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# Assessment of Noise, Gaseous and Particulate Emissions in Warri, Nigeria

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**A B S T R A C T**

**Background:** Warri, the hub of Nigeria's Niger Delta Region, has witnessed mass immigration of people since the advent of oil and gas. Therefore, this study examined the impact of gas flaring in Warri Refinery, Nigeria.

**Methods**: A noise dosimeter was used to determine the noise levels at the designated points. Air Quality Index was estimated for the concentration of $PM_{10}$, $SO_x$, $NO_x$, and CO in air measured for three months using standard methods prescribed by USEPA.

**Results**: The noise level reported 100% compliance with the Department of Petroleum Resources, Nigeria but violated World Health Organisation regulations at 60 and 200m respectively. The average values of PM10 at 60 and 200m from the flare were above the limits while the value at 350m from the flare complied only with the Department of Petroleum Resources regulation. Air Quality Index indicated that human exposure to the flared gas at 60, 200, and 350m from Warri Refinery be hazardous and unhealthy for sensitive groups respectively. A close observation of the locals exposes the prevalence of rampant health problems relating to gas flaring such as skin and respiratory ailments.

**Conclusion**: The results revealed that oil and gas production adversely impacted the environment and also reduced the quality of life and means of livelihood of the people.

## 1. Introduction

The Nigerian nation is abundantly blessed with natural resources such as mineral deposits, natural gases, and crude oil. The Nigerian oil and gas industry accounts for huge income across its range of sectors [1-2]. On the one hand, these natural resources have been a source of blessing and on the other hand a source of pain and sorrow to the host communities. The blessing is due to the windfall accruing to the nation from the sales of petroleum products while the pollution, diseases, and environmental impacts that come with the exploitation of the resources are an immense social and societal worry [3]. Gas flaring is a vital issue within the oil-producing Niger Delta region in Nigeria. It is an anthropogenic activity involving the wasteful greenhouse gases (GHGs) emission that initiates global warming, climate instability, and the earth's imbalance [4]. Gas flares are associated gases released during the extraction of crude oil from the ground [5]. Since the conversion of associated gases into commercial gases is expensive, these gases are said to be more of a waste product than an economic resource [1]. To boost cost-effectiveness, excess gas from natural gas or oil-related drilling is burnt or flared off, expelling carbon (iv) oxide into the air, thereby injecting methane ($CH_4$) into the atmosphere. Flaring of natural gas contributes immensely to the depletion of the Niger Delta [6]. It also increases the pollutants which contaminate the air and water of the region. Accordingly, gas flaring has had a devastating effect on the socio-economy and physical climate of the Niger Delta oil-bearing communities over the past four decades threatening the economy of subsistence [7]. In addition to these adverse environmental effects, gas flaring is uneconomical [8]. The Nigerian government loses approximately $2.5 billion annually due to the gas it flares away. This not only wastes natural resources but also pollutes the air and affects human health [9]. The flared gases emitted into the atmosphere have led to serious environmental problems such as air, soil, and water pollution [10]. Gas-flaring emissions are significant contributors to global warming and climate change [10-11]. Natural gas



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flaring in Nigeria adds about 1% to the worldwide CO which presents significant environmental problems [12]. Methane and Carbon (iv) oxide released in large amounts into the atmosphere during gas flares have a detrimental impact on the environment [5]. The government's environmental policies and legislations are the blight of the Nigerian oil and gas industry. The federal government has failed to exert restraint on the gas flaring issue. As a result, several issues that involve environmental pollution, economic instability, and socio-ecological problems have become prevalent. The people of the Niger Delta region live in abject poverty and are constantly at risk of diseases such as respiratory illness, asthma, blood disorders, and cancer due to the highly polluted environment [9]. A significant proportion of the gas allied with the produced crude oil is flared in Nigeria. This act has been well-thought-out to be reprehensible due to its impacts, wastefulness, and continuous and routine way of doing things. Gas flaring is a sad symbol of a poor nation that eats her chickens and eggs and still expects more eggs to come. Globally, 144 billion cubic meters of natural gas flared in the year 2021 [12]. Each year the flares liberate 400 million tons of carbon (iv) oxide into the air. Nigeria alone accounts for 13% of the world′ s gas flare and stands at about 23 billion cubic meters per year. That amount is sufficient to meet the energy requirements of Nigeria and leave a favorable net export. This research aimed at monitoring and quantifying gaseous emissions in Warri Refinery Plc′ s immediate environment, its impacts on the air quality, and also tracking oil and gas emissions in Warri refinery to identify measures to reduce and mitigate its upsurge in the environment from oil and gas exploitation and production activities.

## 2. Materials and Methods

### *2.1 Area of Study*

Warri is in the Niger Delta region in Nigeria. The Niger Delta is situated along the southern frontier of Nigeria′ s Atlantic coast. It is the entrance of the Niger and Benue Rivers into the ocean through a network of rivers, creeks, and estuaries. It is the largest wetland in Africa and the third in the world covering 2370 $km^2$. The vegetation is primarily of the woodland type with 8600 $km^2$ of swamp forest and about 1900 $km^2$ of mangrove forests [13]. The region located in southern Nigeria is bordered by the Republic of Cameroun in the east and the Atlantic Ocean in the south. The Niger Delta region accounts for about 12 % of Nigeria′ s total surface area [14].

### *2.2 Sample Collection, Handling, and Analyses*

Sampling points from the major sources of emission were designated at distances of 60 m, 300 m, and 450 m. Similarly, sampling was carried out in front of the tip (Generator and Pumps) and between the flare scrubber and flare tip (Flare). The sampling points were located using a portable Garmin 76 $CS_x$ handheld Global Positioning System (GPS) receiver. The collected samples were handled, preserved, and analyzed based on the appropriate test procedures. The amounts of pollutants released into the environment were compared with ambient air quality standards (World Health Organization, WHO and Department of Petroleum Resources, DPR regulations for conformity with values recommended by these standards).

### *2.3 Sample Measurement and Analysis Methods*

#### *2.3.1 Relative Smoke Density*

The British Standard Institute [15] (BS2742; 2009) approved the Ringlermann smoke chart used to measure the density of the smoke at each level. This includes a visual analysis of the smoke density as it leaves the tip of the flare tip with a regular shade of grey to black on a scale of 0-4.

#### *2.3.2 Noise Levels*

A pre-calibrated Delta ohm sound level meter (mode HD8701) was used to test the noise level at different distances based on the provision of IEC 61672-1: 2013 [15]. The noise meter sensor pointed to the source of the noise. The mean readings were taken to be the noise level at every stage for two mins. The noise levels were read at different distances from the digital meter in decibels (dB).

#### *2.3.3 Volatile organic compounds (VOC), Nitrogen oxides ($NO_x$), Sulphur oxides ($SO_x$), and Carbon monoxide (CO)*

A TESTO 350 flue gas analyzer was used to perform automatic ambient air analysis by providing a cyclic or continuous output signal. Air samples were constantly collected from the atmosphere and part of the air samples were sent to the analyzer to determine the relevant polluting gas.

#### *2.3.4 Suspended Particulates Matters (SPM)*

A modification of the Environmental Protection Agency′ s (EPA) Hi-volume Gravimetric method was used to determine suspended particulate matter (SPM). In this method, a known volume of ambient air was drawn through a glass fiber filter of known weight. The glass filter was held between the two halves of the brass holder. Any particulate matter was trapped during sampling. A drying tube was placed before the filter to remove moisture. After sampling, the filter was dried at 105 °C, dried in a desiccator, and weighed. The mass concentration (μg/$m^3$) of SPM in the air was estimated by measuring the mass of the particulate and dividing it by the volume of air sampled [13].

$$\text{Conc.}\ (\mu g/m3) = \frac{Ms - Mo}{V} \quad (1)$$

where: Ms is the mass of filter paper after sampling (μ/g); Mo is the mass of filter paper before sampling (μ/g) and V is the volume of Air sample in $m^3$.

### *2.4 Estimation of Air Quality Index*

Air Quality Index (AQI), a health risk assessment was evaluated for $PM_{10}$, $SO_x$, $NO_x$, and CO using Eq. (2) as provided in the guidelines for reporting air quality index (AQI) [16] and compared with the descriptor of AQI otherwise called EPA′ table of breakpoints [17] presented in Table 3.

$$I = \frac{(I_{high} - I_{low})(C - C_{low})}{C_{high} - C_{low}} + I_{low}$$

Where: $I$ is the AQI for pollutant; $C$ is the concentration of pollutant; $C_{high}$ is the concentration of breakpoint that is greater than or equal to $C$; $C_{low}$ is the concentration of breakpoint that is less than or equal to $C$; $I_{low}$ is the AQI value corresponding to $C_{low}$ and $I_{high}$ is the AQI value corresponding to $C_{high}$.

### *2.5 Statistical Analysis*

All sample data/parameters were subjected to statistical analysis to determine the mean, standard deviation, coefficient of variation, and frequency using Ms-Excel, IBM SPSS Statistics 21, and MINITAB 19.

## 3. Results and Discussion

### *3.1 Environmental Health Risk Assessment of Gaseous Emissions*

#### *3.1.1 Suspended Particulate Matter (SPM):*

The average values of SP) at 60 m, 200 m, and 350 m from the flares were 431.65 µg/m$^3$, 300.48 µg/m$^3$, and 199.23 µg/m$^3$ respectively. SPM concentration was highest at the 60 m radius distance from the flare point. The decrease in SPM as distance increases from the source of pollution agrees with WHO [18]. The average SPM values at the 60 and 200 m distances from the flare were above the regulatory limits of 150-230 µg/m$^3$ of the DPR (Table 2) while the average SPM value at 350 m from the flare was within the limit set by the DPR (Table 2) and also within the short-term regulatory limits for 1 h (150-230 µg/m$^3$) of the Nigerian National Air Quality Guidelines for Maximum Exposure (Table 3). However, the average SPM values measured at all points (60, 200, and 350 m distance from the flare) were above the WHO regulatory limits of 45 µg/m$^3$. The average range of value obtained at the electric power generator was 40.25 µg/m$^3$ and below the regulatory limit. In both developed and developing countries, urban and equally, to some extent, rural populations are currently experiencing adverse health effects due to exposure to airborne particulate matter. There is an extensive range of health effects from suspended particulate matter exposure, but the respiratory and cardiovascular systems are predominantly affected. Most health effects arise from the constituents of particulate matter, although, it is not yet adequate to allow for the distinction of those constituents that are closely linked to particular health effects [19-21].

#### *3.1.2 Volatile organic compounds (VOC):*

Volatile Organic compounds (VOC) values ranged from 314-366 µg/m$^3$, 194.40-238.42 µg/m$^3$, and 102.39-127.84 µg/m$^3$ with an average of 344 µg/m$^3$, 211.47 µg/m$^3$ and 108.56 µg/m$^3$ at 60 m, 200 m and 350 m distances from the flare respectively (Table 2). The average estimate of VOC at 60, and 200 m from the flare points exceeded the regulatory limits of 160 µg/m$^3$ of DPR [22] and WHO (Tables 2,3). However, the mean value of VOC (108.56 µg/m$^3$) at a 350 m radius from the flare point is below the limits of maximum exposure by the DPR and WHO (Table 2). VOC contributes to most health-related effects causing acute symptoms such as irritation of the eyes, nose, and throat, headaches, dizziness, nausea, and allergic reaction to the skin. They can also damage critical internal organs including the liver and kidneys. Furthermore, such volatile organic compounds may not present any immediate hazard but can contribute to chronic health conditions. Serious neurosis could be due to toluene and xylene exposures [23]. Individuals can have headaches, severe fatigue, tremors, decreased focus, and short-term memory due to long-term xylene exposure [24]. Devastating neurological disorders, among which the most dangerous is dementia, could result from toluene exposure [25].

#### *3.1.3 Noise Level:*

Noise is a form of environmental pollution because it can affect human health and most organisms in the ecosystem. The DPR law stipulates that the noise levels for exposed ears must be well below the threshold of pain (80-100 decibels) while WHO encourages a maximum sound level of 70 dB (A). At approximately 60 m away from the flare, the noise level ranged from 83.40 dB (A) to 92.10 dB (A) with an average value of 87.65 dB (A) (Table 2). At 200 m away from the flare, noise levels ranged between 73.30dB (A) and 81.40 dB (A) with an average value of 77.10 dB (A) while at 350 m from the flare point, the noise levels ranged from 59.47 dB (A) to 73.19 dB (A) with an average value of 66.54 dB (A) (Table 2). Noise levels obtained from the generator recorded a mean value of 93.10 dB (A). These values were within the 80 – 100 dB (A) threshold specified by DPR [21] while the noise level at 350 m from the flare alone complied with the WHO limit of 70 dB (A). Exposure to noise frequency exceeding 85-90 dB(A) has been demonstrated to cause hearing loss, which may be temporary or permanent [26].

#### *3.1.4 Smoke Density (Ringlemann):*

Smoke produced from a flare is an indicator of incomplete or poor combustion. This is also the only direct evidence of pollution violations outside a venue [24]. The Ringlemann Scale is used to measure the gradation of the opacity of the relative density of smoke produced from flared gas. The Nigerian regulations just like the WHO mandate that the relative density of smoke produced from gas flaring does not surpass shade 2 on the Ringlemann Scale, which is correlated with 40 percent of smoke density and 60 percent of light transmission through smoke-observed for one year [12; 26]. Mean values for flare smoke densities recorded at 60 m, 200 m, and 350 m from the flare were Ringlemann numbers Nos 7.6, 3.5, and 1.4 respectively (Table 2). The average smoke density recorded at the generator was Ringlemann number Nos 3.6. Smoke density measured at 60 m, and 200 m from the flare and at the generator station were above the DPR and WHO regulatory level of two (2) Ringlemann (Tables 2 and 3). Nevertheless, the smoke density measurements at 350 m from the flare showed 100 percent compliance and were below the two (2) Ringlemann DPR and WHO Regulatory levels (Table 2). Smokeless emissions were reported to not affect the emissions of sulphur (iv) oxide [27].

*3.1.5 Sulphur Oxides ($SO_x$):*

Sulphur is the predominant trace element in Nigeria's natural gas. Sulphur (iv) oxide in the atmosphere arises majorly from the combustion of sulphur-containing fossil fuel. Sulphur (iv) oxide can remain suspended for days giving room for its wide distribution [20]. Sulphur (iv) oxide measurements in this study showed that the means of sulphur (iv) oxide at 60 m, 200m, and 350 m from the flare are 302 µg/m$^3$, 165 µg/m$^3$, and 123 µg/m$^3$, respectively (Table 2). All sulphur (iv) oxide measurements in this study were below short-term regulatory limits for 1 h for Nigerian National Air Quality Guidelines for Maximum Exposure [22]. They were however above the 40 µg/m$^3$ of the WHO (Tables 1 and 2). Sulphur (iv) oxide measurements at 60 m and 200 m distances from the flare were also above the short-term regulatory limits for 24 h while the average value recorded in the 350 m was within the short-term regulatory limits for 24 h by the DPR [22] (Table 3). Regulated research involving asthmatics indicates that a proportion experience improvement in pulmonary function and respiratory symptoms after periods of $SO_2$ exposure to as short as 10 minutes. Based on this evidence, a concentration of $SO_2$ of 500 µg/m$^3$ should not be exceeded over an average of 10 mins [28]. The formation of acid rain is one major effect of sulphur dioxide. Several in the Niger Delta region of Nigeria on the environmental effects of gas flaring have shown that gas flaring induces acidic rain in the region [29-31]. 'People living in Nigeria's Niger delta region or the inhabitants of oil-producing communities' residents have often had acidic rain from gas flaring activities and this causes their zinc roofs to corrugate' [32]. Sulphur (iv) oxide is also toxic to plants and soil. When these compounds fall on the soil and crops, the soil becomes acidic and crops wane causing low agricultural yield in the Niger Delta and leading to hunger and starvation [33].

*3.1.6 Nitrogen Oxides (NOx):*

Nitrogen in fuels is converted to oxides of nitrogen inthecombustion process and by thermal fixation of atmospheric nitrogen in a process parallel to that of sulphur (iv) oxide production during combustion. Nitrogen (iv) oxide concentration was highest at the 60 m distance from the flare with an average value of 166 µg/m$^3$ (Table 2). Nitrogen (iv) oxide measurements in this study showed that the means at 200m and 350 m from the flare are 123 µg/m$^3$ and 118 µg/m$^3$, respectively (Table 2). The measured mean value at 60 m away from the flare was not in compliance with the Department of Petroleum Resources' set limits. The average value exceeded the regulatory limits of 150 µg/m$^3$ for 24 h by the DPR [22] (Table 3). The concentration of $NO_2$ measured at the three distances (60 m, 200 m, 350 m) were not based on the WHO maximum exposure of 25 µg/m$^3$. $NO_2$ as an irritating gas compress the airways of asthmatics and exposure to it at high concentration are associated with the combustion of stationary sources of fuels [26]. $NO_2$ increases bronchial reactivity, after exposure to bronchoconstrictor pharmacological agents by the reaction of normal and asthmatic subjects, even at rates that do not directly affect pulmonary function in the absence of a bronchoconstrictor. Enhanced sensitivity to $NO_2$ levels of bronchoconstrictors even at low concentrations was indicated [34].

*3.1.7 Carbon Monoxide (CO):*

Carbon (ii) oxide is produced by the incomplete combustion of hydrocarbons, charcoal, wood, kerosene, or natural gas. The health effects associated with inhaled CO differ according to their concentration and exposure period. Effects range from mild cardiovascular and neurobehavioral symptoms at low concentrations to unconsciousness and death following prolonged exposures or after acute exposures to high concentrations of CO. Its measurements in this study showed that the means of CO at 60 m, 200 m, and 350 m from the flare are 1.94 µg/m$^3$, 1.32 µg/m$^3$, and 0.48 µg/m$^3$, respectively (Table 2). All measured values for CO were below the short-term regulatory limits for 1 h and 24 h of the Department of Petroleum Resources set limits (Table 3). They are also within the maximum exposure limit of 7 µg/m$^3$ of WHO. Many direct experiments investigating the effects of carbon monoxide on humans have been conducted during the last century. The effects of CO depend on the CO concentration in the air, the duration of the exposure, the health status, and the activity level of the individual concerned. Symptoms of increasing severity of CO poisoning include headache, dizziness, exhaustion, palpitations, nausea, vomiting, breathing difficulty, seizures, rapid heartbeat, visual disturbance, and twitching of the muscles [34]. At very high CO concentrations, unconsciousness and eventually death may occur. Acute exposure to extremely high levels which do not lead to death can cause permanent heart and brain damage. Chronic exposure to low CO levels may result in a cluster of flu-like symptoms such as headache, fatigue, muscle aches, nausea, vomiting, and changes in sensitivity to light, odor, and taste [35].

*3.2 Environmental Health Risk Assessment of Emissions*

Air Quality Index (AQI) for $PM_{10}$, $SO_x$, $NO_x$, and CO was evaluated to estimate the environmental health risk due to gas flaring emissions discharged into the atmosphere at distances 60 m, 200 m, and 350 m from Warri Refinery. AQI of 309.33, 199.17, 113.30, and 22.05 for $PM_{10}$, $SO_x$, $NO_x$, and CO respectively were obtained at a distance of 60 m from

Warri Refinery (Table 4). These values showed that human exposure to $PM_{10}$ is hazardous, to $SO_x$ is unhealthy while to $NO_x$ and Co concerning the estimated amounts of these pollutants as reported in this work is unhealthy for sensitive groups and good respectively. This makes human exposure to flared gas at this distance from the refinery dangerous. The pollutants ($PM_{10}$, $SO_x$, $NO_x$, CO) contained in polluted ambient air could result in human health problems and a low life expectancy of around 40 years of the community [36-37]. AQI of 173.67, 139.66, 105.16, and 15 for $PM_{10}$, $SO_x$, $NO_x$, and CO respectively were equally obtained at a distance of 200 m from Warri Refinery (Table 4). These values showed that human exposure to PM10 is unhealthy, to $SO_x$ and $NO_x$ is unhealthy for sensitive groups while to CO in relation to the estimated amounts of these pollutants as reported in this work is good AQI of 122.89, 122.13, 104.22, and 5.45 for $PM_{10}$, $SO_x$, $NO_x$, and CO respectively were equally obtained at a distance of 350 m from Warri Refinery (Table 4). These values showed that human exposure to $PM_{10}$, $SO_x$, and $NO_x$ is unhealthy for sensitive groups while CO concerning the estimated amounts of these pollutants as reported in this work is good.

Table 1: EPA Table of Breakpoints (USEPA, 2013)

| $PM_{10}$ ($\mu g/m^3$) | CO ($\mu g/m^3$) | $SO_2$ ($\mu g/m^3$) | $NO_2$ ($\mu g/m^3$) | AQI | Category |
|---|---|---|---|---|---|
| 0-54 | 0.0-4.4 | 0-35 | 0-53 | 0-50 | Good |
| 55-154 | 4.5-9.4 | 36-75 | 54-100 | 51-100 | Moderate |
| 155-254 | 9.5-12.4 | 76-185 | 101-360 | 101-150 | Unhealthy for Sensitive Groups |
| 255-354 | 12.5-15.4 | 186-304 | 361-649 | 151-200 | Unhealthy |
| 355-424 | 15.5-30.4 | 305-604 | 650-1249 | 201-300 | Very Unhealthy |
| 425-604 | 30.5-50.4 | 605-1004 | 1250-2049 | 301-500 | Hazardous |

Table 2: Comparison of Noise and Emission values at 60 m, 200m, and 350 m with DPR and WHO limits

| Parameter | 60 m | 200 m | 350 m | DPR Limits | WHO |
|---|---|---|---|---|---|
| Noise Level (dBA) | 90.38 | 78.43 | 66.54 | 80-100 | 70 |
| SPM ($\mu g/m^3$) | 431.65 | 300.48 | 199.23 | 150- 230 | 45 |
| VOC | 344 | 211.47 | 108.56 | 160 | 160 |
| Smoke Density (Ringlemann) | 7.6 | 3.5 | 1.4 | 2 | 2 |
| Sulphur Oxides ($SO_x$), ($\mu g/m^3$) | 302 | 165 | 123 | 100-150 | 40 |
| Nitrogen Oxides ($NO_x$), ($\mu g/m^3$) | 166 | 123 | 118 | 150 | 25 |
| Carbon Monoxide (CO), ($\mu g/m^3$) | 1.94 | 1.32 | 0.48 | 10 | 7 |

Table 3: Nigerian National Air Quality Guidelines for Maximum Exposure

| Pollutants | 1-Hour Mean ($\mu g/m^3$) | Daily Average ($\mu g/m^3$) |
|---|---|---|
| SPM | 150-230 | 60-90 |
| Carbon monoxide | 30 | 10 |
| Nitrogen dioxide | 400 | 150 |
| Sulphur dioxide | 350 | 100-150 |

*Source: Table III-3, DPR [20] Environmental Guidelines & Standards for the Petroleum Industry in Nigeria

Table 4: Air Quality Index (AQI) of Pollutants at 60 m, 200m, and 350 m

| Parameter | 60 m | 200 m | 350 m |
|---|---|---|---|
| SPM ($\mu g/m^3$) | 309.33 | 173.67 | 122.89 |
| Sulphur Oxides ($SO_x$), ($\mu g/m^3$) | 199.17 | 139.66 | 122.13 |
| Nitrogen Oxides ($NO_x$), ($\mu g/m^3$) | 113.30 | 105.16 | 104.22 |
| Carbon Monoxide (CO), ($\mu g/m^3$) | 22.05 | 15 | 5.45 |

## 4. Conclusion

Generally, the concentration of pollutants in the air decreases as distance increases from the source of pollution. Noise levels at all the measured points were within the DPR-specified threshold while the noise level at 350 m from the flare alone complied with the WHO limit. Exposure to noise frequency exceeding these limits could lead to temporary or permanent hearing loss, tinnitus (a disease of the continuous buzzing of the ear), and other related diseases. Smoke density measured at 60 m, and 200 m were above the DPR and WHO regulatory levels while the smoke density measurements at 350 m were within the two (2) Ringlemann DPR and WHO Regulatory levels. Only the measured VOC at a 350 m radius from the flare point was within the 160 μg/m$^3$ regulatory limits of maximum exposure by the DPR and WHO while the average estimate of VOC at 60 and 200 m from the flare points exceeded this limit which could damage critical internal organs such as the liver and kidneys; cause acute health issues including irritation of the eyes, nose, and throat, headaches, dizziness, nausea, and allergic reaction to the skin; and contribute to chronic health conditions. AQI used to estimate the environmental health risk due to gas flaring emissions discharged into the atmosphere at distances 60 m, 200 m and 350 m from Warri Refinery showed human exposure to the flared gas at distances 60 m, 200 m, and 350 m from Warri Refinery to be hazardous and unhealthy for sensitive groups. The pollutants ($PM_{10}$, $SO_x$, $NO_x$, CO) contained in polluted ambient air could result in human health problems and a low life expectancy of around 40 years of the community and the refinery workers who work close to the flare. A close observation of the locals exposes the prevalence of rampant health problems relating to gas flaring such as skin and respiratory ailments.

## 5. Recommendation

The pollutants examined in this work could have a significant influence on the micro-environment of Warri. Flared gases not only pollute soil, air, and water but also the accompanying heat affects farmlands irreparably. Gas flaring should therefore be discouraged and the gases are rather efficiently utilized in the country, especially in the energy sector where electricity could be generated using gas turbines across the country. While these turbines are being installed, the flare combustion efficiency should be improved. The government of Nigeria is a signatory to the United Nations′ sustainable development goals (SDGs), and World Bank campaign (Global Gas Flaring Reduction) in reducing gas flaring. Furthermore, World Bank, United Nations, governments, and oil companies initiative of ˋˋZero Routine Flaring by 2030″ should implement the aforementioned agreements to increase the utilization of natural gas in the country, which will consequently reduce the volume of flared gas. The increased use of natural gas is the primary mitigation method to gas flaring and its ensuing negative environmental impacts of gas flaring in the country. Besides the continuous use of natural gas for power generation, its potential as transport fuel (compressed and liquefied natural gas), substitute for other fossil fuels (diesel, kerosene, gasoline, etc.) in engines, and as feedstock for industrial use is huge and should be explored. This would subsequently add both commodity and monetary value to natural gas. Also, more stringent penalties should be imposed on defaulting oil companies to compel them to find possible alternatives to this wasteful act. The findings in this study will serve as a useful guide, not only to inform decision-makers on how to minimize air pollution rates among the local population but also to support the need for further studies on the growing issue of gas flaring.

## Authors' Contributions

Ayodele Olumuyiwa Owolabi: Project design; field research and laboratory analysis of samples; data analysis; writing manuscript.

## Conflicts of Interest

The Author declares that there is no conflict of interest.

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