FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 6, June, 2025, pp 57 – 63
DOI: https://doi.org/10.33003/fjs-2025-0906-3716

SEASONAL VARIATION IN METEOROLOGICAL PARAMETERS AND ATMOSPHERIC OXIDES AROUND EKET WETLANDS, AKWA IBOM STATE, NIGERIA: ENVIRONMENTAL AND PUBLIC HEALTH IMPLICATIONS

[1]Onyegbule, Chiamaka L., *[2]Mbong, Emem O., [1]Ogbemudia, Felix O. and [1]Anwana, Eno D.

[1]Department of Botany and Ecological Studies, University of Uyo, Uyo. Akwa Ibom State
[2]Department of Biology and Forensic Science, Admiralty University of Nigeria, Delta State

*Corresponding authors' email: mbongemem@yahoo.com Phone: +2349035374893

ABSTRACT

This study investigates the seasonal variations in meteorological parameters and atmospheric oxides within and around Eket wetlands and their environmental and public health implications. Meteorological parameter including air temperature and relative humidity were analyzed to established correlation with concentration of atmospheric oxides such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter (PM_{10}). Results indicate significant ($P<0.05$) seasonal fluctuations, with higher pollutant levels recorded during the dry season due to lower humidity and increased atmospheric stability. During the dry season, NO_2, SO_2, CO, and PM_{10} concentrations averaged 45.2 µg/m³, 32.8 µg/m³, 5.6 mg/m³, and 78.3 µg/m³, respectively, while in the wet season, these values reduced to 28.5 µg/m³, 21.4 µg/m³, 3.2 mg/m³, and 54.6 µg/m³. Correlation analysis reveals strong positive relationships between NO_2 and SO_2 ($r = 0.9409$) and $PM_{2.5}$ and CO ($r = 0.8234$), while relative humidity negatively correlates with all pollutants, emphasizing its role in pollutant dispersion. The findings highlight severe air quality deterioration, particularly in urbanized locations, with public health risks such as respiratory illnesses, cardiovascular diseases, and increased hospital admissions. The study underscores the need for stringent air quality management strategies, including emission control regulations, industrial air monitoring, wetland conservation, and public awareness campaigns to mitigate pollution-related health and environmental impacts.

Keywords: Air pollution, Meteorological parameters, Wetland degradation, Urbanization, Public health

INTRODUCTION

Urban centers and cities are constantly characterized by significant industrial activities, rapid urbanization, and vehicular emissions, which to a large extent impact air quality (Okon *et. al.* 2024). Meteorological parameters also play a significant role in shaping air quality and determining pollutant distribution in this scenario. Understanding the interplay between meteorological conditions and air pollution is essential for assessing environmental and public health risks. The lower atmosphere of Eket experiences seasonal variations due to increasing anthropogeneity which is further influenced by monsoonal patterns, leading to fluctuations in air pollutant levels (Ngele, 2015; Ogbemudia *et. al.* 2025).

Atmospheric oxides and meteorological conditions in urban centers like this are significantly influenced by natural ecosystems such as wetlands, which serve as critical environmental regulators. These ecosystems contribute to atmospheric stability through their role in air purification, carbon sequestration, and microclimate moderation. Wetlands act as natural sinks for airborne particulates and gaseous pollutants, including nitrogen and sulfur oxides, thereby mitigating air pollution and promoting healthier living conditions (Ogbemudia *et. al.*, 2014; Anwana *et al.*, 2020; Xu *et al.*, 2020). However, anthropogeneity manifesting as land reclamation, burning of fossil fuels, and unregulated waste disposal, deforestation, oil exploration, industrial emissions, and rapid urbanization are degrading these wetlands, undermining their capacity to buffer atmospheric pollutants and stabilize meteorological parameters in various cities and urban space including Eket (Day *et al.*, 2003; Ahmad *et. al.*, 2024; Ogbemudia, *et al.,* 2025). This degradation poses serious environmental and public health risks within the metropolis (Mbong *et. al.* 2014a).

Industrial emissions release pollutants like NO_2, SO_2, CO, and particulate matter, which accumulate in the lower atmosphere, impacting both ecosystem health and human well-being (Ahmad, et. al. 2024). The destruction of wetlands further exacerbates these issues by spiking the natural filtration processes, making room for increased pollutant concentration and human exposure risks for neighboring populations (Zhang et al., 2024). Bing linked to several health conditions including respiratory infections, cardiovascular diseases, and chronic obstructive pulmonary disease (COPD), air pollution is a serious threat to human existence within the study area and beyond. It is known that seasonal variations in meteorological conditions influence the dispersion, concentration, and deposition of air pollutants, necessitating comprehensive studies to mitigate associated risks (Kurmi *et. al.* 2020). Without a discreet understanding of the spatial and temporal variations in air pollution dynamics and their health impacts, public health planning remains reactive rather than preventive (Zhou *et. al*. 2020). This inadequacy mediates a continued escalation in respiratory diseases associated with increased healthcare costs, reduced economic productivity, and compromised quality of life, especially among vulnerable populations including the elderly and children, and people with pre-existing conditions (Diaz and Tchepel, 2018; Zhou *et. al*. 2020). Given these gaps, there is a dire need for an integrated, evidence-driven study that explores how variations in meteorological parameters across urbanization gradient influence air quality parameters. Such a study would not only fill a crucial research void but also provide valuable insights for environmental health policy, urban planning, and resource allocation within the metropolis and other similar settings (Wu *et. al.* 2025). The need for the current study arises from the growing recognition that air pollution is not only an environmental issue but also a major public health concern, especially in developing nations like ours where data on pollutant exposure and its associated environmental variables are scarce or fragmented.

MATERIALS AND METHODS

Study Area

Eket Local Government Area is one of the major cities found within the southern parts of Akwa Ibom State. The City is located about 153 meters above sea level at latitude 4.64°N and longitude 7.92°E having grossly 211,255 residents and situates within the Nigeria's Niger Delta region recording an average yearly temperature of 26.7°C. 3119 mm of rainfalls on average each year (DOS-AKSG, 2013; Mbong, *et. al.* 2023). Eket falls within the the tropical rain forest zone bearing a typical tropical humid climate which features distinct dry (November–March) and rainy (April–October) seasons. Trading, hunting, woodcarving, Fishing and craft making are among the occupations practiced in Eket (Ogbemudia, *et al.* 2025).

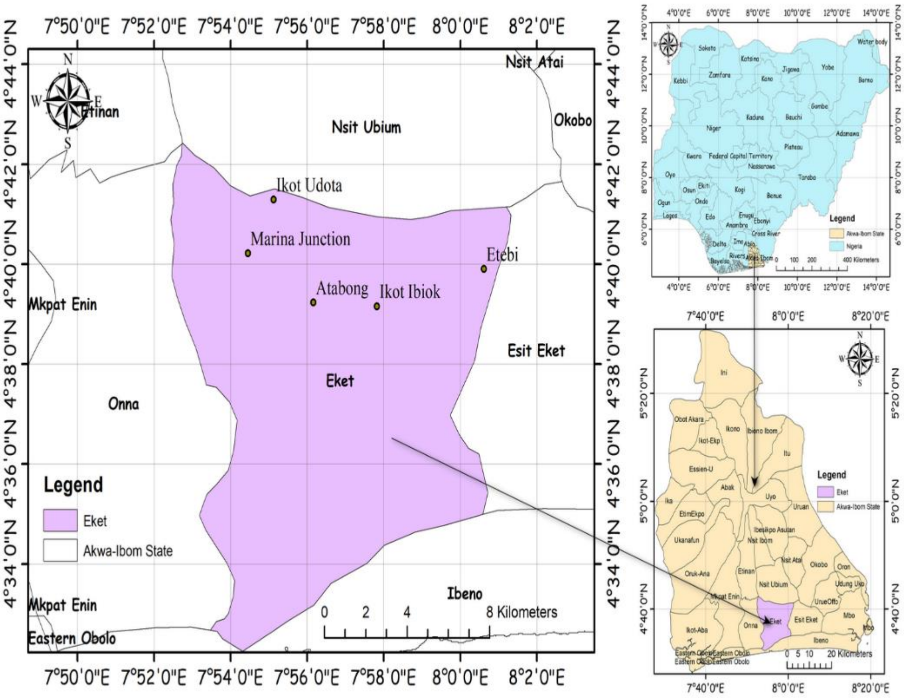

Figure 1: Map of Study Area showing Sampling locations (Source: Field Survey, 2024)

Air Sampling

Sampling for gaseous pollutants was carried during dry season (November – December, 2023) and wet season (May – June, 2024) using high volume sampler according to the method described by Paralovo et.. al. (2018). For the purpose of this study, five sampling sites were chosen within Eket local government area. These gaseous pollutants were determined using their respective gas detectors which worked by electrochemical principles of detection, allowing gases diffuse through a porous membrane to an electrode where it is either chemically oxidised or reduced. The amount of current produced was determined by how much of the gas was oxidised/reduced at the electrode, indicating the concentration of the gas. Gasman model 19831N for NO_2 sampling and concentration determination, Gasman model 19648H was used in the measurement of the concentration of SO_2 at the different monitoring and control sites, Gasman model 19252H was used for CO concentration measurement (Papaconstantino *et. al.* 2023). Sampling of respirable particulate matter (PM_{10}) was carried out using a SKC respirable dust sampler (model 224-PCXR8) following the standard procedures. The gas detectors were positioned at the respective sites consecutively for measurement of the parameters under consideration. The data were collected between early morning and late evening of the day on bi-weekly basis, and they covered both the dry and wet seasons according to the methods described by Omede and Sunday (2022) as well as Bullock (2024). The results were displayed on the respective display screen for each parameter at the respective sites and were respectively recorded for further use.

Determination of Meteorological parameters

Variability in Relative humidity across sites was measured using portable UNI-T hygrometer (model –UT 333) while air temperature readings were taken simultaneously using same device according to the methods of Okon *et al.* (2024).

Statistical analyses

Descriptive statistics was employed to evaluate both meteorological and air pollutants data and displayed on tables. The two-way analysis of variance was employed to find significant variations in the mean values of the parameters across locations. The probability level was set at $P<0.05$ (Mbong, *et. al.* 2013). Using the Statistical Package (SPSS), multivariate correlation technique was employed to identify highly significant associations between pollutant concentration and meteorological data according to the methods employed by Mbong *et. al.* (2014b), Mbong *et. al.* (2020) and Edem *et. al*, (2023).

RESULTS AND DISCUSSION

Variation in Air Quality parameters across study Wetlands

During the dry season, air quality parameters varied significantly across the locations. Nitrogen dioxide (NO_2) concentrations were highest at Ataobong (0.623 ± 0.04 µg/m³) and lowest at Etebi (0.16 ± 0.00 µg/m³). Sulfur dioxide (SO_2) peaked at Ataobong (0.851 ± 0.12 µg/m³), with the lowest detectable level at Ikot Udota (0.215 ± 0.18 µg/m³). Carbon monoxide (CO) levels were most elevated at Marina (8.859 ± 0.21 µg/m³) and least at Ikot Udota (2.875 ± 0.78 µg/m³). Particulate matter ($PM_{2.5}$) was significantly higher at Ataobong (114 ± 25.60 µg/m³), while PM_{10} was highest at Ikot Ibiok (188.34 ± 0.40 µg/m³). Relative humidity (RH) varied, with Etebi recording the highest value (87.59 ± 0.72%), and Ataobong had the highest average temperature (29.44 ± 0.02°C). In the wet season, air quality parameters exhibited noticeable differences. NO_2 concentration reached their maximum at Ataobong (0.92 ± 0.44 µg/m³), while the lowest value was at Ikot Udota (0.14 ± 0.00 µg/m³). SO_2 was most concentrated at Marina (1.83 ± 0.37 µg/m³) and below detectable limits (BDL) at Ikot Udota and Etebi. CO levels were highest at Ataobong (15.03 ± 3.72 µg/m³) and lowest at Ikot Udota (2.38 ± 0.04 µg/m³). $PM_{2.5}$ and PM_{10} peaked at Ataobong (276.82 ± 76.40 µg/m³ and 172.26 ± 0.02 µg/m³, respectively). Relative humidity (RH) was highest at Etebi (91.42 ± 0.21%), while the temperature was most elevated at Etebi (27.64 ± 0.45°C).

Table 1: Mean (± SE) Variation (µg/m³) in Air Quality and Meteorological parameters during the Dry season

	NO2	SO2	CO	$PM_{2.5}$	PM_{10}	RH	Temperature
Ataobong	0.623 ±0.04^a	0.851 ±0.12^a	6.750 ±1.0^a	114±25.60^a	139.80±0.05^a	67.28±0.00^a	29.44±0.02^a
Marina	0.385 ±0.08^b	0.71 ±0.27^a	8.859 ±0.21^b	98.07±12.60^b	122.47±0.02^a	72.94±0.00^b	29.62±0.02^a
Ikot Ibiok	0.203 ±0.021^c	0.36 ±0.02^b	6.095 ±0.61^a	94.33±13.52^b	188.34±0.40^b	76.45±8.24^b	28.46±0.08^a
Ikot udota	0.20 ±0.0^c	0.215 0.18^b	2.875 ±0.78^c	72.12±0.15^c	93.79±0.031^c	81.247±0.81^c	26.21±1.26^b
Etebi	0.16 ±0.0^c	0.13 ±0.04^b	3.02 ±0.96^c	61.84±0.04^c	52.81±0.70^d	87.59±0.72^c	27.63±1.40^b
WHO	25	40	4	15	45	-	-
NESREA	40	20	10	25	50	-	-

Note: Mean are products of triplicate determinations; WHO = World Health Organization; Nigerian Environmental Standards Regulatory Agency. (Source: Field Survey, 2024)

Table 2: Mean (± SE) variation (µg/m³) in Air Quality and Meteorological parameters during the Wet season

	NO2	SO2	CO	$PM_{2.5}$	PM_{10}	RH	Temperature
Ataobong	0.92 ±0.44^a	0.77 ±0.42^a	15.03±3.72^a	276.82±76.40^a	172.26±0.02^a	82.91±0.35^a	27.21±1.47^a
Marina	0.84±0.32^a	1.83 ±0.37^b	10.72±1.29^a	136.52±17.04^b	151.74±0.06^a	85.27±0.02^a	27.42±0.02^a
Ikot Ibiok	0.51±0.10^b	0.43±0.0^c	2.64±0.06^b	112.71±15.89^c	162..91±0.04^a	88.52±0.45^a	26.08±0.04^a
Ikot udota	0.14±0.00^c	BDL	2.38±0.04^b	89.74±0.07^d	113.67±0.07^b	89.35±0.30^a	27.23±0.02^a
Etebi	0.25±0.15^c	BDL	2.96±0.27^b	46.92±0.52^e	81.94±13.20^c	91.42±0.21^a	27.64±0.45^a
WHO	25	40	4	15	45	-	-
NESREA	40	20	10	25	50	-	-

Note: Mean are products of triplicate determinations; WHO = World Health Organization; Nigerian Environmental Standards Regulatory Agency. (Source: Field Survey, 2024)

Correlation between Meteorological Indices and Air Pollutants (Wet Season)

In the wet season, NO_2 exhibited a strong positive correlation with SO_2 (r = 0.9409), indicating that both pollutants likely originate from similar sources such as vehicular emissions and industrial activities. Additionally, NO_2 was significantly correlated with CO (r = 0.6259) and $PM_{2.5}$ (r = 0.8573), suggesting that combustion-related processes contribute to their presence in the atmosphere. Conversely, NO_2 showed a strong inverse relationship with relative humidity (RH) (r = -0.8897), implying that higher humidity levels facilitate the removal of NO_2 from the air, possibly through wet deposition or chemical transformation. Similarly, SO_2 had a strong positive correlation with CO (r = 0.8494) and $PM_{2.5}$ (r = 0.9348), reinforcing the idea that industrial emissions and fuel combustion play a key role in the presence of these pollutants. In contrast, SO_2 had a strong negative correlation with RH (r = -0.9527), indicating that humid conditions help reduce SO_2 concentrations, likely due to increased conversion to sulfate aerosols or washout by precipitation. Carbon monoxide (CO) also displayed a significant positive relationship with $PM_{2.5}$ (r = 0.8234), suggesting that incomplete combustion processes contribute to both gas and particulate emissions. CO was strongly correlated with temperature (r = 0.9113), indicating that higher temperatures may enhance its accumulation in the atmosphere due to reduced atmospheric dispersion. However, CO showed a notable negative correlation with RH (r = -0.7983), further confirming that humidity plays a role in pollutant removal. Particulate matter ($PM_{2.5}$) was positively correlated with PM_{10} (r = 0.7414) and temperature (r = 0.8052), indicating that both fine and coarse particles share common emission sources and that higher temperatures may contribute to the resuspension of particulate matter. However, $PM_{2.5}$ had a strong negative correlation with RH (r = -0.9860), emphasizing the role of moisture in settling particulate pollutants from the atmosphere. Lastly, temperature showed a moderate positive correlation with NO_2 (r = 0.7090) and SO_2 (r = 0.8466), suggesting that elevated temperatures may promote the formation and persistence of these gaseous pollutants. However, temperature was negatively correlated with RH (r = -0.7448), which is expected since higher humidity levels are typically associated with lower temperatures in tropical climates.

Table 3: Karl Pearson Correlates of Meteorological indices and air Pollutants (Wet season)

	NO2	SO2	CO	$PM_{2.5}$	PM_{10}	RH	Temperature
NO2	1						
SO2	0.940926	1					
CO	0.62589	0.849366	1				
$PM_{2.5}$	0.857318	0.934797	0.823425	1			
PM_{10}	0.30733	0.473187	0.595682	0.741392	1		
RH	-0.88971	-0.95272	-0.79834	-0.98602	-0.67495	1	
Temperature	0.708978	0.846603	0.911331	0.805244	0.47979	-0.7448	1

Correlation between Meteorological Indices and Air Pollutants (Dry Season)

During the dry season, NO_2 demonstrated a strong positive correlation with CO (r = 0.9098) and $PM_{2.5}$ (r = 0.8169), indicating that vehicle emissions and combustion activities are dominant sources. Additionally, NO_2 was positively correlated with PM_{10} (r = 0.8094), suggesting that fine and coarse particulates may be influenced by common meteorological conditions, such as atmospheric stability. However, NO_2 exhibited a strong inverse correlation with RH (r = -0.9217), confirming that lower humidity levels in the dry season favor pollutant accumulation due to a reduced washout. Similarly, SO_2 displayed a moderate positive correlation with NO_2 (r = 0.8142) and CO (r = 0.6767), implying that industrial emissions contribute to both gaseous pollutants. However, SO_2 had a negative correlation with RH (r = -0.6984), reinforcing the idea that higher humidity enhances the removal of sulfur-based pollutants from the atmosphere. Carbon monoxide (CO) showed a strong positive correlation with $PM_{2.5}$ (r = 0.8915), indicating that incomplete combustion processes contribute significantly to fine particulate pollution. CO also exhibited a moderate positive correlation with PM_{10} (r = 0.6326), suggesting that resuspended dust and emissions from biomass burning may increase both CO and larger particulate matter concentrations. CO had a strong negative correlation with RH (r = -0.9414), highlighting the impact of dry conditions in increasing pollutant retention in the lower atmosphere. Particulate matter ($PM_{2.5}$) had a strong positive correlation with PM_{10} (r = 0.7856), further confirming that both fine and coarse particulates share common sources. However, $PM_{2.5}$ showed a strong negative correlation with RH (r = -0.9369), emphasizing the efficiency of precipitation in removing fine particulate pollutants from the air. PM_{10} was negatively correlated with RH (r = -0.8352), suggesting that lower humidity in the dry season enhances dust re-suspension and particulate accumulation. Temperature, however, had little correlation with NO_2 (r = -0.0473) but showed a weak positive correlation with CO (r = 0.2679). Overall, the strong inverse relationships between RH and pollutants in both seasons indicate that humidity plays a major role in regulating air quality, while positive correlations between pollutants suggest common emission sources, primarily from vehicular and industrial activities.

Table 4: Karl Pearson Correlates of Meteorological indices and Air Pollutants (Dry Season)

	NO2	SO2	CO	$PM_{2.5}$	PM_{10}	RH	Temperature
NO2	1						
SO2	0.814231	1					
CO	0.909775	0.676725	1				
$PM_{2.5}$	0.816894	0.416355	0.891492	1			
PM_{10}	0.809445	0.584009	0.632637	0.785576	1		
RH	-0.92172	-0.69837	-0.94141	-0.93691	-0.83518	1	
Temperature	-0.04727	0.100118	0.267882	-0.06845	-0.5535	0.012074	1

Discussion

The results of this study reveal marked seasonal and spatial variations in air pollutant concentrations across different wetland sites in Eket, underscoring the influence of meteorological parameters on air quality. Notably, pollutant concentrations (particularly NO_2, SO_2, CO, $PM_{2.5}$, and PM_{10}) were significantly elevated during the dry season compared to the wet season. This pattern was evident at sites such as Ataobong and Marina, where levels of NO_2 (0.623 µg/m³), SO_2 (0.851 µg/m³), and CO (6.750–8.859 µg/m³) were substantially higher in the dry season than at other sites or seasons. The persistence of these high values can be attributed to reduced relative humidity (RH), limited precipitation, and increased atmospheric stability that inhibit pollutant dispersion and promote accumulation. This phenomenon is similarly with documented evidence by Chamseddine *et al.* (2019) and Sahin *et al.* (2021).

During the wet season, pollutant levels declined significantly. For example, NO_2 concentrations dropped to 0.14 µg/m³ at Ikot Udota, while SO_2 was below detectable limits at both Ikot Udota and Etebi. The higher RH (peaking at 91.42% at Etebi) and frequent rainfall during this period likely enhanced pollutant washout through wet deposition, especially for water-soluble gases like SO_2 and NO_2, in line with findings by Landim *et. al.* (2020) and Dhital *et. al.* (2022). The inverse relationship between RH and pollutant concentration was statistically confirmed through Pearson correlation analysis, which showed strong negative correlations between RH and SO_2 (r = -0.9527), NO_2 (r = -0.8897), and $PM_{2.5}$ (r = -0.9860) in the wet season.

Carbon monoxide (CO) displayed unique seasonal pattern. Although dry season concentrations were notably high around Marina wetland, the highest wet season value was unexpectedly associated with Ataobong wetland, suggesting localized emission sources, possibly due to ongoing industrial activities. However, its atmospheric persistence was still modulated by meteorological factors, with temperature and RH exerting significant control. CO was positively correlated with temperature (r = 0.9113) and negatively with RH (r = -0.7983) during the wet season, affirming that higher temperatures promote CO accumulation due to decreased vertical mixing and chemical transformation to CO_2, a trend supported by Signori *et al.* (2023).

Particulate matter followed a similar seasonal pattern. Dry season PM_{10} peaked at Ikot Ibiok (188.34 µg/m³), while $PM_{2.5}$ reached 114 µg/m³ at Ataobong. These values far exceeded both WHO and NESREA thresholds, signaling substantial air quality deterioration. The likely sources include vehicular emissions, industrial dust, and biomass burning, especially under the dry season's stagnant atmospheric conditions. In the wet season, PM levels dropped significantly, further affirming the role of precipitation in pollutant removal. Strong positive correlations between $PM_{2.5}$ and CO (r = 0.8234) and between $PM_{2.5}$ and PM_{10} (r = 0.7414) support the hypothesis that they share combustion-related origins (Losacco and Perillo, 2018; Liu et al., 2020).

Correlation data from both seasons further emphasize the synergistic roles of pollutants and meteorological drivers. For instance, in the dry season, NO_2 had strong positive correlations with $PM_{2.5}$ (r = 0.8169) and PM_{10} (r = 0.8094), suggesting atmospheric stability promotes the coexistence of these pollutants. RH was again negatively correlated with most pollutants, particularly CO (r = -0.9414), highlighting the season's vulnerability to pollution accumulation.

These results confirm that Eket's lower atmosphere is significantly affected by seasonal climatic shifts. Industrial emissions and vehicular activities remain constant, but their impact is modulated by meteorological parameters. Dry season pollution poses serious environmental and public health risks, especially in urbanized areas such as Marina and Ataobong. In line with this, Song *et al.* 2023, Chen *et al.* 2020 and Hu *et al.* 2024 opined that elevated pollutant concentrations particularly ($PM_{2.5}$, NO_2, and CO) have been grossly linked to increased rates of respiratory and cardiovascular illnesses, hospital admissions, and premature mortality. Furthermore, high SO_2 and NO_2 levels increase the risk of acid rain, which may damage ecosystems and reduce agricultural productivity (Kawichai *et al.* 2023). These findings underscore the importance of integrating seasonal and site-specific meteorological data into air quality monitoring systems to guide public health interventions and environmental policy in Eket and similar tropical cities.

CONCLUSION

This study has demonstrated that meteorological parameters significantly influence air pollutant concentrations in Eket, with higher pollution levels recorded during the dry season due to lower humidity, reduced dispersion, and increased atmospheric stability. Strong positive correlations between NO_2, SO_2, CO, and $PM_{2.5}$ indicate common emission sources, while strong negative correlations with RH suggest that humidity plays a critical role in pollutant removal. Given these findings, targeted air quality management strategies are necessary to mitigate pollution levels, particularly during the dry season. Emission control measures, such as stricter vehicular emissions regulations, industrial air quality monitoring, and the promotion of clean energy sources, should be implemented. Additionally, wetland conservation is essential, as these ecosystems act as natural air filters, reducing pollutant concentrations and enhancing environmental resilience. Public awareness campaigns should also be conducted to educate residents on the health risks associated with air pollution and encourage preventive measures, such as reducing outdoor activities during peak pollution periods. Establishing real-time air quality monitoring systems would further help in early detection and mitigation of air pollution risks.

REFERENCES

Ahmad, M., Ahmad, W., Ahmad, S., Jamal, S., and Saqib, M. (2024). Tracing the roots of wetland degradation in India: a systematic review of anthropogenic drivers, ecological consequences and conservation strategies. *Geo Journal*, 89, 1-20. https://doi.org/10.1007/s10708-024-10997-9.

Anwana, E. D., Mbong, E. O and Etim, N. (2020). Trends in Macrophyte Diversity in Anthropogenic Perturbed Lentic ecosystems within Uyo Metropolis. *Journal of Environmental and Waste Management,* 7(1): 339 – 344.

Bullock, W. (2024). 258 An evaluation of respirable and submicron elemental carbon measured using the NIOSH analytical method 5040 in low concentration diesel environments. *Annals of Work Exposures and Health*. https://doi.org/10.1093/annweh/wxae035.252.

Chamseddine, A., Alameddine, I., Hatzopoulou, M., and El-Fadel, M. (2019). Seasonal variation of air quality in hospitals with indoor–outdoor correlations. *Building and Environment*. https://doi.org/10.1016/J.BUILDENV.2018.11.034.

Chen, K., Breitner, S., Wolf, K., Stafoggia, M., Sera, F., Vicedo-Cabrera, A., Guo, Y., Tong, S., Lavigne, É., Matus, P., Valdés, N., Kan, H., Jaakkola, J., Ryti, N., Huber, V., Scortichini, M., Hashizume, M., Honda, Y., Nunes, B., Madureira, J., Holobâcă, I., Fratianni, S., Kim, H., Lee, W., Tobías, A., Íñiguez, C., Forsberg, B., Åström, C., Ragettli, M., Guo, Y., Chen, B., Li, S., Milojevic, A., Zanobetti, A., Schwartz, J., Bell, M., Gasparrini, A., and Schneider, A. (2020). Ambient carbon monoxide and daily mortality: a global time-series study in 337 cities.. *The Lancet. Planetary Health*, 5 4, e191-e199 . https://doi.org/10.1016/S2542-5196(21)00026-7.

Day, J., Arancibia, A., Mitsch, W., Lara-Domínguez, A., Day, J., Ko, J., Lane, R., Lindsey, J., and Lomeli, D. (2003). Using ecotechnology to address water quality and wetland habitat loss problems in the Mississippi basin: a hierarchical approach. *Biotechnology advances*, 22 1-2, 135-59. https://doi.org/10.1016/J.BIOTECHADV.2003.08.012.

Department of Statistics (DOS-AKSG) (2013) Statistical Year Book of Akwa Ibom State of Nigeria. Ministry of Economic Development. Uyo. P. 11

Dhital, N., Bhattarai, D., Sapkota, R., Rijal, K., Byanju, R., and Yang, H. (2022). Comparing the Change in Air Quality during the COVID-19 Lockdown between Dry and Wet Seasons in Nepal. *Aerosol and Air Quality Research*. https://doi.org/10.4209/aaqr.220201.

Dias, D., and Tchepel, O. (2018). Spatial and Temporal Dynamics in Air Pollution Exposure Assessment. *International Journal of Environmental Research and Public Health*, 15. https://doi.org/10.3390/ijerph15030558.

Edem, E. N., Mbong, E. O. and Olaniyan, U. O. (2021). Environmental and Human behavioral Factors associated with Vulvovaginal Candidiasis among Single and Married Women in Eket. *Global Journal of Infectious Disease and Clinical Research.* 7(1): 037 – 042.

Hu, M., Lu, X., Chen, Y., Chen, W., Guo, C., Xian, C., and Fung, J. (2024). High spatiotemporal resolution estimation and analysis of global surface CO concentrations using a deep learning model.. *Journal of environmental management*, 371, 123096 . https://doi.org/10.1016/j.jenvman.2024.123096.

Kawichai, S., Sillapapiromsuk, S., and Bootdee, S. (2023). Health Risk Assessment of Gaseous Pollutants in the Ambient Environment of Rayong City, Thailand: The Initiative of the EEC Area. *Applied Science and Engineering Progress*. https://doi.org/10.14416/j.asep.2023.02.009.

Kurmi, O., Lam, K., and Ayres, J. (2020). Air pollution and health. *Occupational and environmental medicine*, 57 6, 431C . https://doi.org/10.1016/b978-0-12-352335-8.x5074-1.

Landim, A., Teixeira, E., Agudelo-Castañeda, D., Schneider, I., Silva, L., Wiegand, F., and Kumar, P. (2018). Spatio-temporal variations of sulfur dioxide concentrations in industrial and urban area via a new statistical approach. *Air Quality, Atmosphere and Health*, 11, 801-813. https://doi.org/10.1007/s11869-018-0584-2.

Liu, P., Ye, C., Xue, C., Zhang, C., Mu, Y., and Sun, X. (2020). Formation mechanisms of atmospheric nitrate and sulfate during the winter haze pollution periods in Beijing: gas-phase, heterogeneous and aqueous-phase chemistry. *Atmospheric Chemistry and Physics*, 20, 4153-4165. https://doi.org/10.5194/ACP-20-4153-2020.

Losacco, C., and Perillo, A. (2018). Particulate matter air pollution and respiratory impact on humans and animals. *Environmental Science and Pollution Research*, 25, 33901-33910. https://doi.org/10.1007/s11356-018-3344-9

Mbong, E. O., Ogbemudia, F. O., Okon, J. E. and Umoren, U. B. (2013). Evaluation of concentration of Heavy metals in Leaf Tissues of three improved Varieties of *Manihot esculenta* Crantz E3 journal of Environmental Research and Management 4(3): 214 -216.

Mbong, E. O., Akpan, E. E. and Osu, S. R. (2014a). Soil-Plant Heavy Metals Relations and Transfer Factor Index of Habitats Densely Distributed with *Citrus reticulata* (tangerine). *Journal of Research in Environmental Science and Toxiciology,* 3(4): 61- 65.

Mbong, E. O, Ogbemudia, F. O and Essang, Q. (2014b). Biometric Edaphological Assesment: The Role of Soil Properties on the Synthesis of Essential Molecules in Nigerian *Gnetum* species. *International Journal of Research* 2(5): 217-222.

Mbong, E. O., Osu, S. R., Uboh, D. G. and Ekpo, I. (2020). Abundance and distribution of species in relation to soil properties in sedge-dominated habitats in Uyo Metropolis, Southern Nigeria. *Global Journal of Ecology,* 5 (1), 24 – 29.

Mbong, E. O., Ivon, E. A. Idio, E., Utuk, K. E. Okon, J. E. and Anwana, E. D. (2023) Correlating Habitat Dynamism with Foliar Anatomical Modualtions: A study with *Phymatosorus scolopendria* (Burm. F.) CHING. *World Journal of Science and Technology,* 15(1): 61- 68.

Ngele, S., O. (2015). Ambient Air Particulate Matter Levels in Selected Urban Centres of Niger Delta Region, Nigeria.

Ogbemudia, F. O., Anwana E. D., Onyebule, C. L., and Mbong, E. O. (2025). Epiphytic Vascular Cryptogams as Bioindicators of Atmospheric Heavy Metals Pollution in Eket Wetllands, Nigeria. *Asian Journal of Research in Botany,* 8 (1): 214 – 226.

Ogbemudia, F.O; Anwana, E.D., Mbong, E.O and Joshua, E.E. (2014). Plant Diversity Status and Soil Physicochemistry in a Flood Plain. *International Journal of Research,* 1(10): 1977 – 1985.

Okon, G. O., Archibong, B. F. , Antia , U. E., Rhouma, A. , Okon J. E., Mbong, E. O., Ite, A. E. , Bassey, H O. (2024).Lichen Diversity, Substrate Preference and Environmental Dynamics as Indicators of Air Quality. *Dutse Journal of Pure and Applied Sciences (DUJOPAS),* Vol. 10 (2c) : 176 – 187.

Papaconstantinou, R., Demosthenous, M., Bezantakos, S., Hadjigeorgiou, N., Costi, M., Stylianou, M., Symeou, E., Savvides, C., and Biskos, G. (2023). Field evaluation of low-cost electrochemical air quality gas sensors under extreme temperature and relative humidity conditions. *Atmospheric Measurement Techniques*. https://doi.org/10.5194/amt-16-3313-2023.

Paralovo, S., Barbosa, C., Carneiro, I., Kurzlop, P., Borillo, G., Schiochet, M., Godoi, A., Yamamoto, C., De Souza, R., Andreoli, R., Ribeiro, I., Manzi, A., Kourtchev, I., Bustillos, J., Martin, S., and Godoi, R. (2019). Observations of particulate matter, NO2, SO2, O3, H2S and selected VOCs at a semi-urban environment in the Amazon region.. *The Science of the total environment*, 650 Pt 1, 996-1006. https://doi.org/10.1016/j.scitotenv.2018.09.073.

Şahin, E., Özyürek, B., and Dulkadir, B. (2021). Do meteorological changes and air pollution increase the risk of pneumonia?. *Tuberkuloz ve toraks*, 69 1, 21-29. https://doi.org/10.5578/tt.20219903.

Signori, R., Souza, R., Souza, R., Ribeiro, I., and Kayano, M. (2023). Carbon monoxide profile variability over the Manaus Metropolitan Region and its relations with biomass burning. *Revista Brasileira de Ciências Ambientais*. https://doi.org/10.5327/z2176-94781534.

Song, J., Qiu, W., Huang, X., Guo, Y., Chen, W., Wang, D., and Zhang, X. (2023). Association of ambient carbon monoxide exposure with hospitalization risk for respiratory diseases: A time series study in Ganzhou, China. *Frontiers in Public Health*, 11. https://doi.org/10.3389/fpubh.2023.1106336.

Sunday, I and Omode, E (2022).Assessment of Air Quality across different Landuses in Gwagwalada Town, FCT-Abuja, Nigeria. *FUDMA Journal of Sciences*, 6(1): 377 -386. http://doi.org/10.33003/fjs-2022-0601-909.

Wu, B., Zhao, S., Liu, Y., and Zhang, C. (2025). Do meteorological variables impact air quality differently across urbanization gradients? A case study of Kaohsiung, Taiwan, China. *Heliyon*, 11. https://doi.org/10.1016/j.heliyon.2025.e41694.

Xu, X., Chen, M., Yang, G., Jiang, B., and Zhang, J. (2020). Wetland ecosystem services research: A critical review. *Global Ecology and Conservation*, 22. https://doi.org/10.1016/j.gecco.2020.e01027.

Zhang, W., Li, H., Xu, D., and Xia, T. (2024). Wetland Destruction in a Headwater River Leads to Disturbing Decline of In-stream Nitrogen Removal.. *Environmental science and technology*. https://doi.org/10.1021/acs.est.3c07404.

Zhou, W., Chen, C., Lei, L., Fu, P., and Sun, Y. (2020). Temporal variations and spatial distributions of gaseous and particulate air pollutants and their health risks during 2015-2019 in China. *Environmental pollution*, 116031. https://doi.org/10.1016/j.envpol.2020.116031.