



SPATIAL VARIATION OF PM_{2.5} AIR POLLUTION AND ITS ASSOCIATED HEALTH IMPLICATIONS WITHIN BENIN CITY METROPOLIS

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ABSTRACT

Air pollution remains one of the most pressing environmental and public health challenges facing rapidly urbanising cities, and fine particulate matter (PM_{2.5}) is of particular concern due to its ability to penetrate deep into the respiratory system and bloodstream. This study assessed the spatial and temporal variation of PM_{2.5} concentrations within Benin Metropolis, Edo State, Nigeria, using data collected from three representative monitoring sites: The University of Benin, the Edo State Secretariat, and the Edo Geographic Information Service, over a twelve-month period from December 2024 to December 2025. Daily average PM_{2.5} concentrations were measured using low-cost sensors and converted into corresponding Air Quality Index values to assess associated health risks. Results showed that PM_{2.5} levels frequently exceeded international health guidelines across all sites, with the University of Benin consistently recording the highest and most erratic concentrations, particularly during the harmattan season, while levels generally declined during the rainy season. The study recommends the establishment of a continuous, site-specific air quality monitoring network, public advisory systems during high-pollution periods, and stricter controls on generator use, vehicular emissions, and dust-generating activities to guide effective air quality management and public health policy within the metropolis.

Keywords: PM_{2.5}, Air Quality, Particulate Matter, Public Health, Benin Metropolis, Air Quality Index (AQI)

1. INTRODUCTION

Air pollution is one of the largest environmental and public health challenges in the world (Chen and Kan, 2008). It is caused by the release of harmful substances into the atmosphere from natural processes and human activities, which leads to the deterioration of ambient air quality. With the improvement of living standards, rapid urbanisation, technological advancement, industrialisation and increasing energy demands have also aggravated environmental pollution. The intensification of industrial activities, the increase of vehicular transportation, the combustion of fossil fuels and the expansion of urban areas at the global level have all led to a serious degradation of air quality (Woodcock *et al.*, 2007; Chen and Kan, 2008; Sun *et al.*, 2023). Air pollution has therefore become one of the most

important environmental and public health challenges of the twenty-first century (WHO, 2019; Fuller *et al.*, 2022; Orukpe *et al.*, 2025). This research concentrates on fine particulate matter (PM_{2.5}) among different air pollutants because of its significant impact on air quality and human health.

Fine particulate matter (PM_{2.5}) refers to airborne particulate matter with an aerodynamic diameter of less than 2.5 µm. Its particles are extremely small, it has a large relative surface area and it has a strong capacity to adsorb toxic substances (Li *et al.*, 2015; Zhang *et al.*, 2024). It can remain suspended in the atmosphere for extended periods and may be transported over considerable distances, allowing pollution from distant sources to influence local air quality (Jiang *et al.*, 2011; Sulaymon *et al.*, 2020). These unique characteristics increase

the likelihood of human exposure, allowing PM_{2.5} to penetrate deep into the respiratory tract, reaching the alveoli and even entering the blood stream, posing significant risks to human health. The major components of PM_{2.5} which is a mixture of solid and liquid particles are black carbon, metals, nitrates, sulphates and polycyclic aromatic hydrocarbons. PM_{2.5} is primarily emitted from the combustion of fossil fuels, biomass burning and vegetation, while secondary PM_{2.5} is formed by the photo-oxidation of anthropogenic and natural volatile organic compounds (VOCs) (Hallquist, 2009; Ezech *et al.*, 2017). In recent years, anthropogenic PM_{2.5} emissions due to intensive human activities have become a major contributor to severe air pollution worldwide (Yun *et al.*, 2023). In Nigeria, rapid industrialisation and the increasing need for iron and steel production are major contributors to particulate matter (PM) emissions (Owoade *et al.*, 2015). This leads to the release of air pollutants, which stay suspended in the atmosphere and pose serious risks to human health (Brook *et al.*, 2004). Other major sources of PM are vehicle emissions, power generators, open waste burning, and natural sources such as dust and sea salt (Ibitayo, 2012; Oseni, 2016; Adama, 2018). In recent years, the development of satellite remote sensing and data acquisition technologies has improved the capability to monitor and analyse the long-term spatial and temporal variations of PM_{2.5} concentrations, offering useful information for air quality assessment and environmental management (Jin *et al.*, 2022; Tariq *et al.*, 2023).

Benin Metropolis, the capital of Edo State, is one of Nigeria's rapidly expanding urban centres with increasing commercial, educational, and governmental activities. The city also serves as a major transportation hub, linking the southern, eastern, and northern

regions of the country through several major highways (Ovuyovwiroye, 2015). Consequently, it experiences substantial vehicular traffic, commercial transportation, and associated emissions, which may contribute to elevated ambient PM_{2.5} concentrations. Despite its strategic location and growing urbanization, there is limited information on the spatial variation of PM_{2.5} and its relationship with atmospheric variables within the metropolis. Continuous monitoring of particulate matter is therefore essential for assessing air quality, understanding potential public health risks, and providing scientific evidence to support effective air quality management and policy development in Benin Metropolis.

However, there is a lack of site-specific information on PM_{2.5} concentrations in various land use types, particularly in the University of Benin (educational), Edo State Secretariat (administrative), and Edo Geographic Information Service (government/commercial) environments. The study of PM_{2.5} variations along with atmospheric variables (temperature, relative humidity and atmospheric pressure) will improve the knowledge of the processes that influence particulate pollution and will offer scientific evidence for the establishment of effective air quality management, public health protection and environmental policy formulation in Benin Metropolis. Nevertheless, localized studies focusing on Benin City is key to addressing its unique environmental and public health challenges. The involvement of modern air quality monitoring technologies, as demonstrated by Kelly *et al.* (2017), Karin *et al.* (2019), and Orukpe *et al.* (2022), has being positive by improving the accuracy and reliability of air quality assessments. Therefore, this study compares PM_{2.5} concentrations across selected locations within Benin City to

provide site-specific information on particulate pollution and its implications for air quality management (Orukpe *et al.*, 2025). The objectives of this study are to: To determine the spatial and temporal variations of PM_{2.5} concentrations in Benin Metropolis using University of Benin, Edo State Secretariat and Edo Geographic Information Service as representative monitoring sites. The study also aims to assess the potential public health impacts of PM_{2.5} exposure, generating scientific evidence to support air quality management strategies, environmental policies, and human health protection in the metropolis.

2. METHODOLOGY

The PurpleAir sensor is an affordable air quality sensor designed for real-time particulate matter measurements. It is equipped with two laser particle sensors (Plantower PMS5003) and a pressure-temperature humidity sensor (Bosch BME280) and a Wi-Fi enabled processor to send the measured data to cloud-based storage for real-time access and analysis. Because of its relatively low cost (USD 230–260), the PurpleAir sensor has been widely adopted for ambient air quality monitoring, with thousands of units installed for public reporting across Nigeria. The performance and accuracy of PurpleAir sensors have been previously evaluated in outdoor ambient conditions in several locations in Nigeria such as Benin City. Similarly, the reliability of PurpleAir sensors has been investigated in several countries, including the United States (Ardon-Dryer *et al.*, 2020; Barkjohn *et al.*, 2021), South Korea (Kim *et al.*, 2019), Greece (Stavroulas *et al.*, 2020), and Uganda (McFarlane *et al.*, 2021). Particulate matter (PM) is normally divided into classes according to its aerodynamic diameter. Particles with diameter 1 micrometre or less are termed as PM_{1.0},

those measuring 2.5 micrometres or less are known as PM_{2.5} and particles with diameters up to 10 micrometres are called as PM₁₀. Of these categories, PM_{2.5} is the most harmful to human health as it can bypass the body's natural respiratory defences, penetrate deep into the lungs, and adversely affect respiratory function (Babagana, 2017; Adaes and Pires, 2019; Babatunde *et al.*, 2020).

The dataset used in this study was sourced from the PurpleAir air quality monitoring network and is publicly available on the PurpleAir webpage, www.purpleair.com. PurpleAir is a web-based platform that incorporate data from a network of community-operated sensors, enabling the continuous collection, transmission, and storage of real-time particulate matter (PM) measurements for air quality monitoring and analysis. The sensor measures PM levels using PMSX003 laser counters, with readings taken every ten minutes and averaged. Each laser counter possesses a fan that pulls a sample of air through a laser beam. These class IIIa/3R lasers will reflect light from any particles on a detection plate with their beam. The detection plate measures the reflection as a pulse, with the pulse length used to determine particle size and the pulse count used to determine particle count. This information is then used to calculate PM_{2.5} and PM₁₀ concentrations for standard indoor (CF 1) and outdoor or atmospheric (ATM) particles (Orukpe *et al.*, 2025).

The daily average PM_{2.5} data used in this study were collected over a period of 51 weeks and 2 days from 31 December 2024 to 25 December 2025. Data collection was carried out at three monitoring locations in Benin Metropolis, namely, the Edo GIS (6°17'58.4" N 5°37'47.0" E), Edo State Secretariat (6.3237165" N, 5.6240914" E) and the Space-Earth Environment Research

Laboratory (6°24'14.2" N 5°37'10.1" E), University of Benin.

The sites were selected to represent areas with varying levels of anthropogenic activities, including high vehicular traffic,

commercial and administrative activities and waste generation which are potential contributors to particulate matter pollution and may influence ambient air quality.

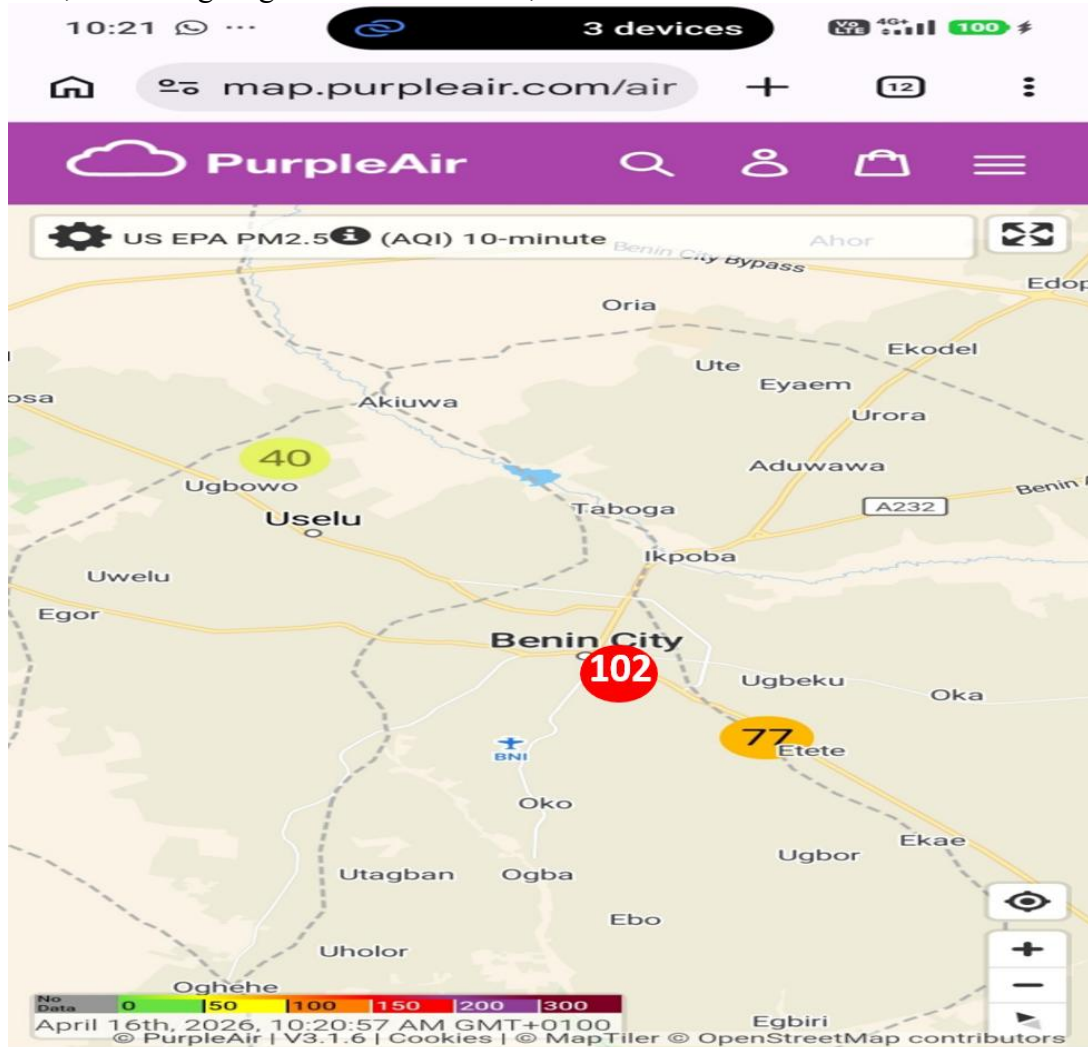


Plate 1: Shows the Map of the Locations

To determine the daily variation of air pollution, the AQI values were plotted against the days at the three locations to study the daily variation of air pollution. We found the air quality index by looking at the concentration of particulate matter or pollutants in the atmosphere.

Calculating AQI from pollutant concentration data:

The AQI can be calculated from the pollutant concentration data using the equation (linear interpolation):

$$I_p = \frac{I_{HI} - I_{Lo}}{BP_{HI} - BP_{Lo}} (C_p - BP_{Lo}) + I_{Lo}$$

Where I_p = the index for pollutant p

C_p = the rounded concentration of pollutant p

BP_{HI} = the breakpoint that is greater than or equal to C_p

BP_{Lo} = the breakpoint that is less than or equal to C_p

I_{HI} = the AQI value corresponding to BP_{HI}

I_{Lo} = the AQI value corresponding to BP_{Lo}

The data set we focused on was the full data set from 31 December 2024 to 25 December

2025 and the date used was accessed in early January 2026. The data were downloaded every 5 minutes and aggregated on a monthly basis. The parameter that constitutes the data is particulate matter (PM_{2.5}).

The data was adequately arranged and sorted (U.S. EPA, 2014). The data were analysed using Graph Prism 2016 and Microsoft Excel 2017. Results were presented according to scientific norms and compared to those established by the US Environmental Protection Agency (US-EPA-2016) and World Health Organization (WHO 2018, US-EPA 2021).

3. RESULT/DISCUSSION:

This section presents the results of the assessment of PM_{2.5} variations at University

of Benin, Edo State Secretariat and Edo GIS across Benin Metropolis. The results represent the spatial variation of PM_{2.5} concentrations and their corresponding Air Quality Index (AQI) values. The AQI is a standardised indicator that categorises air quality and its health implications, with lower AQI values indicating better air quality and minimal health risk, moderate AQI values indicating acceptable air quality and potential health risks to sensitive groups, and higher AQI values indicating deteriorating air quality and increasing health concerns for the general population. Differences are discussed with respect to local emission sources and possible implications for public health.

Table 1: Air Quality Index (AQI) levels of health concern.

Air Quality Index (AQI) Value	Level of Health Concerns
Good (0-50)	Air quality is considered satisfactory and poses little or no significant risk to public health.
Moderate (51-100)	Air quality is acceptable; however, unusually sensitive individuals may experience minor health effects.
Unhealthy for Sensitive Groups (101-150)	Children, older adults, and individuals with respiratory or cardiovascular diseases may experience adverse health effects.
Unhealthy (151-200)	Everyone may begin to experience health effects, while sensitive groups are likely to experience more serious effects.
Very Unhealthy (201-300)	Health alert: the risk of adverse health effects increases for the entire population.
Hazardous (301-500)	Health warning of emergency conditions; the entire population is likely to be affected.

Source: U.S. Environmental Protection Agency (EPA), 2024.

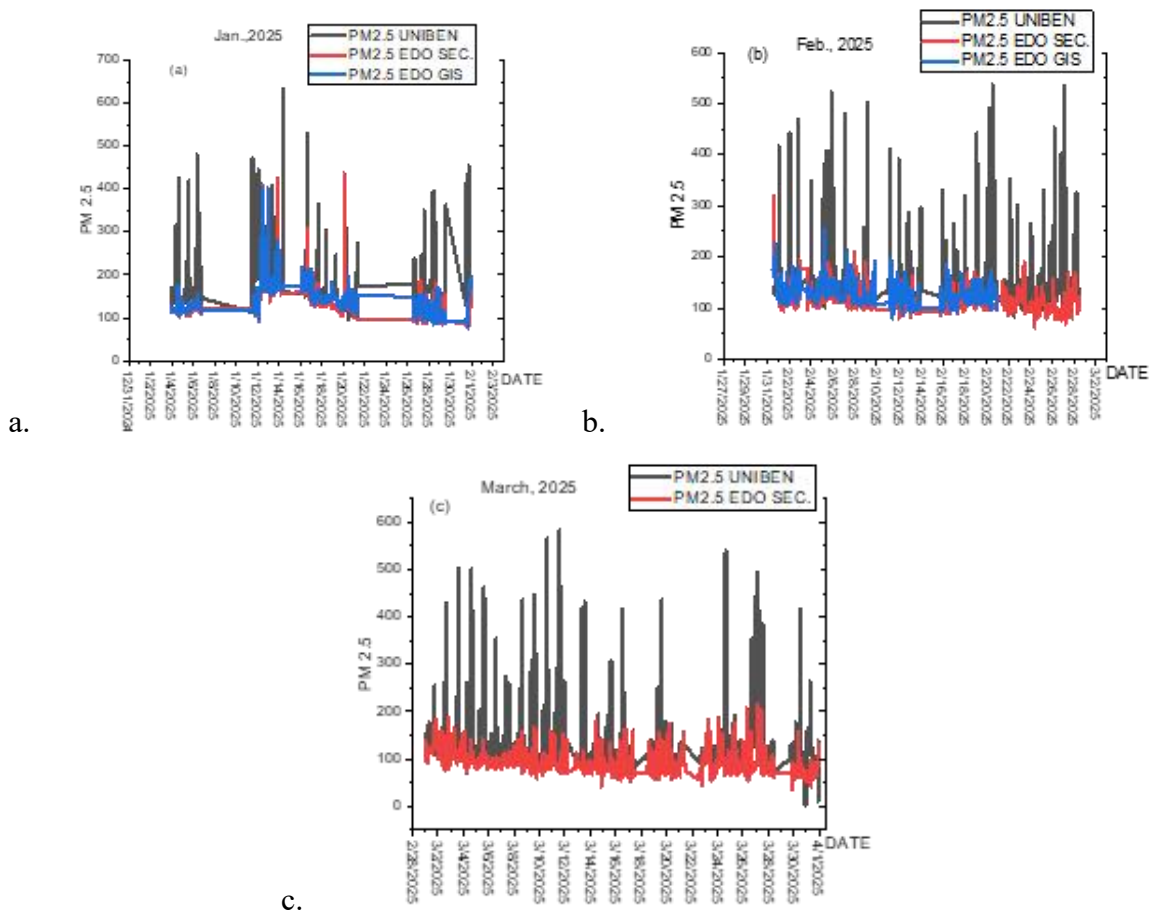


Fig. 1a, b, c: Shows the values for January, February and March 2025 of PM_{2.5} for the three stations. Note that the Edo GIS sensor experienced technical issues during March 2025, resulting in the absence of data for this station for that month.

The three charts reveal a clear and rather worrying pattern from January to March 2025, with the University of Benin (UNIBEN) location consistently registering the highest and most erratic PM_{2.5} concentrations of the three sites, frequently spiking well above 400 and even 600 micrograms per cubic metre. In contrast, the Edo State Secretariat and Edo GIS stations, while still elevated in relation to global health benchmarks, tend to be relatively lower and more stable.

In January, all three sites show considerable volatility, with UNIBEN and Edo Secretariat frequently trading places as the most polluted location, both swinging between roughly 100 and over 500 on several days, while Edo GIS stays somewhat more contained, mostly hovering between 100 and 250. Such variability indicates a mixture of localised

sources that may include traffic, generator use, dust from unpaved or dry surfaces, and harmattan-related particulate loading, which is common during this season in southern Nigeria. The implications are profound for those who live and work and study through these swings. Repeated exposure to PM_{2.5} levels many times above the World Health Organization's recommended daily guideline can irritate the respiratory tract, aggravate asthma and other chronic lung diseases, and tax the cardiovascular system. Particles this fine can penetrate deep into the lungs and even pass into the bloodstream.

By February the pattern becomes much sharper at UNIBEN, with spikes becoming more frequent and more extreme, with values regularly above 300 and frequently hitting 450 to 550. This month, Edo Secretariat

settles into a comparatively calmer range, mostly under 200, and Edo GIS remains the most stable of the three, staying close to 100 to 150 for much of the month. The fact that such high readings persisted at UNIBEN throughout February is a matter of concern because it is a densely populated academic community with many young people, staff and surrounding residential areas. The risk of cumulative respiratory injury (impairment of lung function in the long term, increased frequency of coughing, irritation of the throat and the eyes, and greater susceptibility to infections) is increased by continuous exposure for weeks rather than days alone. Fine particulate matter can also impair local immune defences in the airway. March maintains this troubling trend for UNIBEN, again showing dramatic and frequent spikes

reaching from the low hundreds up to nearly 600. This suggests whatever sources are driving pollution at this site, whether vehicular emissions, construction activity, biomass burning, or dust resuspension, are not easing up as the harmattan season transitions toward the wetter months. Edo Secretariat, the only comparison site available for March due to technical issues at Edo GIS, remains comparatively subdued, generally staying under 150 with only occasional upward movement. The scale of difference between the two sites in this final month is striking and reinforces a wider concern that UNIBEN as a location suffers disproportionately poor air quality compared to the more administrative or office-based environment of the Edo Secretariat.

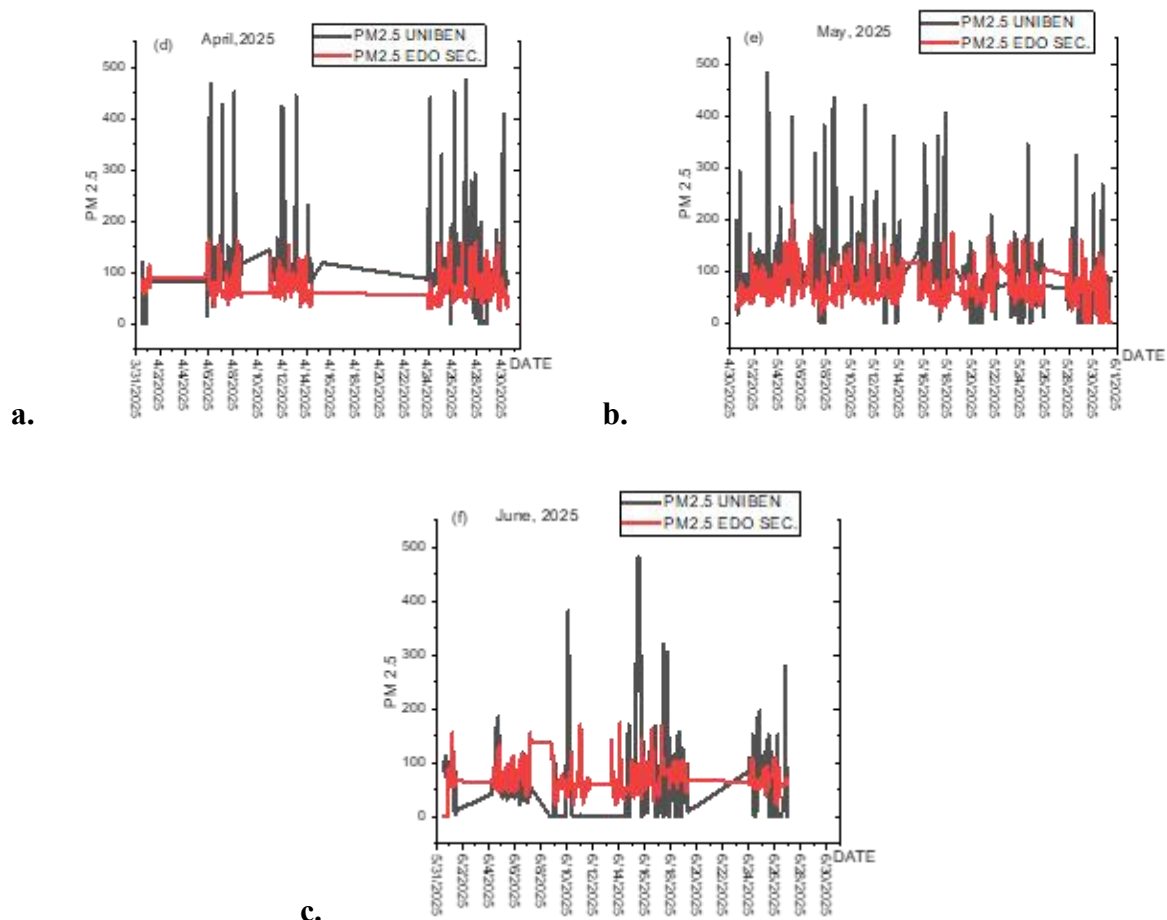


Fig. 2a, b, c: Shows the values for April, May and June 2024 of PM_{2.5} for the two stations. Note that the Edo GIS sensor experienced technical issues during these three months in 2025, resulting in the absence of data for this station for that month.

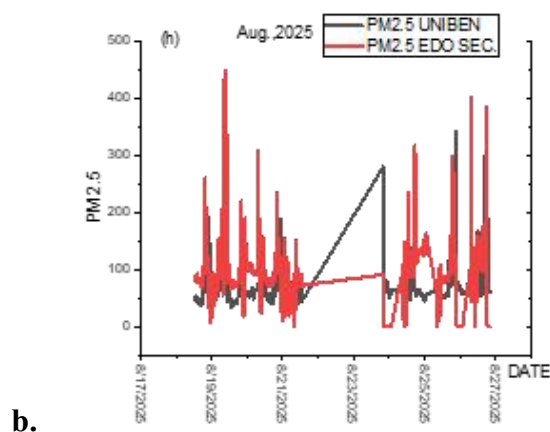
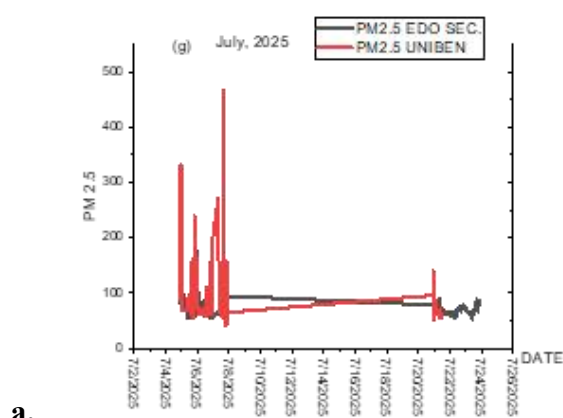
Continuing into the second quarter of the year, the charts for April, May, and June 2025 reveal that the pattern established earlier in the year persists, with UNIBEN consistently registering higher and more erratic PM_{2.5} concentrations than the Edo State Secretariat, even as the overall intensity of pollution begins to show some month-to-month variation.

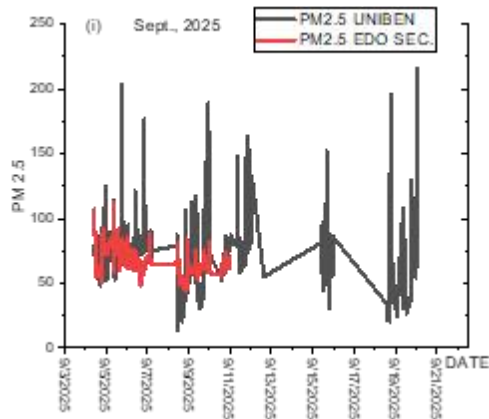
The April chart shows UNIBEN continues to be the more volatile and polluted site with recurring spikes around 300 to nearly 500, punctuated by calmer spells near 100 while Edo Secretariat remains notably steadier, mostly oscillating gently between 50 and 150 with only mild variation. The pattern of sharp surges and short lulls at UNIBEN suggests intermittent source of pollution.

May continues the pattern of UNIBEN for having regular, large spikes, many going above 300 and some nearly 450, while Edo Secretariat is relatively steady, swinging between about 50 and 200 with a distinctively smoother rhythm. Edo Secretariat sees a slightly wider spread this month, compared to April, with a few moderate peaks approaching 200, indicating a slightly higher degree of variability at this site, compared to the previous month. The

UNIBEN pattern remains one of sharp, repeated surges, rather than a steady high baseline: between spikes, the value often falls back to about 100. Overall, both datasets display a steady gap during the month of May. The peak values in UNIBEN are consistently two to three times higher than the corresponding peak values in Edo Secretariat on the same dates.

By June something actually shifts at UNIBEN, and it's worth pausing on. The extreme spikes, the ones we kept seeing in April and May, don't show up nearly as often now, though a few sharp peaks near 400 to 480 still sneak in on random days. There's also this new thing happening, where readings drop close to zero for stretches at a time, which honestly wasn't really there in the earlier months. Edo Secretariat, meanwhile, displays a more erratic pattern than in previous months, bouncing between 50 and 150 more than before, losing that steadiness it had back in April and May. So, the gap between the two sites narrows, probably the clearest change across the whole six months, though UNIBEN's occasional spikes remind us the high-exposure days haven't fully gone away.





c.

Fig. 3a, b, c: Shows the values for July, August and September 2025 of $PM_{2.5}$ for the two stations (UNIBEN and Edo SEC)

July is a dramatic story concentrated in the first ten days, with UNIBEN spiking sharply, reaching close to 330, dropping, then climbing again past 460 around July 8th, while Edo Secretariat stays remarkably flat and low, barely moving above 100 for nearly the entire stretch. Both lines are essentially flat after about the 10th of July and remain near each other between 50 and 100 for the rest of the month except for a little blip around July 22, where UNIBEN jumps briefly to around 140. This is a far cry from previous months where the volatility of UNIBEN was spread out the whole period rather than one early burst that settled in to a long, quiet stretch.

August starts off with the roles reversed; Edo Secretariat's the more volatile line, swinging between 100 and over 400 in that first week, while UNIBEN just stays comparatively subdued, mostly between 50 and 150. Then around the 21st, something strange happens, UNIBEN's line shoots up in this oddly clean, triangular spike toward 300, and right around

then Edo Secretariat's data just stops for a few days before picking back up past the 23rd. Once it does, Edo Secretariat goes back to being volatile, touching 250 to 350 again, while UNIBEN drops into a lower, choppy rhythm around 50 to 100, though it does peak above 300 once more near the end of the month.

September is different altogether. UNIBEN is the more erratic line for the full month, and Edo Secretariat is only present for roughly the first third before its data seems to just cut off. UNIBEN bounces all over, down to 30 in a few places, up past 200 jaggedly a couple times, with an unpredictable rhythm from start to finish. Edo Secretariat, for as long as it lasts, is gentler, moving between 50 and 100, tracking close to UNIBEN during the days they overlap but never hitting those same extremes. Once Edo Secretariat drops out, UNIBEN just keeps going alone, dips to its lowest points of the month, then climbs back up near 210 close to the 21st.

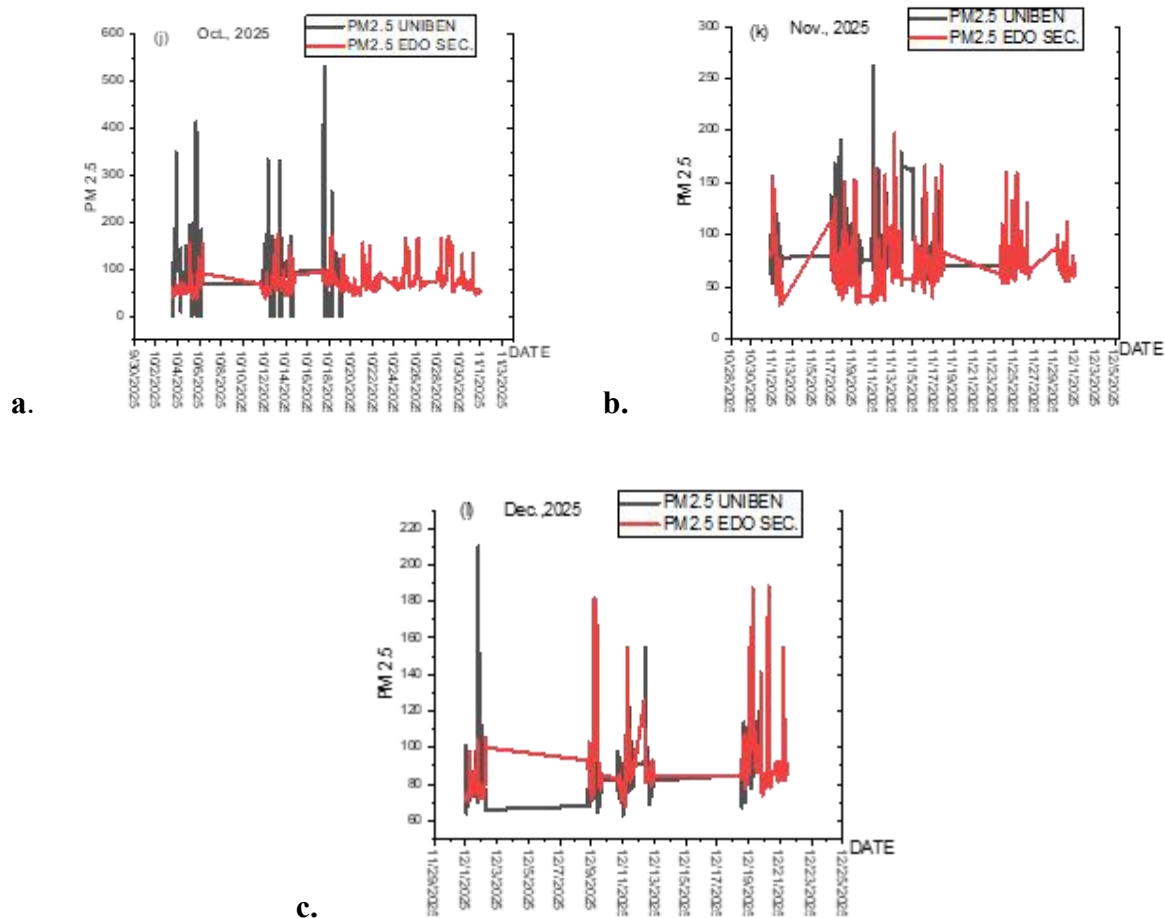


Fig. 4a, b, c: Shows the values for October, November and December 2025 of PM_{2.5} for the two stations (UNIBEN and Edo SEC)

October starts with UNIBEN producing three distinct sharp spikes, one past 300 around the 4th, another climbing close to 420 near the 6th, then a third around 380 near the 16th, and each time it shoots up it drops right back down after. Edo Secretariat's tame through the first half, sitting mostly between 50 and 150, but somewhere around the 20th it gets choppy, more jagged, repeatedly bouncing in that same 50 to 150 zone but with tighter, quicker moves than before. And then, once UNIBEN's third spike settles down past mid-month, its data appears to stop, leaving Edo Secretariat as the sole active line for the remainder of October.

November shows both sites more actively overlapping than in October. UNIBEN producing sharp peaks, one close to 260,

another around 200, with quieter dips back toward 50 in between. Edo Secretariat is busier, running this saw-toothed rhythm most of the month, swinging between 50 and 150 rapidly, tighter than UNIBEN's wider spikes. What's interesting is the two lines don't really move together, UNIBEN's peaks land on different days than Edo Secretariat's highs, like they're on their own separate schedules almost. By the last third of the month things calm down for both, settling into a lower range, mostly 50 to 100, with less dramatic movement than earlier weeks.

December's range is narrower overall compared to the months before it with UNIBEN opening the month at a notably high point near 210 before dropping sharply and settling into a flatter stretch closer to 60

to 80 for much of the middle of the month. Edo Secretariat is the busier one this time, moving up and down more often, a few peaks reaching 180 to 190 scattered across different points, so it looks a lot more active than UNIBEN's quieter middle stretch. Near the end, UNIBEN climbs again toward 150 before both lines converge closer together, generally sitting within a tighter 60 to 100 band as the month closes out.

4. DISCUSSION

The results of this study indicate considerable variation in PM_{2.5} concentrations across the three monitoring locations in Benin Metropolis, with the University of Benin (UNIBEN) generally recording higher and more variable concentrations than Edo Secretariat and Edo GIS. Several of the observed concentrations exceeded the World Health Organization (WHO) 24-hour guideline value of 15 µg/m³, indicating periods of substantially degraded air quality. The WHO guideline is health-based and is intended to reduce the adverse effects associated with particulate-matter exposure (WHO, 2021). The elevated concentrations observed in this study are therefore of public-health concern, particularly because exposure to PM_{2.5} has been consistently associated with respiratory and cardiovascular outcomes (Atkinson *et al.*, 2014; Alexeeff *et al.*, 2021). A systematic review of studies from low- and middle-income countries found that long-term PM_{2.5} exposure was associated with increased cardiovascular and respiratory morbidity and mortality, with respiratory risks being particularly important in these settings (Guo *et al.*, 2023).

The relatively high concentrations observed at UNIBEN may reflect the influence of activities occurring within and around the university environment. The campus is characterised by human movement, vehicular activity, generator use, construction and other

activities capable of producing or resuspending particulate matter. However, because this study measured ambient PM_{2.5} rather than directly identifying emission sources, these factors should be regarded as possible contributors rather than confirmed sources. This distinction is important when interpreting the spatial differences observed between the monitoring locations.

The temporal pattern also suggests a clear seasonal influence on PM_{2.5} concentrations. Higher concentrations were observed during the drier months, particularly around January and February, whereas lower and less frequent peaks occurred during the wetter months. This pattern is consistent with findings from other Nigerian studies. For example, a recent study conducted in Ibadan Metropolis using PurpleAir measurements reported substantial seasonal variability in PM_{2.5}, with concentrations remaining high overall and showing differences between wet and dry periods (Omokungbe *et al.*, 2026). Similarly, research conducted in Ilorin, Nigeria, reported relatively lower PM_{2.5} concentrations from May to October and a sharp increase in December, which the authors associated with the onset of the dry season, biomass burning, Harmattan dust transport and reduced atmospheric dispersion (Nwabachili *et al.*, 2025).

The higher PM_{2.5} concentrations during the Harmattan period can therefore reasonably be linked to the increased presence of dust and dry-season particulate sources, together with atmospheric conditions that may favour the accumulation and persistence of particles (Lala *et al.*, 2023; Balogun *et al.*, 2015). The lower concentrations recorded during the rainy season may, in part, be explained by rainfall scavenging, whereby precipitation removes suspended particles from the atmosphere. However, rainfall should not be considered the only explanation, since

changes in emission activities, wind conditions and atmospheric mixing may also contribute to seasonal differences. The consistency between the present findings and observations from other Nigerian cities strengthens the interpretation that seasonal meteorological conditions and dry-season activities play an important role in determining ambient PM_{2.5} levels.

The observed seasonal pattern is particularly important from a public-health perspective. During periods of elevated PM_{2.5}, prolonged exposure may increase the risk of adverse respiratory and cardiovascular effects. A systematic review and meta-analysis found that short-term PM_{2.5} exposure was associated with increased cardiovascular and respiratory morbidity and mortality, while long-term exposure was associated with a range of cardiovascular and respiratory diseases (Luo *et al.*, 2023; Guo *et al.*, 2023). In individuals with asthma, PM_{2.5} exposure has also been associated with reduced lung function and an increased risk of acute asthma exacerbation (Qibin *et al.*, 2020). These findings provide a basis for considering the elevated PM_{2.5} levels observed in Benin Metropolis as a potential environmental health concern, particularly during periods when concentrations remain elevated for extended periods.

The implications are therefore not limited to the measured air-quality values themselves. For a large institutional population such as that of UNIBEN, where students and staff may spend several hours within the campus environment each day, repeated exposure to elevated PM_{2.5} warrants greater attention to air-quality monitoring and exposure reduction. This does not mean that the present study demonstrates that the measured PM_{2.5} concentrations directly caused specific diseases among the university population; rather, the observed concentrations represent

an environmental exposure of potential health significance, based on the established evidence linking PM_{2.5} exposure with adverse health outcomes. Continuous monitoring, public air-quality information, improved control of local emission sources and measures to reduce exposure during periods of elevated concentrations could therefore contribute to better protection of public health in Benin Metropolis.

CONCLUSION

What makes this research on PM_{2.5} air quality worth something is just how broad it is. A full year's worth of data drawn from three quite different site types, an academic institution, a state administrative office and a mapping agency, gives a much fuller picture than any single-location snapshot could offer on its own. Across the months, PM_{2.5} concentrations repeatedly pushed the corresponding Air Quality Index into unhealthy and, at times, hazardous categories, particularly around UNIBEN, underscoring how far conditions strayed from what's considered safe. The study captures both the seasonal variation between the harmattan and the rainy season and the everyday unpredictability of urban air quality, and together that builds a solid evidence base for anyone thinking seriously about public health interventions, urban planning, or environmental policy within Benin Metropolis going forward.

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