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Article

Criteria air pollutants on Bonny Island: gas flaring - a contributor

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Abstract

Bonny Island is a typical oil and gas-producing community in the Niger Delta region of Nigeria, where gas flaring has been practiced for decades. In this study, the concentrations of five criteria air pollutants and hydrogen sulfide were measured at six locations on the island using air quality test kits, and the results were compared with the World Health Organization's permissible standards. The air pollutants considered were hydrogen sulfide (H_2S), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ground-level ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}). The study revealed that SO2 levels on the island were low, remaining below the acceptable limit of 40 µg/m³. Although the atmospheric concentrations of CO were within the permissible standard of 4 mg/m³, they were found to be close to the upper limit in most areas. However, at nearly all the locations, the levels of ground-level O_3, H_2S, NO_2, $PM_{2.5}$ and PM_{10} exceeded the permissible limits. In the case of NO_2, the situation was particularly severe in Finima, likely due to the concentration of industrial activities in that area. The elevated levels of these criteria pollutants are primarily attributed to gas flaring, which poses serious health risks and environmental consequences. It is therefore recommended that effective measures be implemented to reduce the emission of pollutants into the atmosphere, and that concerted efforts be made to halt gas flaring in oil and gas-producing communities in the Niger Delta to mitigate air pollution.

Keywords: *pollutants, ozone, carbon monoxide, particulate matter, nitrogen dioxide*

INTRODUCTION

Air is essential for the sustainability of life on Earth, but its quality is often compromised by pollution. Air pollution can be defined as the presence of one or more contaminants—or a combination of contaminants—in concentrations that are harmful to humans, animals, plants, and the ecosystem. Air pollutants are generally categorized as either primary or secondary. Primary pollutants are directly emitted from natural events, such as volcanic eruptions, or human activities, such as the combustion of fossil fuels. In contrast, secondary pollutants are formed through chemical reactions involving primary pollutants and components of the natural atmosphere.
Examples of primary pollutants include carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2), while secondary pollutants include compounds such as sulfuric acid (H_2SO_4), nitric acid (HNO_3), and ozone (O_3).

Criteria Air Pollutants

Criteria air pollutants are major pollutants for which ambient air standards have been set to protect man and the environment. There are six criteria air pollutants and they are CO, O_3, NO_2, SO_2, lead

(Pb) and PM. The importance of five of these air pollutants are briefly highlighted. CO is a colorless, odorless, non-irritating and a harmful gas that is released into the atmosphere due to incomplete combustion of fossil fuels [1]. Inhaling CO can result in respiratory and heart problems and can lead to death if it is not properly managed early enough. CO attacks the hemoglobin of the red blood cells by displacing oxygen and reducing the oxygen carrying capacity of blood, hence inhaling large doses of it is fatal [1].

SO_2 is an oxide of sulfur that is emitted into the atmosphere through burning of fossil fuels in power plants, industrial processes of metal extraction from ores and from volcanic activities [1]. SO_2 in air reacts with atmospheric gases to form sulfuric acid which dissolves in rainwater to give acid rain, causing damage to plants, structures, the ecosystem and environment. High concentrations of SO_2 in air react with other compounds in the atmosphere to form small particulate matters that cause fog and reduced visibility. Inhaling SO_2 causes respiratory problems especially for asthmatic patients, the elderly, children and those with cardiovascular diseases [1].

NO_2 is formed and released into the atmosphere during the high-temperature combustion of fossil fuels in vehicles and power plants [1]. It is one of the nitrogen oxides (NO_x) and is highly reactive, capable of reacting with other atmospheric gases to form compounds such as NO_3, N_2O_5 and HNO_3. When inhaled at high concentrations, NO_2 can cause respiratory, cardiovascular, and lung problems. Additionally, it contributes to acid rain, reduced visibility, fog formation, and the suppression of plant growth [1].

There are two types of ozone: good ozone and bad ozone [2]. Good ozone is found in the Earth's stratosphere and protects living organisms by blocking harmful ultraviolet radiation from the sun. Ground-level ozone, often referred to as bad ozone, is one of the six criteria air pollutants and is associated with various health problems [2]. Ground-level ozone is the focus of this study because it is a secondary air pollutant, a greenhouse gas, and a reactive oxidant gas formed in the atmosphere through sunlight-driven reactions involving CO, NO_x, CH_4, and volatile organic compounds (VOCs). High concentrations of ozone in the atmosphere can cause headaches, coughing, and respiratory problems. Ozone acts as a pulmonary irritant, affecting the respiratory mucous membranes, lung tissues, respiratory function, and other aspects of health. Additionally, ozone is harmful to plants [2].

Particulate matter consists of suspended mixtures of solid particles and liquid droplets in the air, including soot, smoke, dust, and dirt [3]. These particles are emitted into the environment through various sources such as construction activities, smokestacks, burning fires, fossil fuel combustion, power plants, gas flaring, unpaved roads, iron and steel mills, mining operations, and volcanic activity. When inhaled, particulate matter can aggravate respiratory and cardiovascular diseases. Additionally, high concentrations of particulate matter in the atmosphere reduce visibility and contribute to the formation of fog [3].

Inhaled particulate matter is classified into two size categories: fine and coarse particles. Fine particles, known as $PM_{2.5}$, have a diameter of 2.5 μm or less (≤ 2.5 μm), while coarse particles, known as PM_{10}, have a diameter of 10 μm or less (≤ 10 μm). The major components of fine particles include sulphates, carbonaceous materials, nitrates, trace elements, and water. Coarse particles are primarily composed of aluminosilicates and oxides of crustal elements found in soil and dust. $PM_{2.5}$ has been associated with increased mortality and morbidity and is considered more hazardous to human health than PM_{10} because it can penetrate deeply into the lungs when inhaled [1, 4].

H_2S is a colourless gas with a characteristic odour of rotten eggs and is heavier than air. It is highly toxic at elevated concentrations and is both an industrial and environmental pollutant, though it is not classified among the six criteria air pollutants. H_2S has toxic effects on the respiratory tract, brain, eyes, and olfactory system, and is considered a broad-spectrum pollutant. Further discussions on the health and environmental toxicity of H_2S can be found in the scientific literature [5, 6]. Although H_2S is not a criteria air pollutant, it is included in the present study due to its high toxicity and frequent occurrence during oil and gas production.

Gas flaring: a source of air pollution in the Niger Delta

One of the major sources of air pollution in oil and gas producing communities in Africa and other developing countries is gas flaring. Gas flaring is the burning of associated natural gas (composed mainly of methane) produced during oil exploitation as a means of disposal. It is a deliberate act by oil producing companies to dispose the associated natural gas since better options for handling the gas are not immediately convenient. Gas flaring mainly produces carbon dioxide (CO_2) and water vapour which are greenhouse gases. CO_2 is a primary greenhouse gas which has been reported to be responsible for the increased global atmospheric temperature that has led to global warming in recent times [7÷9]. Any unburnt methane that escapes into the atmosphere during gas flaring increases the effects of global warming because methane is many times more potent than CO_2.

During gas flaring operations, some quantity of other air pollutants escapes as emissions into the atmosphere. These air pollutants include hydrogen, hydrocarbons, unburnt fuel components of methane, non-methane VOCs, sulphur dioxide and by-products of combustion process such as sooth, carbon monoxide and oxides of nitrogen [10].

In Oyibo, an area of the Niger Delta in Rivers State, Nigeria, the effect of gas flaring on air quality has been studied. Conducted air quality sampling in the area showed that the annual average of NO_x and SO_x emissions ranged between 81μg/m^3 to 150μg/m^3 and 92μg/m^3 to 430μg/m^3 respectively which sometimes exceeded the acceptable limits [8]. Hence, gas flaring introduces pollutants into the air and these air pollutants have different health and environmental effects which have been discussed in various literatures [11÷21].

Gas flaring is a common sight in oil and gas producing communities of the Niger Delta region of Nigeria. It has been identified as a major contributor to increased concentration of atmospheric CO_2, CO and NO_x in the Niger Delta region of the country. Studies have shown that the concentrations of these air pollutants often exceed the National Air Quality Standards (NAQS) in Nigeria [22]. In an air quality study conducted on the Island, it was reported that the concentrations of SO_2, CO_2 and particulate matter exceeded the WHO and USEPA limits for criteria air pollutants [23]. Another air quality study conducted on Bonny Island due to the vast industrial operations by Nigerian Liquefied Natural Gas (NLNG) has shown that the compounds likely to be emitted into the surrounding atmosphere are particulate matter (PM_{10} and $PM_{2.5}$), CO_2, CO, NO_x, and SO_x [24].

Bonny Island, particularly the Finima area, is home to several multinational oil companies as well as the NLNG company, which operates the largest liquefied natural gas plant in Nigeria. Finima hosts major international oil companies such as Shell, ExxonMobil, Chevron, TotalEnergies, and Agip, all attracted by the abundant oil and gas reserves in the region. The crude oil produced around the island, known as Bonny Light oil, is highly valued on the international market. As a result, Bonny Island serves as a significant national revenue-generating center for Nigeria due to the extensive oil and gas industrial activities taking place there. The presence of these companies has also attracted numerous service providers, particularly with the ongoing expansion projects at the NLNG site in Finima.

However, Bonny Island is susceptible to environmental degradation associated with oil and gas industries, and its residents face the consequences of pollution, including air pollution. Despite the fact that wind helps to dilute, disperse, and carry away pollutants, and frequent rainfall absorbs and washes some pollutants into the soil and ocean, it remains essential to study the air quality of this area to better understand and manage the impact of industrial activities on the environment and public health.

This paper focuses specifically on criteria air pollutants and their atmospheric concentrations on Bonny Island, compared against the acceptable limits set by the World Health Organization (WHO). The criteria air pollutants considered in this study are CO, NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$. The 24hour concentration of these compounds on six locations on the Bonny Island constitute the focus in this study.

MATERIALS AND METHODS

Studied Area

Bonny is a historic coastal town in West Africa, located in Rivers State, one of the nine states in the Niger Delta region of Nigeria. Figure 1(A) presents the map of Nigeria, highlighting the Niger Delta region with Rivers State (9) situated between Bayelsa State (3) and Akwa Ibom State (2) in the southern part of the country. An enlarged map of Rivers State is shown in Figure 1(B), indicating the precise location of Bonny Island within the state. Figure 1(C) illustrates Bonny's position relative to the Atlantic Ocean. Due to its strategic coastal location, Bonny Island serves as a major terminal for the export of oil and gas from Nigeria.

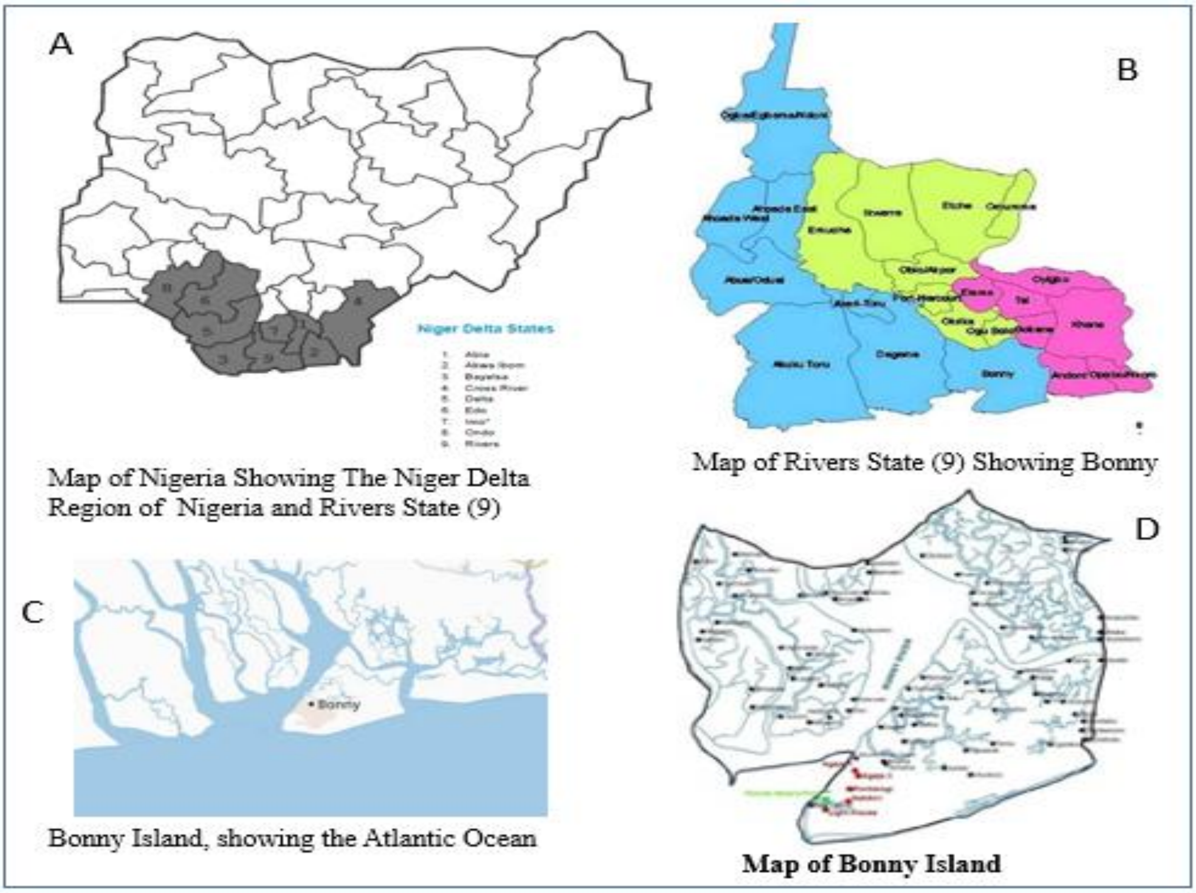

Fig. 1. Location of Bonny Island in the Niger Delta Region of Nigeria

An enlarged map of Bonny Island is shown in Figure 1(D). The island covers a total area of approximately 645.6 km² and has a population of well over 200,000 people. It experiences an average atmospheric humidity of about 92%. Bonny Island is situated approximately 40 km southwest of Port Harcourt, the capital of Rivers State, and lies at Latitude 4°24'5.76"N and Longitude 7°10'14.66"E. It borders the shores of the southern Atlantic Ocean, into which its main river, the Bonny Estuary, flows. The island is located in the Bight of Bonny and is divided into two segments: the mainland (township) and the hinterland (surrounding villages). The mainland consists of Bonny (Okoloama) and Finima.

The study was conducted on Bonny Mainland (township), not in the hinterlands. Three locations for air sampling were selected in Finima (F1, F2 and F3) and three locations were selected in Bonny (B1, B2 and B3). The location coordinates of the selected areas are presented on Table 1.

Table 1. Location coordinates of sample sites on Bonny Island

Location	Longitude	Latitude	Location	Longitude	Latitude
F1	4°24'02.2"N	7°08'57.2"E	**B1**	4°25'57.2"N	7°10'45.2"E
F2	4°24'04.6"N	7°08'39.8"E	**B2**	4°26'23.5"N	7°09'59.0"E
F3	4°24'11.7"N	7°08'16.2"E	**B3**	4°27'13.8"N	7°10'16.2"E

Fig. 2. Map location of sampling points (F1, F2, F3, B1, B2, B3), source: Google Maps

Methods applied

Air sampling was carried out at the six selected locations repeatedly at 24-hour intervals using air quality test equipment. Prior to deployment, all air quality sampling equipment were calibrated and then installed at the designated sites. The criteria air pollutants measured at each location included CO, NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$.

Three types of air quality monitoring equipment were used:

1. Bosean air quality equipment (Zhengzhon, Henan Province, China) for measuring CO, SO_2, and NO_2 (detection sensitivity: 1mg for CO; 1µg for SO_2 and NO_2; accuracy $\leq \pm 5\%$);
2. Bosean air quality equipment (Zhengzhon, Henan Province, China) for measuring O_3 and H_2S (detection sensitivity: 1µg for O_3 and H_2S; accuracy $\leq \pm 5\%$);
3. HTI Particle counter HT-9000 for measuring particulate matter (PM_{10} and $PM_{2.5}$). Accuracy particle size detection: evaluates $PM_{2.5}$, $PM_{0.3}$, and PM_{10} particles with measurement error: < ±20%, detection sensitivity: 1ug, ensuring precise air quality readings.

Although H_2S is not classified as a criteria air pollutant, its atmospheric concentrations were also measured at each location due to its high toxicity and frequent occurrence during oil and gas production.

Reference limit values

The concentrations of the measured air pollutants were compared against the WHO standards for ambient air quality, using the environmentally permissible limits [25]. It is important to note that the

permissible limit for H_2S, which is 0.15 mg/m³ [26], is not included in Table 2, as H_2S is not classified as a criteria air pollutant.
An interim target (Table 2) refers to a concentration level of an air pollutant that is associated with a measurable reduction in health risks. These targets act as transitional milestones in the gradual reduction of air pollution, guiding progress toward achieving full compliance with air quality guideline levels. They are particularly useful in regions with high pollution levels, where immediate attainment of guideline standards may not be feasible. Interim targets are intentionally set higher than the recommended guideline values but provide realistic and achievable benchmarks for authorities to implement effective pollution control strategies. Importantly, these targets should be viewed as temporary steps—not final goals—on the path to reaching the established air quality guidelines [25].

Table 2. The WHO Recommended Limits (AQG level) for Criteria Air Pollutants [25]

Pollutant	Averaging time	Interim Target 1	Interim Target 2	Interim Target 3	Interim Target 4	AQG Level
$PM_{2.5}$, μg/m³	Annual	35	25	15	10	5
	24-hours	75	50	37.5	25	15
PM_{10}, μg/m³	Annual	70	50	30	20	15
	24-hours	150	100	75	50	45
O_3 μg/m³	Peak Session	100	70	-	-	60
	8-hours	160	120	-	-	100
NO_2, μg/m³	Annual	40	30	20	-	10
	24-hours	120	50	-	-	25
SO_2, μg/m³	24-hours	125	50	-	-	40
CO, mg/m³	24-hours	7	-	-	-	4

RESULTS AND DISCUSSION

Results of concentrations of criteria air pollutants determined on Bonny Island during this study are presented in Figures 2 to 4. Graphical plots of the results from the six sampling locations were generated and labelled as F1, F2, F3, B1, B2, and B3. In each set of plots, the WHO standard values—provided in Table 2—were included as reference lines and denoted as “S,” based on a 24-hour averaging time, except for O_3, for which the peak season standard was applied.
The results for H_2S and CO concentrations are presented in Figure 3. As shown, the concentrations of H_2S in most locations exceed the permissible limit of 0.15 mg/m³, indicating the need for urgent and effective measures to reduce its emission into the environment.

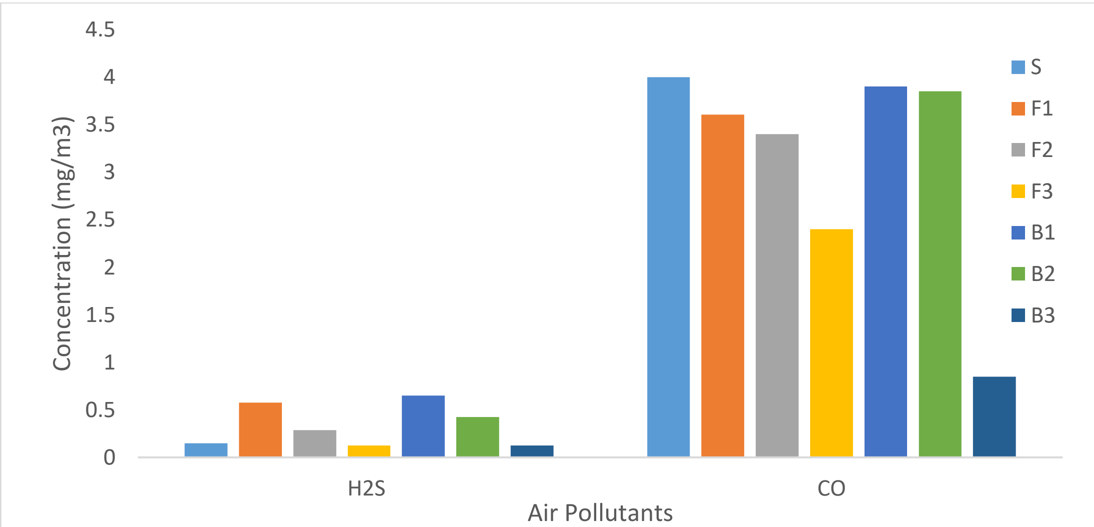

Fig. 3. Results of 24-hour average atmospheric concentrations of H_2S and CO

Carbon monoxide, a criteria air pollutant, has a permissible limit of 4 mg/m³. The results in Figure 3 show that CO concentrations in some locations are approaching this limit, suggesting that strategic actions should be implemented to prevent the limit from being reached or exceeded. Elevated atmospheric CO levels can cause respiratory and cardiovascular issues and, if not properly managed, may become life-threatening.

Figure 4 presents the atmospheric concentrations of NO_2 and SO_2, both of which are classified as criteria air pollutants. According to WHO standards, the permissible limits for NO_2 and SO_2 are 25 µg/m³ and 40 µg/m³, respectively. It is observed that NO_2 levels at all six locations exceed the permissible limit, with the highest concentrations recorded in the Finima area. This may be attributed to the concentration of oil and gas industrial activities currently taking place in Finima.

Exposure to high levels of NO_2 is harmful to both human health and the environment, underscoring the need for operating companies in the area to implement strategic measures to significantly reduce NO_2 emissions.

In contrast, SO_2 concentrations were low across all sampled locations, with values remaining below the 40 µg/m³ limit. Bonny Island experiences a high rate of rainfall, and since SO_2 is water-soluble and forms acids upon dissolution, this may explain the reduced atmospheric levels. This is especially noteworthy given that H_2S—another sulfur-containing compound—exceeded the permissible limit at nearly all sampled locations.

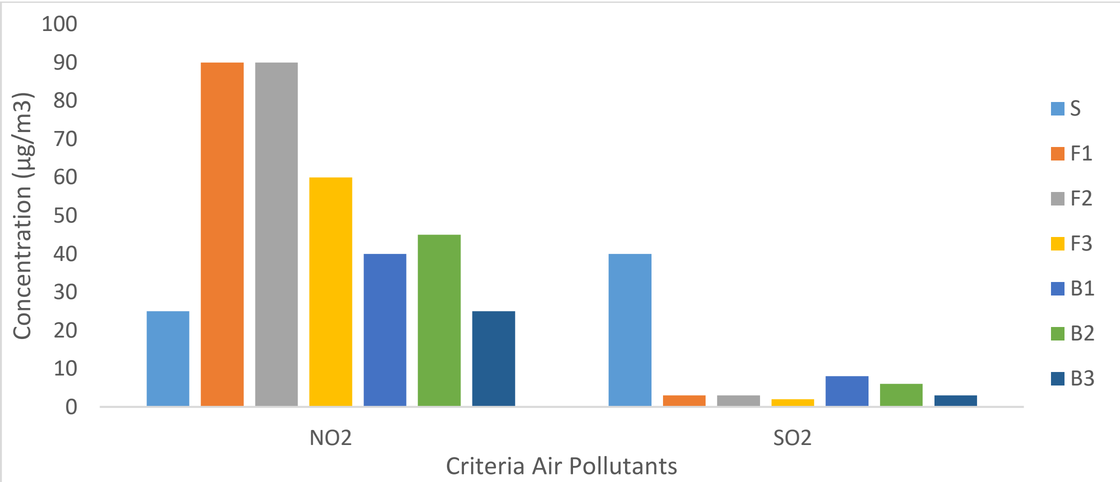

Fig. 4. Results of 24-hour average atmospheric concentrations of NO_2 and SO_2

Figure 5 presents the results for O_3 and PM_{10} and $PM_{2.5}$, all of which are classified as criteria air pollutants. According to WHO standards, the permissible peak level for ground-level O_3 is 60 µg/m³, while the limits for PM_{10} and $PM_{2.5}$ are 45 µg/m³ and 15 µg/m³, respectively.

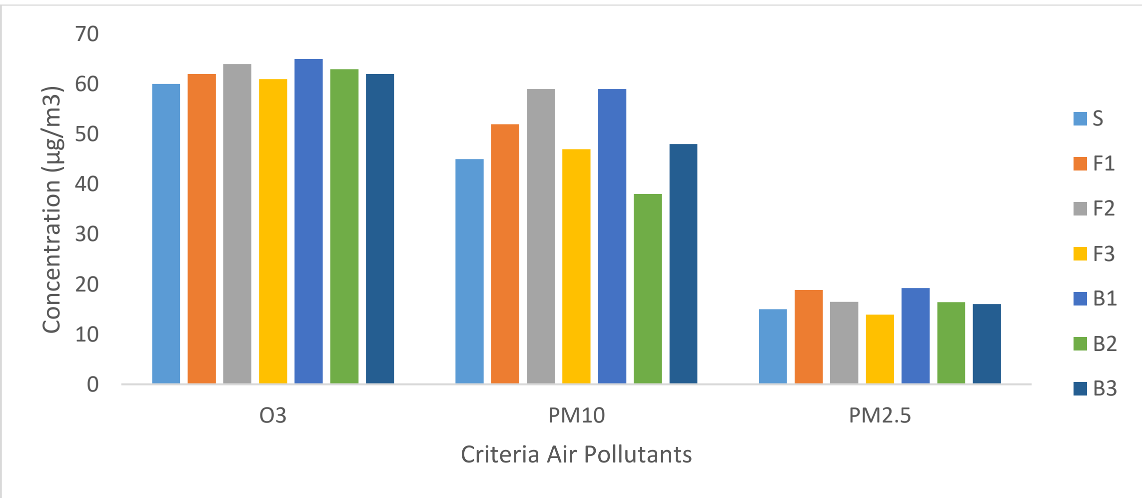

Fig. 5. Results of 24-hour average atmospheric concentrations of O_3, PM_{10} and $PM_{2.5}$

At nearly all sampling locations, these acceptable limits were exceeded for both ground-level ozone and particulate matter. While the O_3 concentrations slightly exceeded the standard, this suggests that existing mitigation measures require enhancement to further reduce emissions. However, the concentrations of PM_{10} and $PM_{2.5}$ were significantly above the permissible levels, indicating a more pressing issue. One major contributing factor is gas flaring, which is prevalent on the island.

This pollution has also affected rainwater quality in the area. The rainwater is often dark in color due to suspended particles and emits a smoky odor after settling, making it unsuitable for consumption [27, 28].

Meteorological factors such as wind direction and speed, temperature, atmospheric pressure, humidity, and rainfall significantly influence pollutant concentrations in a given area. A statistical analysis conducted in a study around Bonny Island indicated that wind speeds are generally moderate, predominantly blowing from the southwest. This wind pattern tends to disperse pollutants toward the northern and northeastern human settlements [23].

Sunshine on Bonny Island is also moderate, although atmospheric temperatures can occasionally be high. The island experiences a high rate of rainfall, which helps regulate average atmospheric temperatures and contributes to the removal of some air pollutants through dissolution. As a result, seasonal variation plays a critical role in air quality, with the likelihood of higher pollutant concentrations during the dry season compared to the rainy season.

To better understand these seasonal dynamics, long-term, seasonal studies of criteria air pollutants are recommended. Such studies, conducted over several years, could support the development of a comprehensive data bank that may be used to create predictive seasonal air quality models for the area.

Other anthropogenic activities on Bonny Island that may have given rise to air pollution aside from oil and gas production operations include transportation and commercial fishing businesses. Generally, the use of fossil fuels for transportation releases pollutants such as CO and NO_2 into the atmosphere. Definitely, this has contributed to the increase in criteria air pollutants on the Island because there are thousands of old vehicles that ply the Island [22]. Presently, the efficient and affordable means of crossing the sea from the Island is by speedboats which use fossil fuels, and there is an airbase in Finima; all of these means of transportation release criteria air pollutants into the atmosphere. Additionally, local fishing business thrives on Bonny Island and the local method of fish drying releases CO_2, smoke and particulate matter into the environment, contributing to air pollution.

Some sources of air pollution on Bonny Island are significant while others are insignificant. For example, air pollution from domestic sources on the Island is insignificant because the primary means of cooking is the use of electric cookers rather than fossil fuels or firewood due to the constant power supply in the town. Waste burning as a means of disposal and burning of farmlands in preparation for a new farming season as practised in some remote areas of Nigeria is not a common practice on the Island. On the other hand, gas flaring and other oil and gas activities are major sources of air pollution in the Niger Delta region of Nigeria including Bonny Island [22]. An area for further studies on this subject will involve investigating the percentage contribution to each criteria air pollutant from different sources on the Island. The sources include domestic activities, transportation, fishing business, waste disposal (such as burning) and activities of the oil and gas industry. This kind of study will quantify the contributions of each air pollution source to criteria air pollutants in oil and gas producing communities in the Niger Delta.

In addition to oil and gas production activities, other anthropogenic sources of air pollution on Bonny Island include transportation and commercial fishing. The use of fossil fuels for transportation is a known contributor to atmospheric pollutants such as CO and NO_2. This is particularly relevant on Bonny Island, where thousands of aging vehicles operate daily [22]. Currently, the most efficient and affordable means of crossing the sea from the island is by speedboat, which also relies on fossil fuels. Additionally, there is an airbase located in Finima. Each of these modes of transportation contributes to the release of criteria air pollutants into the atmosphere.

The local fishing industry also plays a role in air pollution. Traditional fish-drying methods release CO_2, smoke, and particulate matter into the environment, further exacerbating air quality issues.

While some pollution sources are significant, others are relatively minor. For instance, air pollution from domestic sources on Bonny Island is considered negligible, primarily because electric cookers—rather than firewood or fossil fuels—are commonly used, as result to the town's stable electricity supply. Practices such as open waste burning or burning farmland for cultivation, which are common in other remote areas of Nigeria, are not prevalent on the island.

However, gas flaring and other oil-related activities continue to be major pollution sources across the Niger Delta region, including Bonny Island [22].

An important area for further research would involve assessing the percentage contribution of each pollution source to the levels of criteria air pollutants on the island. These sources may include domestic activities, transportation, fishing operations, waste disposal methods, and oil and gas industry activities. Such a study would provide valuable data for quantifying pollution sources and guiding air quality management strategies in oil and gas-producing communities in the Niger Delta.

This study has also demonstrated that environmental pollution resulting from oil and gas activities has negatively impacted the air quality of Bonny Island, which has undoubtedly affected human health and contributed to environmental degradation. Investigating the specific health impacts of air pollution on the island would represent a valuable contribution to future research.

Another key direction for future research is the assessment of greenhouse gas concentrations—including CO_2, CH_4, N_2O, and fluorocarbons—on the island. Additionally, long-term monitoring of atmospheric temperature is recommended, given that gas flaring and rising concentrations of greenhouse gases are known to contribute to increases in atmospheric temperature.

CONCLUSIONS

The 24-hour concentrations of air pollutants on Bonny Island were studied across six locations. The results indicate that the atmospheric concentrations of CO and O3 are approaching the acceptable limits, highlighting the need for additional efforts to reduce their emissions. The levels of H2S, NO2 exceeded the WHO permissible limits at nearly all locations. Similarly, PM10 and PM2.5 concentrations were above the acceptable thresholds in most areas.

It is therefore imperative that companies operating in the region implement stronger pollution control measures to mitigate air pollution on the island, as these pollutants pose serious risks to both human health and the environment. Several areas for further research have been identified, and findings from these studies will contribute to the development of an air quality data bank and facilitate the quantitative attribution of pollutants to specific sources.

RECOMMENDATION

It is recommended that all oil and gas companies, along with service providers operating on Bonny Island, strengthen efforts to reduce air pollution, particularly targeting emissions of H_2S, NO_2, CO, O_3, PM_{10} and $PM_{2.5}$. Gas flaring significantly contributes to these pollutant emissions and should be discontinued, with the captured gas redirected for productive use.

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REFERENCES

[1] WORLD HEALTH ORGANIZATION. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. 2021. Available from: https://www.who.int/publications/i/item/9789240034228 [10.03.2025].

[2] US ENVIRONMENTAL PROTECTION AGENCY. Ground-level Ozone Basics. Available from: https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics. 2025. [17.03.2025].

[3] U.S. ENVIRONMENTAL PROTECTION AGENCY. Particulate matter (PM) basics. 2021. Available from: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics [17.03.2025].

[4] SUH, H.H., BAHADORI, T., VALLARINO, J., SPENGLER, J.D., Environ. Health Perspect., **108**, no. 4, 2000, p. 625.
[5] ROTH, S.H., Chapter 17: Toxicological and Environmental Impact of Hydrogen Sulfide in Book: Signal Transduction and the Gasotransmitters, Humana Press, Totowa, New Jersey, 2004, p. 293-313. https://doi.org/10.1007/978-1-59259-806-9_17.
[6] MALONE RUBRIGHT, S.L., PEARCE, L.L., PETERSON, J., Nitic Oxide, **71**, 2017, p. 1, https://doi.org/10.1016/j.niox.2017.09.011.
[7] MCNUTT, M., RAMAKRISHMAN, V., Climate Change Evidence and Causes – Update 2020. The National Academies Press, Washington, DC, 2020, p. 3-36, https://doi.org/10.17226/25733.
[8] FORSTER, P.M., SMITH, C.J., WALSH, T., LAMB, W., LAMBOLL, R., HAUSER, M., RIBES, A., ROSEN, D., GILLETT, N., PALMER, M.D., ROGELJ, J., VON SCHUCKMANN, K., SENEVIRATNE, S.I., TREWIN, B., ZHANG, X., ALLEN, M., ANDREW, R., BIRT, A., BORGER, A., BOYER, T., BROERSMA, J.A., CHENG, L., DENTENER, F., FRIEDLINGSTEIN, P., GUTIÉRREZ, J.M., GÜTSCHOW, J., HALL, B., ISHII, M., JENKINS, S., LAN, X., LEE, J.-Y., MORICE, C., KADOW, C., KENNEDY, J., KILLICK, R., MINX, J.C., NAIK, V., PETERS, G.P., PIRANI, A., PONGRATZ, J., SCHLEUSSNER, C.-F., SZOPA, S., THORNE, P., ROHDE, R., CORRADI, M.R., SCHUMACHER, D., VOSE, R., ZICKFELD, K., MASSON-DELMOTTE, V., ZHAI, P., Earth Syst. Sci. Data, **15**, no. 6, 2023, p. 2295, https://doi.org/10.5194/essd-15-2295-2023.
[9] BOETIUS, A., EDENHOFER, O., GABRYSCH, S., GRUBER, N., HANG, G., KLINGENFELD, D., RAHMSTORF, S., REICHSTEIN, M., STOCKER, T., WINKELMANN, R., Climate Change: Causes, Consequences and Possible Actions, German National Academy of Sciences Leopoldina, Halle, Germany, 2021, p. 5–28, https://doi.org/10.26164/leopoldina_03_00417.
[10] ISMAIL, O.S., UMUKORO, G.E., Energy Power Eng., **4**, no. 4, 2012, p. 290, https://doi.org/10.4236/epe.2012.44039.
[11] ADOKI, A., J. Appl. Sci. Environ. Manage., **16**, no. 1, 2012, p. 125.
[12] ABDULKADIR, M., ISAH, A.G., SANI, Y., J. Basic Appl. Sci. Res., **3**, no. 4, 2013, p. 283.
[13] OPAFUNSO, Z.O., Afr. J. Environ. Pollut. Health, **4**, no. 1, 2005, p. 52.
[14] JULIUS, O.O., Arch. Appl. Sci. Res., **3**, no. 6, 2011, p. 272.
[15] AFOLABI, E.A., AKPAN, U.G., AMEH, A.H., Proceedings of 1st International Engineering Conference (IEC 2015), Federal University of Technology, Minna, Nigeria, 1-3 September 2015, p. 476.
[16] AGORCHI, O.C., Int. J. Energy Environ. Eng., **8**, no. 7, 2014, p. 2354.
[17] NTA, S.A., USOH, G.A., JAMES, U.S., Int. J. Adv. Eng. Res. Sci, **2**, no.4, 2017, p. 181.
[18] UZOEKWE, S.A., Ann. Ecol. Environ. Sci., **3**, no. 4, 2019, p. 14.
[19] DANIEL-KALIO, L.A., BRAIDE, S.A., Ghana J. Sci., **46**, 2006, p. 3, https://doi.org/10.4314/gjs.v46i1.15911.
[20] OZABOR, F., OBISESAN, A., J. Sustain. Soc., **4**, no. 2, 2015, p. 5.
[21] AJUGWO, A.O., Int. J. Environ. Res. Public Health, **1**, no. 1, 2013, p. 6, https://doi.org/10.12691/jephh-1-1-2.
[22] FAGBEJA, M.A., CHATTERTON, T.J., LONGHURST, J.W.S., AKINYEDE, J.O., ADEGOKE, J.O., WIT Trans. Ecol. Environ., **116**, 2008, p. 207, https://doi.org/10.2495/AIR080221.
[23] ESIEVO, L., BRIGHT, C.A., CHUKWU, E.O., Int. Res. J. Modern. Eng. Technol. Sci., **6**, no. 11, 2024, p. 6034, https://www.doi.org/10.56726/IRJMETS64698.
[24] EDE, P.N., EDOKPA, D.O., AYODEJI, O., Energy Environ., **22**, No. 7, 2011, p. 891.
[25] WORLD HEALTH ORGANIZATION. WHO Global Air Quality Guidelines. Particulate Matter (PM_{10} and $PM_{2.5}$), Ozone, Nitrogen dioxide, Sulfur dioxide and Carbon monoxide. 2021, p. 135-136, https://www.who.int/publications/i/item/9789240034228 [10.03.2025].
[26] WORLD HEALTH ORGANIZATION. Environmental Health Criteria 19. Hydrgen Sulfide., IPCS International Programme on Chemical Safety, 1981, p. 1-39.

[27] OGOLO, N.A., UGWU, P., UKUT, I., OTOPA, M., ONYEKONWU, M., SPE Nigeria Annual International Conference and Exhibition, 6-8 August 2018, Lagos, Nigeria, p. 1, https://doi.org/10.2118/193398-MS.
[28] EZENWAJI, E.E., OKOYE, A.C., OTTI, V.I., J. Toxicol. Environ. Health Sci., **5**, no. 6, 2013, p. 97, https://doi.org/10.5897/JTEHS2013.0265.

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