# EFFECT OF GAS FLARING ON HEAT AND SOIL AROUND AGBADA FLOW STATION RIVERS STATE, NIGERIA

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***ABSTRACT***

***This study investigates the effect of gas flaring on heat and soil around the Agbada flow station Rivers State, Nigeria. The study adopted the completely randomized block design (CRBD). Ambient air quality was measured at four stations using the Aeroqual 500 Series Gas Monitor, GT 321 Particulate Meter, GPS, Extech Meteorology Meter, and measuring tape to assess pollutants. The study revealed that Station 1 (Upstream) recorded the highest $CO_2$ (613 ppm), temperature (34.0°C), and wind direction (WS 520), indicating it's the hottest location. Station C (Life Camp) recorded the highest $PM_{2.5}$ (0.011 µg/m³), $PM_{10}$ (0.016 µg/m³), and $O_3$ (0.03 µg/m³), indicating highest air impurity. The Control site recorded the highest levels of $NO_2$ (0.090 µg/m³), noise (58.1 dBA), wind speed (2.0 m/s), and relative humidity (78.1%), suggesting the influence of external anthropogenic activities like vehicular emissions, and environmental factors like microclimatic conditions unrelated to direct gas flaring activities. The study found that Ammonia (0.200 µg/m³) and Carbon Dioxide (575.67 µg/m³) exceeded WHO limits of 0.53 µg/m³, and 462 µg/m³ respectively, indicating emissions from gas flaring, posing risks of soil acidification and long-term soil fertility decline. It was also found that Carbon Dioxide ($CO_2$) recorded a high mean concentration (575.67 µg/m³), exceeding the control (527 µg/m³) and WHO limits (462 µg/m³), making it the dominant heat-contributing gas. The study recommended that government institute environmental management and intervention measures such as gas capture and utilization, flaring reduction technology, regular air quality monitoring, and planting a temperature resistant plant like Lantana, to mitigate the emission and absorption of the excess $CO_2$, which hampers the goal of safeguarding environmental and public health around the environs of the Agbada Flow Station.***

***Keywords: Gas Flaring, Heat, Soil, Agbada Flow Station, Rivers State.***

## Introduction

Gas flaring involves burning natural gas, releasing heat, particulate matter, and pollutants into the atmosphere and soil, instead of adopting eco-friendly alternatives like liquefied natural gas and cooking gas (Fawole et al., 2016; Seiyaboh & Izah, 2017). The composition and quantity of natural gas flared during oil exploration especially in the Niger Delta region, elevates the temperature leading to meteorological changes as well as stirs the emission of pollutants that accentuates environmental degradation (Odjugo & Osemwenkhae, 2021). The elevated surface temperatures caused by gas flaring contribute to soil moisture loss and heat stress, which can further inhibit plant growth and soil biological activity (Enetimi & Izah, 2017; Odjugo & Osemwenkhae, 2021). Thus, the prolonged exposure to intense heat and pollutant-laden emissions has been reported to alter soil properties, including pH, organic matter content, nutrient availability, and microbial population dynamics (Chukwu, 2021; Ehumadu & Ndekwu, 2021).

Gas flaring as the continuous burning of excess gas from oil extraction processes releases large quantities of heat and various atmospheric pollutants into the surrounding environment (Enetimi & Izah, 2017). One of the major effects of gas flaring is the elevation of surface and sub-surface soil temperatures. Thus, this localized increase in temperature has profound effects on soil quality, vegetation health, and microclimatic conditions, especially around the communities adjoining the Agbada Flow Station (Chukwu, 2021). Odjugo and Osemwenkhae (2021) reported that gas flaring increased soil temperatures near flare sites to 36-40°C compared to unaffected areas. This rise in temperature accelerates soil moisture loss, leading to dry and hardened soils that are less conducive for plant growth (Ehumadu & Ndekwu, 2021).

Gas flaring is the primary source of anthropogenic and toxic pollutants that are responsible for poor air quality, public health issues, and ecological degradation (Osuoha, 2017). Alluding to this, Amaechi-Onyerimma (2019) stressed that gas flaring releases pollutants such as $CO_2$, $NO_2$, $SO_2$, $H_2S$, $CH_4$, CO, $NH_3$, etc., which significantly degrade air quality and increase the risk of health problems like skin diseases, cancer, and respiratory ailments, like cough, cold, and catarrh in the Agbada Flow Station. The American Association for the Advancement of Science reported that these pollutants cause greenhouse gases, respiratory diseases, and vegetative discoloration (AAAS, 2015). Thus, gas flaring degrades air, water, land, and wetlands, undermining 85-90% petroleum revenue generated for national earnings and exports **(**Izah & Ohimain**,** 2015).

Gas flaring releases acidic gases like $SO_2$ and $NO_2$, lowering soil pH and increasing acidity, which reduces nutrient availability, hinders microbial activity, and disrupts plant nutrient uptake (Nwankwo et al., 2021). Gas flaring increases heavy metal contamination in soils near flare sites, with elevated lead, cadmium, and nickel levels, harming soil health, groundwater, crops, and microbial populations due to toxicity and acidity in the gas flare environment (Nwaugo et al., 2006; Olorunfemi et al., 2021). In specificity, Chukwu (2021) observed that soils within a 500-meter radius of the Agbada flow station had significantly lower pH and organic matter content compared to control sites. This was accompanied by reduced levels of essential nutrients like nitrogen, phosphorus, and potassium, all of which are critical for healthy plant growth.

Gases like Carbon Dioxide ($CO_2$), Methane ($CH_4$), Carbon Monoxide (CO), Sulphur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Hydrogen Sulphide ($H_2S$), Ammonia ($NH_3$), and Ozone ($O_3$) greatly impact soil (Nduka et al., 2021). These gases contribute to soil acidification, loss of soil fertility, alteration of soil microbial composition, and heavy metal mobilization in the soil matrix, posing risks to agricultural productivity and groundwater quality (Eze & Nwosu, 2021; Okoro et al., 2021). Conversely, the key gases linked to heat increase are: $CO_2$, $CH_4$, $NO_2$, $O_3$, CO, and to a lesser extent, $SO_2$. These gases, primarily from gas flaring, combustion, and industrial emissions, contribute to local warming, elevated ambient temperatures, and microclimatic changes (Enetimi & Izah, 2017; Chukwu, 2021).

A spatial analysis by Ehumadu and Ndekwu (2021) showed increased temperatures (up to ~40°C at 5 cm depth) and acidic pH (4.0-4.2) near flares, with reduced moisture content and degraded fertility in the Niger Delta region. Equally, heat and pollutants from flaring reduce soil quality leading to acidic soil pH values dipping to 4.0-4.2 near flares, rising to near-neutral beyond 650 m near Agbada II Flow Station in Igwuruta Community, Rivers State (Chukwu, 2021). Moreover, flaring-induced heat and emissions facilitate acid rain formation and destroy sensitive vegetation like mangroves, contributing to deforestation and further soil deterioration in the Niger Delta (ThisDayLive, 2024). Thus, the cumulative effects of gas flaring cause reduced soil fertility, poor yields, and ecological imbalance. Given this, farmers near Igwuruta Community that is hosting the Agbada Flow Station, report declining crop productivity, stunted growth, and soil degradation, threatening food security (Ezeani & Nwosu, 2021).

The combined thermal and chemical impacts of gas flaring leads to elevated soil temperatures, acidification, and pollutant buildup that diminishes ecosystem productivity and threatening agricultural sustainability (Okoro et al., 2021). Studies show that gas flares emit immense heat, temperatures reaching 13,000-14,000 °C at the flame tip, raising ambient and surface soil temperatures significantly within the flare radius (Eze & Nwosu, 2020; Nduka et al., 2021). The release of sulfur and nitrogen oxides during flaring contributes to acid rain formation, further acidifying soil and water bodies, corroding infrastructure, and damaging vegetation (Chukwu, 2021). Accordingly, such acidity inhibits plant growth, stunts vegetation, and amplifies soil degradation. Also, heat stress, soil acidification, moisture loss, and heavy metal contamination make land near flares unsuitable for farming, causing nearly 100% crop loss within 200 m and reduced yields up to 600 m (Odigure & Abdulkareem, 2018; Odunze & Abubakar, 2019). In a nutshell, the adverse changes degrade soil fertility, hamper crop productivity, and pose risks to human and ecosystem health through trace metal accumulation. This is the crux of the matter.

## Statement of the Problem

Gas flaring persists as a major environmental challenge in the Niger Delta, especially around Agbada flow station. Continuous heat and emissions significantly affect soil quality and surface temperature, altering pH, organic matter, nutrient availability, and microbial populations, despite existing regulations and public awareness efforts to mitigate these impacts. Given this, communities and farmlands near Agbada flow station face reduced crop yields, poor soil fertility, and degradation. Limited research exists, despite gas flaring-induced heat causing soil moisture loss, heat stress, and hindered plant growth.

Despite studies on gas flaring impacts in the Niger Delta, localized research on Agbada flow station is limited. Urgent investigation is needed on its effects on soil chemistry, microbes, and temperature. Addressing this gap is vital for developing mitigation strategies, improving agricultural practices, and shaping policies to protect ecosystems and livelihoods. Therefore, this study seeks to assess the effect of gas flaring on heat and soil characteristics around the Agbada flow station in Rivers State, Nigeria, with the goal of providing empirical data that will aid in environmental management and policy formulation. This prompted the articulation of the following questions that guided this research.

1. What is the composition of the flared gases around the Agbada flow station?
2. What is the impact of the mean composition of the gases that affect soils around the environs of Agbada flow station?
3. What is the impact of the mean composition of the gases responsible for heat build-up around the environs of Agbada flow station?

## Aim and Objectives of the Study

The aim of this study was to examine the effect of gas flaring on heat and soil around the Agbada flow station in Ikwerre Local Government Area Rivers State. The specific objectives are to:

1. Determine the composition of the flared gases around the Agbada flow station.
2. ascertain the impact of the mean composition of the gases that affect soils around the Environs of Agbada flow station.
3. Identify the impact of the mean composition of the gases responsible for heat build-up around the environs of Agbada flow station.

## Significance of the Study

1. The study would provide data on gas flaring’s impact on soil pH, nutrients, microbial activities, and surface temperature alterations, enhancing environmental and soil quality assessment.

2. The findings would help farmers adopt better soil management practices to reduce heat stress, prevent degradation, increase yields, and protect livelihoods. The attainment of this would aid agricultural productivity and livelihood protection.
3. The study would enhance policy development and corporate environmental responsibility. This awareness would offer evidence for policymakers and oil companies to strengthen environmental laws, control pollution, and fund soil remediation programmes.
4. The research would advance environmental science literature and provide baseline data to support climate adaptation, sustainability planning, and future pollution studies.
5. This study would serve as a reference material for researchers and future studies that would help to advocate compliance to zero flaring of gases, whose effluences impacts negatively on environmental components.

## Materials and Methods

**Study Area:** The study was carried out at the Agbada Flow Station, situated within Igwuruta Community in Ikwerre Local Government Area of Rivers State, Nigeria. This facility is jointly owned and operated by the Nigerian National Petroleum Corporation (NNPC) and the Shell Petroleum Development Company (SPDC) under a joint venture gas gathering project. The station features an open gas flaring system with two prominent vertical gas flare stacks, as shown in Plate 1 (Amaechi-Onyerimma, 2019). Geographically, the Agbada Flow Station lies between longitudes 7°00'–7°10'E and latitudes 4°31'–4°40'N (Gobo et al., 2009). It is bordered to the north by Igwuruta Town, to the south by Eneka Town, to the east by the Eneka-Igwuruta Road, and to the west by the Airport Road. Notably, the facility comprises three flare points: two vertical flare stacks and one horizontal flare stack (see Plate 1 below).

**Research Design:** This study employed an experimental design, which is typically used in research where manipulation and control of one or more intervening variables are influenced by factors such as the subjects, the experimenter, experimental tools, and critical environmental conditions (Nwankwo, 2016). Additionally, the Completely Randomized Block Design (CRBD) was adopted, given the similarity and homogeneity among the experimental sampling points.

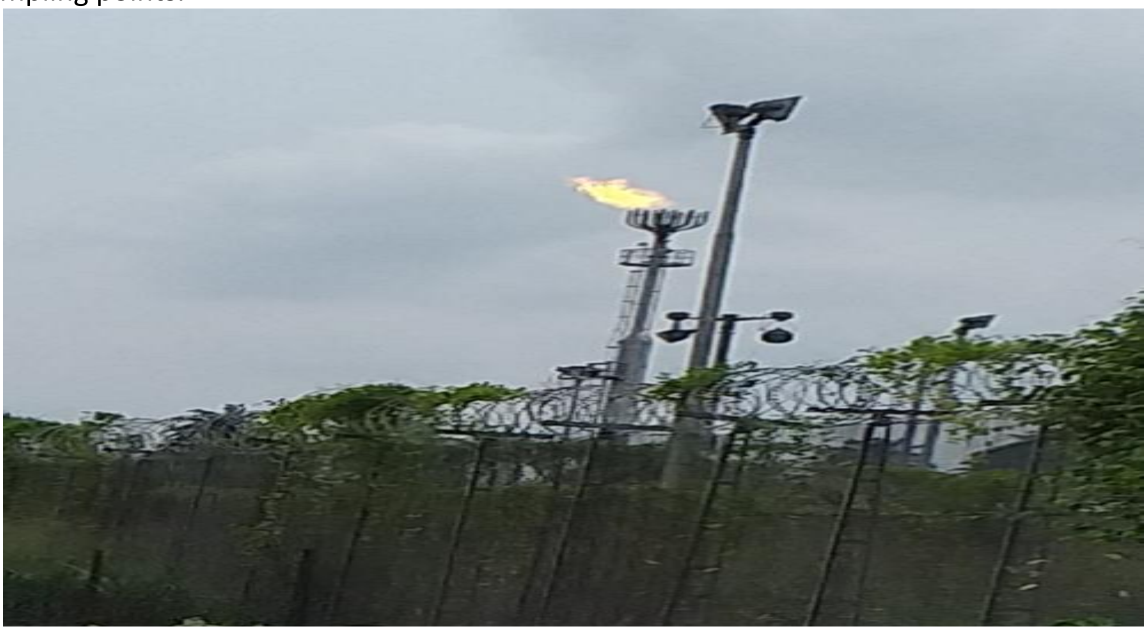

**Plate 1: One of the Two Vertical Flare Stack or Point in the Agbada Flow Station**

**Sample Site Location:** Four (4) sampling stations were established and monitored over a four-month period (June to September 2020) at monthly intervals, forming the basis for the study's sample locations and duration. The sampling stations were purposively selected to capture variations in air quality parameters. These included: Station A (100 meters upstream from the Agbada Flow Station II) at coordinates Northings 04°55'57.0"N and Eastings 07°00'55"E; Station B (200 meters downstream) at Northings 04°55'57.0"N and Eastings 07°00'56"E; Station C (Life Camp, 500 meters from the flow station) at Northings 04°55'58.446"N and Eastings 07°00'53.598"E; and Station D (Control Point), located at Bolingo Junction, Igwuruta, approximately 1000 meters from the flow station, at Northings 04°56'5.568"N and Eastings 07°00'27.75"E.

**Instrumentation and Method of Data Collection:** Five instruments were employed by the researcher and research assistant to conduct the air quality assessment around the Igwuruta Flow Station, a known gas-flared environment. These included the Aeroqual 500 Series Gas Detector (for measuring Indoor Air Quality - IAQ), the Handheld GT 321 Particle Counter (a portable device that detects particles as small as 0.3 microns), an Automated GPS Unit (for recording the coordinates of sampling points), the Extech Meteorology Meter (used to measure temperature, relative humidity, and wind speed), and a Measuring Tape (used to determine the distance between sampling locations). Notably, four of these instruments, the Aeroqual 500 Series, GT 321, Automated GPS, and Extech Meteorology Meter, were pre-calibrated before use to ensure data quality and accuracy, with the measuring tape being the only exception.

**Data Analysis:** Relevant statistical analysis tools such as mean, standard error, line and bar charts, and graphs were employed to address the study's stated objectives.

**Results**

**Table 1: Composition of flared gases in the four selected stations around the Agabda flow station**

| Gases | Unit | Period | Measured Values | | | | WHO Daily Standard | DPR Standard Compared |
|---|---|---|---|---|---|---|---|---|
| | | | ST A | ST B | ST C | Control | | |
| $Pm_{2.5}$ | µg/m3 | 30 mins | 0.009 | 0.009 | 0.011 | 0.008 | 35 µg/m$^3$ | 150 – 230 |
| $Pm_{10}$ | µg/m3 | 30 mins | 0.013 | 0.013 | 0.016 | 0.012 | 150 µg/m$^3$ | 250 |
| $NO_2$ | µg/m3 | 30 mins | 0.056 | 0.064 | 0.069 | 0.090 | 100 ppb | 0.04 – 0.06 |
| CO | µg/m3 | 30 mins | 0.2 | 0.2 | 0.2 | 0.2 | 200 µg/m3/ 9 ppm | 10 – 20 |
| $SO_2$ | µg/m3 | 30 mins | 0.00 | 0.00 | 0.00 | 0.00 | 75 ppb/ 0.5 ppm | 0.01 – 0.10 |
| $CH_4$ | µg/m3 | 30 mins | 0 | 0 | 0 | 0 | 0.83 µg/m3 | 2 |
| $H_2S$ | µg/m3 | 30 mins | 0.00 | 0.00 | 0.00 | 0.00 | 125 µg/m3 | 120 |
| $O_3$ | µg/m3 | 30 mins | 0.02 | 0.01 | 0.03 | 0.01 | 100 µg/m3 | 0.070 ppm |
| $NH_3$ | µg/m3 | 30 mins | 0.2 | 0.2 | 0.2 | 0.2 | 0.53 µg/m3 | 0.51-0.55 |
| $CO_2$ | µg/m3 | 30 mins | 613 | 565 | 549 | 527 | 462 µg/m3 | 467 |
| Noise | dBA | 30 mins | 57.2 | 55.6 | 46.0 | 58.1 | 75 - 90 | 80 -100 |
| Temp. | $^oC$ | 30 mins | 34.0 | 30.4 | 30.6 | 31.6 | - | - |
| WS | m/s | - | 0.9 | 0.9 | 1.9 | 2.0 | - | - |
| RH | % | - | 65.3 | 69.9 | 71.6 | 78.1 | - | - |

**Source:** Researcher's Fieldwork**,** 2021; DPR, 2002; WHO, 2015; Akpoghelie et al., 2016; USEPA, 2016.

Table 1 presents the various air quality parameters measured at the experimental site. The results indicate that Station C (Life Camp of the Flow Station) recorded the highest concentrations of $PM_{2.5}$ (0.011 µg/m³), $PM_{10}$ (0.016 µg/m³), and $O_3$ (0.03 µg/m³). Station 1 (Upstream of the Agbada Flow Station) showed the highest levels of $CO_2$ (613 ppm), temperature (34.0°C), and wind direction (WS 520). The Control site recorded the highest levels of $NO_2$ (0.090 µg/m³), noise (58.1 dBA), wind speed (2.0 m/s), and relative humidity (78.1%). In contrast, Station B (Downstream of the Agbada Flow Station) exhibited the lowest concentrations across most measured parameters. Additionally, the mean concentrations of CO (Carbon Monoxide), $SO_2$ (Sulphur Dioxide), $CH_4$ (Methane), $H_2S$ (Hydrogen Sulphide), and $NH_3$ (Ammonia) at all sample locations around the Agbada Flow Station were similar to those at the Control Point. However, the mean levels of $NO_2$, noise, wind speed, and relative humidity at the sample stations were lower than at the Control Point. Conversely, mean values for $O_3$, $CO_2$, and temperature were higher than those recorded at the Control.

Overall, the findings indicate that air quality parameters around the Agbada Flow Station varied significantly and, in most cases, exceeded the World Health Organization (WHO) and Department of Petroleum Resources (DPR) daily permissible standards. Specifically, Station 1 was the hottest location, Station C had the highest air impurity levels, the Control was the noisiest, and Station B had the comparatively lowest pollutant levels. The elevated concentrations of $CO_2$, temperature, $O_3$, $PM_{2.5}$, and $PM_{10}$, coupled with high noise levels, wind speed, and humidity, suggest potential health risks for residents, including hearing impairment, stress-induced shock, and an increased risk of hypertension.

**Table 2: The impact of the mean composition of the gases that affect soils around the environs of Agbada flow station**

| Soil Impacting Gases | Unit | Mean | Control | WHO Daily Standard | Decision |
|---|---|---|---|---|---|
| Nitrogen Dioxide ($NO_2$) | µg/m3 | 0.063 | 0.090 | 100 ppb | Within limit |
| Carbon Monoxide (CO) | µg/m3 | 0.200 | 0.2 | 200 µg/m3 | Within limit |
| Sulphur Dioxide ($SO_2$) | µg/m3 | 0.000 | 0.00 | 75 ppb/ 0.5 ppm | Within limit |
| Methane ($CH_4$) | µg/m3 | 0.000 | 0 | 0.83 µg/m3 | Within limit |
| Hydrogen Sulphide ($H_2S$) | µg/m3 | 0.000 | 0.00 | 125 µg/m3 | Within limit |
| Ozone ($O_3$) | µg/m3 | 0.020 | 0.01 | 100 µg/m3 | Within limit |
| Ammonia ($NH_3$) | µg/m3 | 0.200 | 0.2 | 0.53 µg/m3 | Above limit |
| Carbon Dioxide ($CO_2$) | µg/m3 | 575.67 | 527 | 462 µg/m3 | Above limit |

**Source:** Researcher's Fieldwork**,** 2021; WHO, 2015; Akpoghelie et al., 2016; USEPA, 2016.

The interpretation of the data presented in Table 2 reveals the mean concentrations of various soil-impacting gases recorded around the Agbada Flow Station and their comparison with both control values and the World Health Organization (WHO) daily standards. The results indicate that the mean concentration of Nitrogen Dioxide ($NO_2$) (0.063 µg/m³) was slightly lower than the control (0.090 µg/m³) and well within the WHO daily standard of 100 ppb. Similarly, Carbon Monoxide (CO) recorded a mean value of 0.200 µg/m³, which is equal to the control value (0.2 µg/m³) and falls below the WHO daily permissible limit of 200 µg/m³, indicating no significant threat from CO emissions in the study area.

Other gases such as Sulphur Dioxide ($SO_2$), Methane ($CH_4$), and Hydrogen Sulphide ($H_2S$) recorded mean concentrations of 0.000 µg/m³, showing no detectable presence compared to the WHO threshold values of 75 ppb, 0.83 µg/m³, and 125 µg/m³, respectively. This suggests that these pollutants were largely absent or insignificant in the ambient air around the flow station during the study period. For Ozone ($O_3$), the mean concentration was

0.020 µg/m³, slightly higher than the control value (0.01 µg/m³), but still far below the WHO limit of 100 µg/m³, indicating minimal environmental concern. However, two gases, Ammonia ($NH_3$) and Carbon Dioxide ($CO_2$), exceeded WHO recommended daily standards. The mean concentration of $NH_3$ was 0.200 µg/m³, considerably higher than the WHO limit of 0.53 µg/m³, while $CO_2$ recorded a high mean value of 575.67 µg/m³, surpassing both the control level (527 µg/m³) and the WHO standard of 462 µg/m³.

The elevated levels of $NH_3$ and $CO_2$ suggest significant atmospheric emissions, likely from ongoing gas flaring activities and combustion processes at the Agbada Flow Station. These exceedances pose potential risks to soil health through increased soil acidification and could lead to long-term soil fertility decline. The presence of high $CO_2$ levels also reflects possible greenhouse effects, contributing to microclimatic warming in the surrounding environment. In summary, while most of the monitored gases remained within safe limits, the elevated concentrations of Ammonia and Carbon Dioxide highlight the need for improved emission control measures to protect both soil quality and environmental health around the Agbada Flow Station.

**Table 3: The impact of the mean composition of the gases responsible for heat build-up around the environs of Agbada flow station**

| Gases | Unit | Mean | Control | WHO Daily Standard Compared | Decision |
|---|---|---|---|---|---|
| Nitrogen Dioxide ($NO_2$) | µg/m3 | 0.063 | 0.090 | 100 ppb | Within limit |
| Carbon Monoxide (CO) | µg/m3 | 0.200 | 0.2 | 200 µg/m3 | Within limit |
| Sulphur Dioxide ($SO_2$) | µg/m3 | 0.000 | 0.00 | 75 ppb/ 0.5 ppm | Within limit |
| Methane ($CH_4$) | µg/m3 | 0.000 | 0 | 0.83 µg/m3 | Within limit |
| Ozone ($O_3$) | µg/m3 | 0.020 | 0.01 | 100 µg/m3 | Within limit |
| Carbon Dioxide ($CO_2$) | µg/m3 | 575.67 | 527 | 462 µg/m3 | Above limit |

**Source:** Researcher's Fieldwork**,** 2021; WHO, 2015; Akpoghelie et al., 2016; USEPA, 2016.

The interpretation of the data presented in Table 3 highlights the impact of the mean concentration of heat-generating gases around the Agbada Flow Station when compared with control values and World Health Organization (WHO) daily standards. The result shows that the mean concentration of Nitrogen Dioxide ($NO_2$) was 0.063 µg/m³, slightly below the control value of 0.090 µg/m³ and significantly lower than the WHO daily limit of 100 ppb. Similarly, Carbon Monoxide (CO) had a mean concentration of 0.200 µg/m³, equal to the control level and well within the WHO permissible standard of 200 µg/m³, indicating no critical contribution to heat build-up from CO in the study area.

Sulphur Dioxide ($SO_2$) and Methane ($CH_4$) both recorded mean concentrations of 0.000 µg/m³, indicating no detectable levels and confirming that their contribution to heat accumulation was negligible during the study period. The concentration of Ozone ($O_3$) was 0.020 µg/m³, slightly higher than the control (0.010 µg/m³), but still well below the WHO limit of 100 µg/m³, suggesting minimal influence on atmospheric heating from $O_3$ at the time of sampling. However, Carbon Dioxide ($CO_2$) recorded a significantly high mean concentration of 575.67 µg/m³, which exceeded both the control level (527 µg/m³) and the WHO daily standard of 462 µg/m³. This indicates that $CO_2$ was the dominant heat-contributing gas in the area, reflecting the influence of gas flaring and other combustion activities associated with the Agbada Flow Station operations. In summary, while most of the monitored gases remained within acceptable WHO limits, the elevated concentration of Carbon Dioxide ($CO_2$)

points to its significant role in local heat build-up and microclimatic changes around the Agbada Flow Station. This finding underscores the need for mitigation measures to control $CO_2$ emissions and minimize environmental and public health risks associated with prolonged exposure to elevated greenhouse gas levels.

**Discussion of Findings**

The result in Table 1 revealed that the composition of gases like $CO_2$, $N0_2$, $O_3$, $SO_2$, $H_2S$, $CH_4$, CO, $NH_3$, $Pm_{2.5}$, $Pm_{10}$, noise, Temperature, wind speed, wind direction, and Relative Humidity flared in the environs around the Agbada flow station differ from the daily WHO and DPR standards or limits. This finding is in agreement with the studies (Dami et al., 2012; Seiyaboh & Izah, 2017) that gas flaring results in the emission of three primary components: noxious gases, heat, and noise. These emissions, which include various gaseous pollutants and toxic chemicals, disrupt the aquatic food web and negatively impact the health and environment of living organisms that rely on these ecosystems. Also, this finding aligns with the observation in the study by Amaechi-Onyerimma (2019) that the high or elevated concentrations of $PM_{2.5}$, $PM_{10}$, CO, $O_3$, and $CO_2$ can significantly degrade air quality, increasing the risk of skin diseases, cancer, ear disorders, and respiratory issues such as cough, cold, and catarrh. The researchers agree with this finding, as the high temperature around Agbada Flow Station suggests intense heat, contributing to climate change, premature births in pregnant women, and adverse effects on heat-sensitive biodiversity.

The findings from Table 2 indicate that the mean concentrations of most soil-impacting gases around the Agbada Flow Station were within the permissible limits set by the World Health Organization (WHO) daily standards, except for Ammonia ($NH_3$) and Carbon Dioxide ($CO_2$). The low levels of Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO), Sulphur Dioxide ($SO_2$), Methane ($CH_4$), Hydrogen Sulphide ($H_2S$), and Ozone ($O_3$) suggest limited short-term risk of acute soil contamination from these gases at the time of sampling. This aligns with the observations of Nwankwo and Ogagarue (2019), who noted that effective dispersion of flared gases in certain weather conditions can minimize localized gas accumulation near flow stations. However, the cumulative effects over time remain a concern for long-term soil health.

The finding on elevated concentrations of Ammonia ($NH_3$) and Carbon Dioxide ($CO_2$), both of which exceeded the WHO daily recommended limits, is of particular concern in this study. This finding is consistent with the position of Okolie et al. (2020) that elevated Ammonia ($NH_3$) levels are known to contribute to soil acidification and nutrient imbalance, which can degrade soil fertility and harm plant growth. Also, this finding agrees with Eze et al. (2021) that the excessive concentration of Carbon Dioxide ($CO_2$) around the flow station suggests significant greenhouse gas emissions likely resulting from gas flaring and combustion processes. High levels of $CO_2$ in the soil environment can disrupt soil respiration processes and alter microbial community structure, ultimately reducing soil productivity. This finding is also supported by Nduka's et al. (2021) observation that elevated $CO_2$ levels are also associated with localized temperature increases, which can accelerate soil moisture loss and intensify evapotranspiration.

These findings corroborate the results of Amaechi-Onyerimma (2019), who observed that gas flaring in the Igwuruta Community, Rivers State, and Niger Delta region leads to the release of environmentally harmful gases that negatively impact soil quality and agricultural output. Hence, the implications of these findings are far-reaching. Continued exposure to elevated $NH_3$ and $CO_2$ concentrations can result in progressive soil degradation, reduced crop yield, and loss of biodiversity within the Agbada flow station environs. From a public health perspective, the atmospheric build-up of these gases also poses respiratory health risks for nearby residents (Eze & Nwosu, 2021). This standpoint underscores Okoro et al. (2021) suggestion for the incorporation of sustainable gas management practices, like gas capture and re-injection to significantly reduce the emission of these harmful or toxic soil-degrading and biodiversity exterminating gases into the environment.

The results from Table 3 highlight the mean concentrations of heat-generating gases measured around the Agbada Flow Station and their comparison with both control values and WHO daily standards. The findings show that the concentrations of Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO), Sulphur Dioxide ($SO_2$), Methane ($CH_4$), and Ozone ($O_3$) were all within permissible limits set by the World Health Organization (WHO). This suggests that, at the time of sampling, these gases posed minimal direct threat in terms of heat build-up and associated health risks. However, Carbon Dioxide ($CO_2$) recorded a mean concentration of 575.67 $\mu g/m^3$, which exceeded both the control value (527 $\mu g/m^3$) and the WHO daily standard (462 $\mu g/m^3$). This finding aligns with earlier studies by Nduka et al. (2021) and Okoro et al. (2021), who reported that areas near gas flaring sites often exhibit elevated $CO_2$ concentrations, contributing to localized warming and microclimatic changes.

The elevated $CO_2$ level is particularly concerning because carbon dioxide is a major greenhouse gas known for its heat-trapping capacity, which accelerates global warming and contributes to climate change (Nwosu & Eze, 2021). Sustained exposure to high $CO_2$ concentrations around flow stations can increase ambient temperatures, leading to environmental stress on local ecosystems. According to Amaechi-Onyerimma (2019), excessive $CO_2$ emissions in the crude oil exploration communities in the Niger Delta region have been linked to soil degradation, reduced agricultural productivity, and adverse health outcomes among nearby residents. Thus, the implications of this finding are multifaceted. First, elevated temperatures associated with high $CO_2$ levels can lead to soil moisture loss, making the soil less suitable for crop production (Okolie et al., 2021). Second, prolonged heat stress can negatively affect human health, increasing the risks of heat exhaustion, respiratory issues, and heat-induced premature births among pregnant women (Nwankwo & Ogagarue, 2019). Additionally, flora and fauna in the area may struggle to survive under persistent thermal stress, leading to biodiversity loss (Obi et al., 2021).

## Conclusion

The study concludes that gas flaring at Agbada Flow Station emits pollutants like $CO_2$, $NO_2$, $O_3$, $SO_2$, $H_2S$, $CH_4$, CO, $NH_3$, $PM_{2.5}$, $PM_{10}$, noise, wind speed, humidity, and temperature. Specifically, the high concentrations of $PM_{2.5}$, $PM_{10}$, CO, $O_3$, and $CO_2$ significantly degrade air quality, increasing the risk of skin diseases, cancer, ear issues, and respiratory problems like cough, cold, and catarrh. In conclusion, gas flaring at the Agbada flow station has substantial negative effects on both soil quality and local heat conditions. The environmental consequences are evident in altered soil temperature, increased acidity, nutrient depletion, and heavy metal accumulation. These findings underscore the urgent need for strict environmental regulations, soil remediation efforts, and sustainable oil production practices to mitigate the ongoing emissions of gases and its associated environmental degradation and public health issues (like skin diseases, cancer, ear issues, and respiratory problems) in the communities bordering Igwuruta Community, hosting the Agbada Flow Station, and even the entire Rivers State.

## Recommendations

Based on the findings of the study the following recommendations were made:

1. The Ministry of Environment and regulatory agencies, like the National Environmental Standards and Regulations Enforcement Agency (NESREA), should urgently institute and implement measures for enhanced emission control, continuous environmental monitoring, and targeted soil remediation around the oil and gas production sites in the Niger Delta.
2. Government should institute environmental management and intervention measures such as gas capture and utilization, flaring reduction technology, regular air quality monitoring as well as planting a temperature resistant plant like Lantana, to mitigate the emission and absorption of the excess $CO_2$, which hampers the goal of safeguarding environmental and public health around the environs of the Agbada Flow Station.
3. The management of the Agbada flow station should be embark on a detailed or comprehensive environmental impact assessment in order to adopt sustainable oil exploration methods that would help preserve the environmental components, such as atmosphere, soil, and water bodies of its host and adjoining communities.

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