity of stricter environmental regulations, improved air quality monitoring, and sustainable urban development.

MATERIALS AND METHODS

One of Nigeria's most resource-rich and ecologically delicate areas is the Niger Delta in the south of the country (Nwankwoala & Okujagu, 2021). Comprising nine states, including Rivers, Delta, Bayelsa, and Akwa Ibom, it has a population of over 50 million and occupies an area of roughly 70,000 square kilometres (Nwilo & Badejo, 2006; Boyitie et al., 2024). The Niger Delta lies between latitude 3˚00'N and 6˚00'N and longitude 5˚00'E and 8˚00'E (see Figure 1). Its varied ecosystems sustain industrial, agricultural, and fishing endeavours, all of which exacerbate environmental problems and economic growth. Air quality has significantly declined as a result of petrol flaring, oil spills, and industrial emissions; $PM_{2.5}$ pollution is becoming a serious public health problem (Olalekan et al., 2021). Major cities such as Port Harcourt, Warri, and Yenagoa have experienced significant population surges due to rural-urban migration and economic opportunities linked to the oil sector (Adibe & Ohochuku, 2022).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue XIII October 2025
Special Issue on Innovations in Environmental Science and Sustainable Engineering

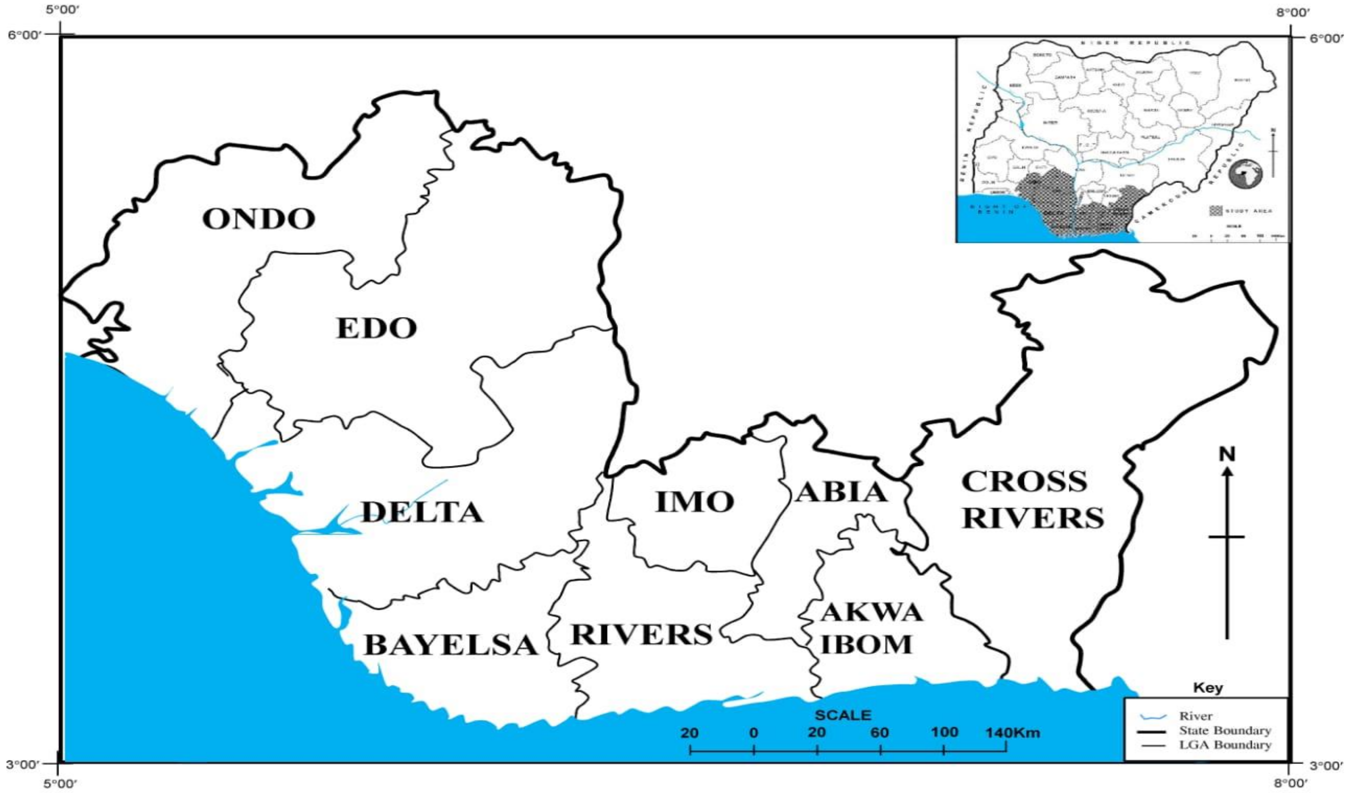

Figure 1: Map of the Niger Delta Cartographic Unit of the Department Urban and Regional Planning Dennis Osadebay University, Asaba

The study uses an ex post facto research approach to investigate the connection between $PM_{2.5}$ geographical distribution and population increase. By integrating quantitative analysis with qualitative insights, it provides a comprehensive assessment of air pollution dynamics in the Niger Delta. The study focuses on nine major urban and industrial centres where population expansion and environmental concerns are most pronounced (see Table 1). A preliminary reconnaissance visit identified key locations for on-site air quality measurements, ensuring representative sampling across the study area.

Table 1: Sampling Areas

Sample States	**Sample Areas**	**Coordinates of Sample locations**
Abia	Aba	5°06'56.8"N 7°22'19.9"E
Akwa Ibom	Uyo	4°40'08.5"N 7°57'04.2"E
Bayelsa	Yenagoa	4°57'17.0"N 6°21'49.5"E
Cross Rivers	Calabar	4°58'17.5"N 8°20'21.0"E
Delta	Warri	5°32'44.7"N 5°46'46.3"E
Edo	Benin	6°20'03.7"N 5°37'19.9"E
Imo	Owerri	5°27'27.6"N 7°02'27.6"E
Ondo	Akure	7°15'08.0"N 5°11'09.6"E
Rivers	Port Harcourt	4°49'12.3"N 6°58'34.7"E

Fieldwork, 2024

Both ground-based air quality monitoring stations and satellite-based remote sensing provided the data on $PM_{2.5}$ concentrations. NASA's Earth Observing System satellite data was included in the study because of its accessibility and worldwide coverage. The Terra and Aqua satellites' MODIS sensor, which has 36 spectral channels, provided the data. Collection 9 Terra MODIS data, which were taken every day at five-minute intervals, were used to derive Aerosol Optical Depth (AOD) values, which show light extinction by atmospheric particles. Monthly and yearly means were calculated by averaging these numbers. The satellite data span nearly three decades (1995–2024), offering a long-term perspective on pollution trends. Ground-based measurements were conducted biweekly in February and July 2024 using an open-air sampling method with Sage thermal mass flow meters. These devices recorded $PM_{2.5}$ concentrations in all nine selected locations, providing localized data to validate satellite observations. A thorough evaluation of pollution levels and regional variations is ensured by the integration of various sources. Population data were obtained from demographic databases and the Nigerian National Population Commission, enabling an analysis of population density fluctuations over time. To determine empirical regional differences in $PM_{2.5}$, correlations between population growth and $PM_{2.5}$ concentrations, and projected trends in $PM_{2.5}$, statistical approaches such as ANOVA, regression analysis, and time series analysis were used. Secondary data from environmental reports, government records, and previous studies provided additional context and validation. This methodological approach ensures a reliable and well-contextualized examination of how demographic trends influence air quality. The findings will contribute to the development of targeted policies aimed at mitigating pollution and improving environmental management in the Niger Delta.

RESULTS AND DISCUSSION

Table 2: Niger Delta States' Average Population and Population Growth Rates (2006–2024)

States	Growth Rate	Average Population
Abia	2.7	3,667,857
Akwa Ibom	3.4	5,391,277
Bayelsa	2.9	2,240,869
Cross Rivers	2.9	3,803,315
Delta	3.2	5,569,641
Edo	2.7	4,167,994
Imo	3.2	5,319,248
Ondo	3	4,595,077
Rivers	3.4	7,182,817

Source: Population Gazette of National Bureau of Statistics

Table 2 presents the population growth rates and average population for nine states in the Niger Delta, reflecting demographic trends that influence environmental changes, including air quality. The region's population has grown significantly, according to the data, with growth rates ranging from 2.7% to 3.4%. The biggest growth rates (3.4%) are found in Rivers and Akwa Ibom, suggesting that these areas are rapidly becoming more urbanised and populated, which may lead to rising pollution levels. In terms of absolute population, Rivers State leads with an average population of 7,182,817, followed by Delta (5,569,641) and Akwa Ibom (5,391,277). The lowest population is recorded in Bayelsa (2,240,869), which, despite its resource-rich environment, has a relatively smaller population due to its extensive water bodies and difficult terrain. These demographic trends are crucial in assessing the impact of population growth on $PM_{2.5}$ distribution (Liyanage & Yamada, 2017).

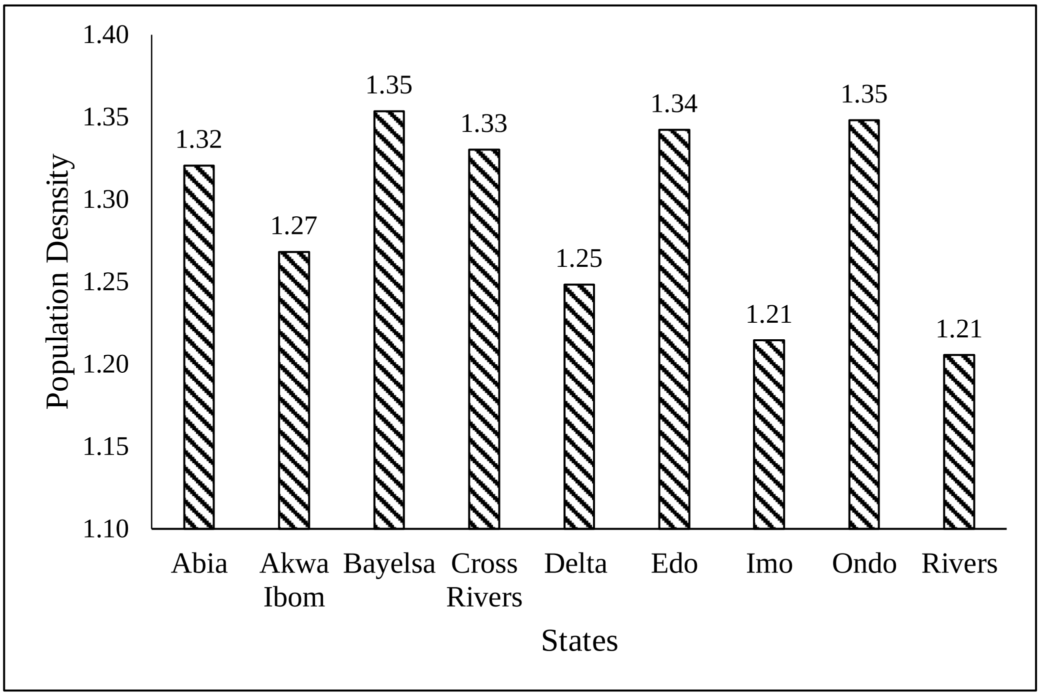

Figure 2: Niger Delta Population Density by State

Figure 2 shows population density variations across Niger Delta states, with Edo, Ondo, and Bayelsa having the highest density. These differences may be attributed to factors like urbanization, industrial activities, and economic opportunities. Edo and Ondo are known for their growing urban centres, which attract migration and increase population density. Lower densities may have more dispersed settlements or less industrial activity. The results highlight how crucial it is to take population distribution into account when planning infrastructure and the environment, especially when it comes to air pollution levels. It is essential to comprehend these trends in order to create strategies for environmental preservation and sustainable urban expansion.

Table 3: Mean Decadal $PM_{2.5}$ Concentrations Across States in the Niger Delta (1990–2024)

	Mean Decadal $PM_{2.5}$ Concentrations in Part Per Million (PPM) Across States		
States	**1990-2004**	**2005-2014**	**2015-2024**
Abia	499	683.1	854.6
Akwa Ibom	438.8	605.2	788.8
Bayelsa	132.8	180.7	225.1
Cross Rivers	115.6	153	189
Delta	203.8	282.8	359.2
Edo	148.5	191.4	238
Imo	582.7	785.9	967.3
Ondo	179.6	233.8	287.6
Rivers	471.5	688.1	882.9
Mean	**308**	**422.7**	**532.5**

Source: NASA’s Earth Observing System

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue XIII October 2025
Special Issue on Innovations in Environmental Science and Sustainable Engineering

The mean decadal concentrations of fine particulate matter ($PM_{2.5}$) in the Niger Delta from 1990 to 2024 show a consistent upward trend, rising from 308 PPM (1990–2004) to 532.5 PPM (2015–2024). Imo, Abia, and Rivers recorded the highest $PM_{2.5}$ levels, possibly due to rapid urbanization, industrial emissions, and increased vehicular activities. Bayelsa and Cross Rivers had the lowest concentrations, likely due to lower industrial activities and more extensive vegetation cover as opined by Nwosisi et al. (2021).

Table 4: $PM_{2.5}$ Levels in a Selection of Cities in 2024

	$PM_{2.5}$ Concentration in PPM								
	Aba	**Uyo**	**Yenagoa**	**Calabar**	**Warri**	**Benin**	**Owerri**	**Akure**	**Port Harcourt**
Average $PM_{2.5}$	3.55	4.47	5.43	5.35	4.67	4.16	3.80	3.53	4.83

Source: Field Data, 2024

Table 4 presents the average $PM_{2.5}$ concentration (in parts per million) across nine cities: Aba, Uyo, Yenagoa, Calabar, Warri, Benin, Owerri, Akure, and Port Harcourt. The highest concentration is recorded in Yenagoa (5.43 PPM), closely followed by Calabar (5.35 PPM) and Port Harcourt (4.83 PPM). These values indicate relatively higher air pollution levels in these locations, likely due to industrial activities, vehicular emissions, or other anthropogenic factors as opined by Yu et al. (2024). Conversely, Akure (3.53 PPM) and Aba (3.55 PPM) report the lowest concentrations, suggesting comparatively cleaner air. The variations in $PM_{2.5}$ levels across the cities may be influenced by differences in population density, industrial presence, and meteorological conditions as opined by Afifa et al. (2024). Monitoring and controlling $PM_{2.5}$ pollution are essential for public health, as prolonged exposure to elevated levels can lead to respiratory and cardiovascular complications.

Table 5: ANOVA Results for $PM_{2.5}$ Emission

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10844044.934	8	1355505.617	284.473	.000
Within Groups	643270.713	135	4764.968		
Total	11487315.646	143			

Source: SPSS Computed

The ANOVA results in this table 5 examine the differences in $PM_{2.5}$ emissions across various states in the Niger Delta. The F-value of 284.473 and the p-value of 0.000 indicate a statistically significant difference in $PM_{2.5}$ emissions between the groups. This variation is largely due to differences in industrialization, population density, and regulatory enforcement. Intra-state variations are less pronounced, indicating a need for state-specific policy interventions. High-pollution areas may require stricter emissions controls, improved air quality monitoring, and targeted mitigation strategies to effectively address environmental and public health concerns.

Table 6: Multiple Comparisons of $PM_{2.5}$ Emissions Across States

Tukey HSD						
(I) State	(J) States	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 Abia	3 Bayelsa	557.86250*	24.40535	.000	480.9183	634.8067

	4 Cross Rivers	589.15625*	24.40535	.000	512.2120	666.1005
	5 Delta	441.57500*	24.40535	.000	364.6308	518.5192
	6 Edo	546.26875*	24.40535	.000	469.3245	623.2130
	7 Imo	-108.56875*	24.40535	.001	-185.5130	-31.6245
	8 Ondo	500.48125*	24.40535	.000	423.5370	577.4255
2 Akwa Ibom	3 Bayelsa	485.58750*	24.40535	.000	408.6433	562.5317
	4 Cross Rivers	516.88125*	24.40535	.000	439.9370	593.8255
	5 Delta	369.30000*	24.40535	.000	292.3558	446.2442
	6 Edo	473.99375*	24.40535	.000	397.0495	550.9380
	7 Imo	-180.84375*	24.40535	.000	-257.7880	-103.8995
	8 Ondo	428.20625*	24.40535	.000	351.2620	505.1505
	9 Rivers	-87.68125*	24.40535	.013	-164.6255	-10.7370
3 Bayelsa	5 Delta	-116.28750*	24.40535	.000	-193.2317	-39.3433
	7 Imo	-666.43125*	24.40535	.000	-743.3755	-589.4870
	9 Rivers	-573.26875*	24.40535	.000	-650.2130	-496.3245
4 Cross Rivers	5 Delta	-147.58125*	24.40535	.000	-224.5255	-70.6370
	7 Imo	-697.72500*	24.40535	.000	-774.6692	-620.7808
	8 Ondo	-88.67500*	24.40535	.012	-165.6192	-11.7308
	9 Rivers	-604.56250*	24.40535	.000	-681.5067	-527.6183
5 Delta	6 Edo	104.69375*	24.40535	.001	27.7495	181.6380
	7 Imo	-550.14375*	24.40535	.000	-627.0880	-473.1995
	9 Rivers	-456.98125*	24.40535	.000	-533.9255	-380.0370

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue XIII October 2025
Special Issue on Innovations in Environmental Science and Sustainable Engineering

6 Edo	7 Imo	-654.83750*	24.40535	.000	-731.7817	-577.8933
	9 Rivers	-561.67500*	24.40535	.000	-638.6192	-484.7308
7 Imo	8 Ondo	609.05000*	24.40535	.000	532.1058	685.9942
	9 Rivers	93.16250*	24.40535	.006	16.2183	170.1067
8 Ondo	9 Rivers	-515.88750*	24.40535	.000	-592.8317	-438.9433
*. The mean difference is significant at the 0.05 level.						

Source: SPSS Computed

Table 6 compares $PM_{2.5}$ emission levels between states in the Niger Delta, revealing significant disparities in air pollution levels. In comparison to Bayelsa, Cross Rivers, and Rivers, states such as Abia, Akwa Ibom, Delta, and Edo have much greater $PM_{2.5}$ emissions. Compared to Bayelsa, Cross Rivers, and Delta, Abia and Akwa Ibom have much greater emissions. Conversely, states with lower $PM_{2.5}$ emissions, such as Bayelsa and Cross Rivers, show significantly lower values compared to high-pollution states like Imo and Rivers. There are notable differences in the air quality across Bayelsa, Imo, and Rivers; the $PM_{2.5}$ levels in Cross Rivers are lower. Rivers has greater $PM_{2.5}$ levels than Imo, the most polluted state, suggesting that industrialisation and urbanisation may be contributing factors to the latter's high pollution levels. The necessity for specific environmental policies and regulatory actions to address air pollution inequalities in the Niger Delta is highlighted by the statistical significance of these comparisons ($p < 0.05$), which demonstrates that observed discrepancies in $PM_{2.5}$ levels are unlikely to be the result of chance.

Table 7: Population Density and Average $PM_{2.5}$ Concentrations in the Niger Delta

States	**Population Density**	**Average $PM_{2.5}$ (PPM)**
Abia	1.32	758.3
Akwa Ibom	1.27	686
Bayelsa	1.35	200.4
Cross Rivers	1.33	169.1
Delta	1.25	316.7
Edo	1.34	212
Imo	1.21	866.8
Ondo	1.35	257.8
Rivers	1.21	773.7
Average	**1.29**	**471.18**

Source: Population Gazette of National Bureau of Statistics and NASA’s Earth Observing System

Table 7 reveal a general pattern where states with higher population density tend to exhibit elevated $PM_{2.5}$ levels, though some variations exist. Imo and Rivers, which have the lowest population densities (1.21), recorded some of the highest $PM_{2.5}$ levels (866.8 PPM and 773.7 PPM, respectively). This suggests that factors beyond population density, such as industrial activity and transportation emissions, significantly contribute to air pollution (Afifa et al., 2024). Similarly, Abia (1.32) and Akwa Ibom (1.27) also recorded high $PM_{2.5}$ levels, supporting the link between urbanization and air quality deterioration. Conversely, Bayelsa and Cross Rivers, despite having relatively high population densities (1.35 and 1.33, respectively), reported much lower $PM_{2.5}$

concentrations (200.4 PPM and 169.1 PPM, respectively). This could be attributed to lower industrialization, better environmental policies, or greater forest cover mitigating pollution levels (Rafaj et al., 2018). On average, the region's $PM_{2.5}$ concentration stands at 471.18 PPM, which significantly exceeds global air quality standards, posing serious health risks. The findings reinforce the need for effective pollution control measures, sustainable urban development, and improved air quality monitoring to address the rising environmental concerns in the Niger Delta.

Table 8: Regression on the Relationship between Population and $PM_{2.5}$ Concentrations

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.570[a]	.325	.321	233.62100	.325	68.472	1	142	.000
a. Predictors: (Constant), Population in Niger Delta									

Sources: SPSS Computed

The statistical correlation between Niger Delta $PM_{2.5}$ values and population increase are seen in Table 8. According to the R value (0.570), there is a slightly positive association between population size and air pollution levels, indicating that $PM_{2.5}$ concentrations tend to rise along with population growth. The R Square value (0.325) signifies that 32.5% of the variance in $PM_{2.5}$ levels is explained by population growth, while the Adjusted R Square (0.321) accounts for potential overfitting, maintaining a stable explanatory power. Population significantly impacts air pollution levels, but other factors like industrial emissions, land-use changes, and regulatory effectiveness may also contribute (Shaddick et al., 2020). This is supported by the F-statistic, however 67.5% of unexplained variation points to the need for more study.

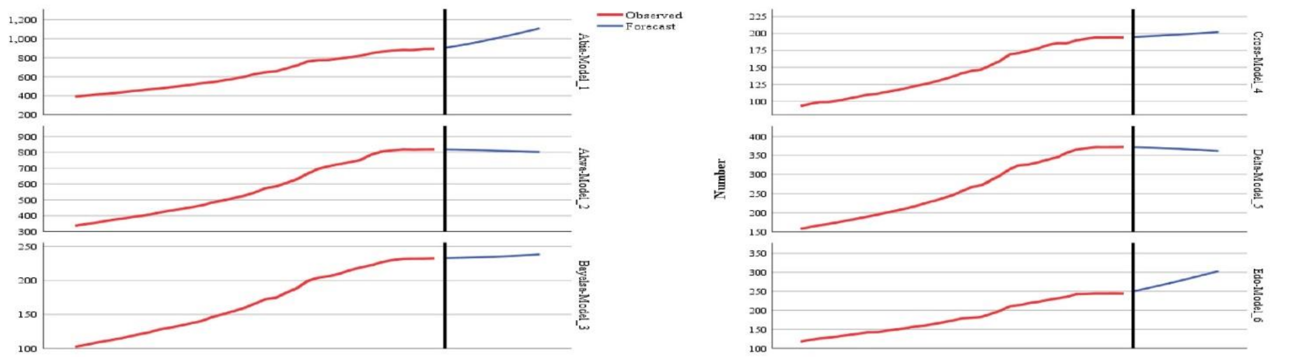

Figure 3 shows the predicted $PM_{2.5}$ trends for the states of Abia, Akwa Ibom, Bayelsa, Cross Rivers, Delta, and Edo between 1990 and 2034

Source: SPSS Output

Over the next ten years, the emissions prediction for the Niger Delta indicates a change in patterns (see Figures 3 and 4). Akwa Ibom is anticipated to progressively drop from 818.09 in 2025 to 801.96 in 2034, whereas Abia is predicted to rise steadily from 904.68 in 2025 to 1109.52 by 2034. Bayelsa remains stable, with a slight increase from 232.79 to 238.38. Cross Rivers follows a similar pattern, increasing from 194.70 to 202.13. Delta's forecast shows a slow decline, starting at 371.47 in 2025 and dropping to 361.69 by 2034. Edo steadily increases from 249.74 to 303.41, suggesting a gradual but predictable rise in emissions over time. Imo experiences a slow decline, going from 993.47 in 2025 to 956.11 by 2034. Ondo stays almost flat, with emissions barely shifting from 293.74 to 291.70 over the decade (see Figure 4). Rivers stands out with a strong upward trajectory, increasing from 950.18 in 2025 to 1227.83 in 2034. The confidence intervals widen significantly, suggesting potential for even higher emissions than predicted. Overall, the trends indicate that since every region has unique patterns, state-specific initiatives to regulate emissions will be required.

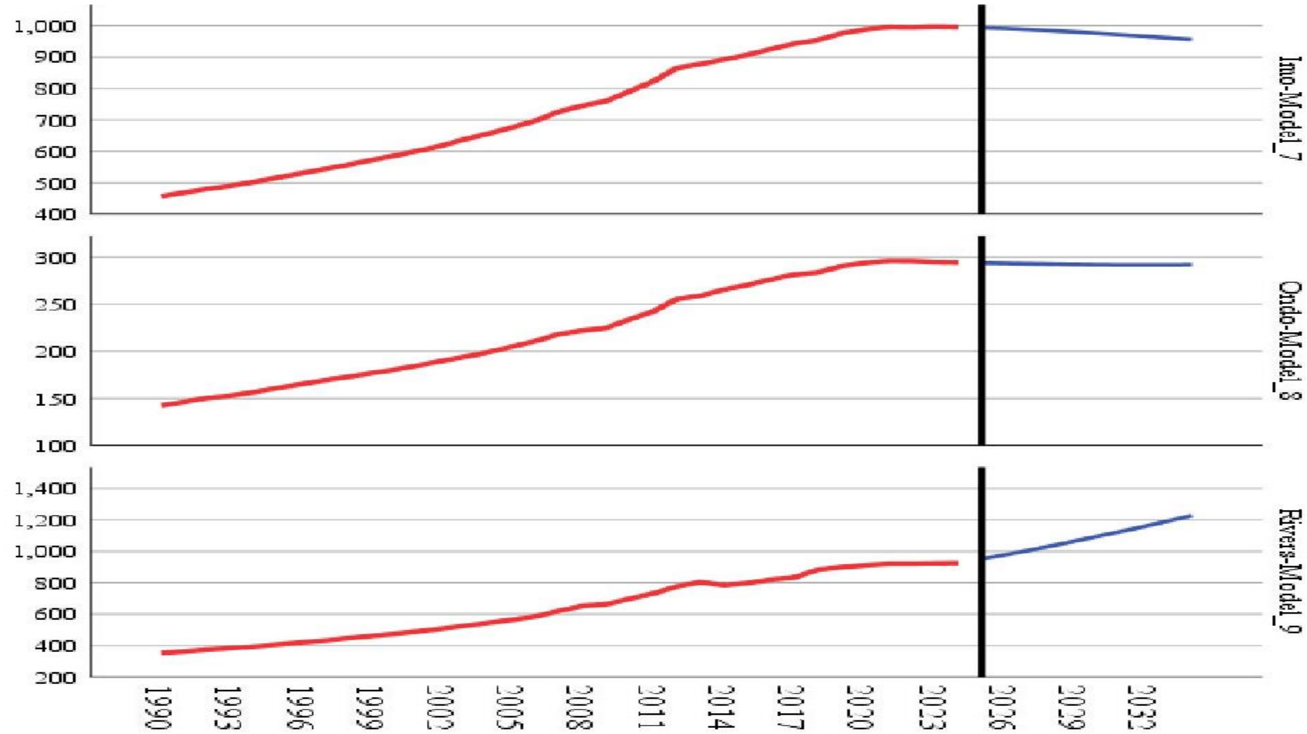

Figure 4: Forecast trend of PM2.5 of Imo, Ondo and Rivers States from 1990 to 2034

Source: SPSS Output

Between 2006 and 2024, the population of the Niger Delta increased dramatically, with Rivers State having the largest average population (7,182,817). In high-growth regions, rapid urbanisation exacerbates environmental issues like air pollution. Increased human activity is correlated with the population density in metropolitan regions like as Edo and Ondo, which may exacerbate pollution. Increased density frequently results in more emissions from industry and automobiles, which affects public health and air quality. Over the course of three decades, $PM_{2.5}$ levels have gradually climbed throughout the Niger Delta, with Imo continuously registering the highest levels, followed by Abia and Rivers. Bayelsa and Cross Rivers had the lowest concentrations, attributed to lower industrial activity and higher vegetation cover. ANOVA results demonstrate statistically significant disparities in emissions among states, necessitating state-specific policies rather than broad interventions. Multiple comparison analysis further reveals significant disparities in $PM_{2.5}$ emissions between high-pollution states such as Imo and Rivers and lower-emission states like Bayelsa and Cross Rivers. A moderate positive correlation ($R = 0.570$) between population growth and $PM_{2.5}$ concentrations is established, with 32.5% of pollution variance attributed to population increase. However, additional elements like land-use changes and industrial emissions also have a role, calling for more comprehensive policy considerations.

CONCLUSION

The results demonstrate a strong correlation between rising $PM_{2.5}$ levels and population growth throughout the Niger Delta, with the greatest pollution levels seen in states that are rapidly urbanising and expanding industrially. Significant environmental and public health issues are raised by the most severe air quality degradation, which is often reported in Imo, Rivers, and Abia. Given the significant variance in pollution levels across states, a uniform approach to air quality management may be ineffective. Instead, targeted interventions, such as stricter emissions regulations in high-pollution areas and improved environmental policies in rapidly urbanizing states, are essential (Izah et al., 2024). To address the growing air pollution crisis, policymakers should prioritize sustainable urban planning, enforce stricter industrial and emissions controls. Long-term environmental and health concerns can be reduced with the support of green infrastructure investments and public awareness campaigns about pollution reduction techniques. Future studies should explore the impact of specific pollution sources, such as industrial activities and transportation, on $PM_{2.5}$ concentrations. Further understanding of seasonal fluctuations and long-term patterns may also be possible by including meteorological data into pollution models. A comparative analysis of mitigation strategies in other regions facing similar challenges may also offer valuable solutions for improving air quality in the Niger Delta.

REFERENCES

1. Abulude, F. O., Oyetunde, J. G., & Feyisetan, A. O. (2024). Air Pollution in Nigeria: A Review of Causes, Effects, and Mitigation Strategies. Continental Journal of Applied Sciences, 19, 1-23.
2. Adibe, N. O., & Ohochuku, C. P. (2022). Rural Insecurity and Urbanization: Empirical Evidence from Port Harcourt, Rivers State, Nigeria. In IIARD International Institute of Academic Research and Development, IIARD International Journal of Geography and Environmental Management, 8(1), 38-39.
3. Afifa, N., Arshad, K., Hussain, N., Ashraf, M. H., & Saleem, M. Z. (2024). Air pollution and climate change as grand challenges to sustainability. The Science of the Total Environment, 928, 172370. https://doi.org/10.1016/j.scitotenv.2024.172370
4. Akinwumiju, A. S., Adelodun, A. A., & Ogundeji, S. E. (2020). Geospatial assessment of oil spill pollution in the Niger Delta of Nigeria: An evidence-based evaluation of causes and potential remedies. Environmental Pollution, 267, 115545. https://doi.org/10.1016/j.envpol.2020.115545
5. Apte, J. S., Brauer, M., Cohen, A. J., Ezzati, M., & Pope, C. A. (2018). Ambient PM2.5 reduces global and regional life expectancy. Environmental Science & Technology Letters, 5(9), 546–551. https://doi.org/10.1021/acs.estlett.8b00360
6. Boyitie, P. O., Ojoh, C. O., & Onyemenam, P. I. (2024). Evaluation of GHG emissions on climate of the braced states in the Niger Delta. British Journal of Environmental Sciences, 12(9), 1–8. https://doi.org/10.37745/bjes.2013/vol12n418
7. Brida, J. G., Alvarez, E., Cayssials, G., & Mednik, M. (2024). How does population growth affect economic growth and vice versa? An empirical analysis. Review of Economics and Political Science, 9(3), 265–297. https://doi.org/10.1108/reps-11-2022-0093
8. Gul, H., & Das, B. K. (2023). The Impacts of Air Pollution on Human Health and Well-Being: A Comprehensive Review. Journal of Environmental Impact and Management Policy, 36, 1–11. https://doi.org/10.55529/jeimp.36.1.11
9. Guo, J., Xu, Y., & Pu, Z. (2016). Urbanization and Its Effects on Industrial Pollutant Emissions: An Empirical Study of a Chinese Case with the Spatial Panel Model. Sustainability, 8(8), 812. https://doi.org/10.3390/su8080812
10. Huang, Y., Elahi, E., You, J., Sheng, Y., Li, J., & Meng, A. (2024). Land use policy implications of demographic shifts: Analyzing the impact of aging rural populations on agricultural carbon emissions in China. Land Use Policy, 147, 107340. https://doi.org/10.1016/j.landusepol.2024.107340
11. Izah, S. C., Onwudiegwu, C. A., Sylva, L., & Etim, N. G. (2024). Health and Environmental Justice Strategies for mitigating air pollution. In ˜The œhandbook of environmental chemistry. https://doi.org/10.1007/698_2024_1121
12. Liyanage, C., & Yamada, K. (2017). Impact of population growth on the water quality of natural water bodies. Sustainability, 9(8), 1405. https://doi.org/10.3390/su9081405
13. Maji, S., Ahmed, S., Kaur-Sidhu, M., Mor, S., & Ravindra, K. (2023). Health Risks of Major Air Pollutants, their Drivers and Mitigation Strategies: A Review. Air Soil and Water Research, 16. https://doi.org/10.1177/11786221231154659
14. Murano, H., Inoue, S., Sato, K., Sato, M., Igarashi, A., Fujimoto, S., Iseki, K., Moriyama, T., Shibagaki, Y., Kasahara, M., Narita, I., Yamagata, K., Tsuruya, K., Kondo, M., Asahi, K., Watanabe, T., Konta, T., & Watanabe, M. (2023). The effect of lifestyle on the mortality associated with respiratory diseases in the general population. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-34929-8
15. Numbere, A. O. (2020). Impact of Urbanization and Crude oil Exploration in Niger Delta Mangrove Ecosystem and its Livelihood Opportunities: A Footprint Perspective. In Springer eBooks (pp. 309–344). https://doi.org/10.1007/978-981-15-9496-0_10

16. Nwadiaro, C. J., Okonkwo, C. C., & Nwafor, S. O. (2019). Urbanization and environmental degradation in Nigeria: Challenges and policy implications. International Journal of Environmental Studies, 76(4), 570-589.
17. Nwankwoala, H. O., & Okujagu, D. (2021). A Review of Wetlands and Coastal Resources of the Niger Delta: Potentials, Challenges and Prospects. Environment & Ecosystem Science, 5(1), 37–46. https://doi.org/10.26480/ees.01.2021.37.46
18. Nwilo, P. C., & Badejo, O. T. (2006). Impacts and management of oil spill pollution along the Nigerian coastal areas. Administering Marine Spaces: International Issues, 119, 1-15.
19. Nwosisi, M., Oguntoke, O., Taiwo, A., Agbozu, I., & Noragbon, E. (2021). Spatial patterns of gas flaring stations and the risk to the respiratory and dermal health of residents of the Niger Delta, Nigeria. Scientific African, 12, e00762. https://doi.org/10.1016/j.sciaf.2021.e00762
20. Olalekan, A. S., Amadi, A. N., & Ugochukwu, C. N. (2021). Assessing the impact of industrial emissions on air quality in the Niger Delta. African Journal of Environmental Science and Technology, 15(5), 237-248.
21. Pryor, J. T., Cowley, L. O., & Simonds, S. E. (2022). The physiological effects of air pollution: particulate matter, physiology and disease. Frontiers in Public Health, 10. https://doi.org/10.3389/fpubh.2022.882569
22. Rafaj, P., Kiesewetter, G., Gül, T., Schöpp, W., Cofala, J., Klimont, Z., Purohit, P., Heyes, C., Amann, M., Borken-Kleefeld, J., & Cozzi, L. (2018). Outlook for clean air in the context of sustainable development goals. Global Environmental Change, 53, 1–11. https://doi.org/10.1016/j.gloenvcha.2018.08.008
23. Ramayah, M., Rasiah, R., Somasundram, S., & Turner, J. J. (2019). Determinants of environmental degradation: reflections on the impact of identified economic variables on the environment. Mining of Mineral Deposits, 13(4), 42–52. https://doi.org/10.33271/mining13.04.042
24. Shaddick, G., Thomas, M. L., Mudu, P., Ruggeri, G., & Guy, S. (2020). Half the world's population are exposed to increasing air pollution. Npj Climate and Atmospheric Science, 3(1). https://doi.org/10.1038/s41612-020-0124-2
25. Yu, W., Ye, T., Chen, Z., Xu, R., Song, J., Li, S., & Guo, Y. (2024). Global analysis reveals region-specific air pollution exposure inequalities. One Earth. https://doi.org/10.1016/j.oneear.2024.09.017
26. Zambrano-Monserrate, M. A., Subramaniam, Y., Adnan, N., Bergougui, B., & Adebayo, T. S. (2024a). Dynamic factors driving PM2.5 concentrations: Fresh evidence at the global level. Environmental Pollution, 362, 124940. https://doi.org/10.1016/j.envpol.2024.124940
27. Zhang, Z., Chen, Z., Zhang, J., Liu, Y., Chen, L., Yang, M., Osman, A. I., Farghali, M., Liu, E., Hassan, D., Ihara, I., Lu, K., Rooney, D. W., & Yap, P. (2024). Municipal solid waste management challenges in developing regions: A comprehensive review and future perspectives for Asia and Africa. The Science of the Total Environment, 930, 172794. https://doi.org/10.1016/j.scitotenv.2024.172794