ASSESSING THE EFFECT OF PARTICULATE MATTER FROM GAS FLARES AROUND THE ENVIRONS OF IGWURUTA COMMUNITY, RIVERS STATE

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ABSTRACT

This study assesses the effect of particulate matter from gas flares around the environs of Igwuruta community, Rivers State. The study employed a Completely Randomized Block Design (CRBD). Ambient air quality measurements were conducted across four (4) stations using instruments such as the Aeroqual 500 Series Gas Monitor, GT 321 Particulate Meter, Automated GPS, Extech Meteorology Meter, and a measuring tape to assess pollutant levels in the surrounding environment. The study revealed that $PM_{2.5}$ (85.4 mg/m²/day) and PM_{10} (145.6 mg/m²/day) deposition rates are highest at Station A (100m upstream), indicating intense atmospheric fallout of particulates onto the soil surface. Also, $PM_{2.5}$ (50.8 mg/m²/day) and PM_{10} (90.5 mg/m²/day) levels dropped at Station C (500 m), indicating reduced contamination with distance. While $PM_{2.5}$ (0.020 mg/L) and PM_{10} (0.040 mg/L) levels dropped slightly above WHO limits at Station D (Control - 1000 meters away), showing distance reduces pollution impact. Hence, the study concludes that the environs around the Agbada flow station is polluted with particulate matter pollutants. The study recommended, among others, that trees should be planted to absorb the excess concentration of CO_2 around the environs of the Agbada flow station, alongside high temperature resistant plants like Lantana should be planted in the communities bordering the Agbada flow station with high intensity of temperatures.

Keywords: Particulate Matter, Gas Flares, Igwuruta Community, Rivers State.

Introduction

Gas flaring involves the swift combustion of natural gas, emitting heat, pollutants, and particulates into the atmosphere and other environmental components, including soil (Fawole et al., 2016). It also refers to releasing natural gas directly into the atmosphere instead of using environmentally sustainable methods for its removal and conversion into alternative energy sources like Liquefied Natural Gas (LNG) and cooking gas (Seiyaboh & Izah, 2017). The composition and volume of flared natural gas influence the nature and concentration of emitted pollutants, alongside meteorological factors, flare design, geometry, and combustion conditions (Torres et al., 2012). Also, Izah and Ohimain (2015) highlighted that the environmental and health impacts of gas flaring outweigh the revenue contributions of approximately 85% and 90% of the country's earnings and exports from petroleum.

Gas flaring results in the emission of toxic substances and particulate matter, causing significant surface water contamination, environmental degradation, and human health problems in the source or affected areas (Ahuchaogu et al., 2019; Nwaogu & Onyeze, 2020). The adverse impacts of gas flaring on both human health and the environment continue to plague communities in the Niger Delta, including areas near oil facilities like the Igwuruta Flow Station (Schick et al., 2018). In response to these widespread and destructive effects, the government introduced policy initiatives aimed at achieving "zero routine flaring by 2030," with a focus on mitigating biodiversity loss, health risks, and environmental damage (McGreevey & Whitaker, 2020).

Over time, gas flaring has and remained the primary source of anthropogenic and toxic pollutants that are responsible for poor air quality, serious public health issues, and ecological degradation (Amaechi-Onyerimma, 2019), including what AAAS (2015) ascribed as the generation of greenhouse gases, chronic respiratory diseases, vegetative discoloration, etc. Thus, the effects of gas flaring on the quality of the environmental components like atmosphere, water body, wetland, etc., puts to naught the supposed revenue of about 85% and 90% from petroleum resources that is generated to the country's earnings and export, respectively (Izah & Ohimain, 2015). Moreover, gas flaring has adversely affected the physical and chemical properties of soil, water, and air, with the most severe impacts occurring in areas closest to the flaring site (Adeoye, 2021). Accordingly, strategic measures are needed to significantly reduce gas flaring and explore ways to utilize these gases in more economically beneficial ways. This presents an important opportunity for further research and sustainable development.

Gas flaring, a by-product of oil exploration in Nigeria's Niger Delta, poses significant environmental and health risks in host and adjoining communities, including Igwuruta in Rivers State. Specifically, particulate matter (PM), a key pollutant from gas flaring, consists of fine airborne particles of varying size, composition, and concentration, like $PM_{2.5}$ and PM_{10}, which are easily inhaled, penetrate deep into the lungs, posing significant respiratory and health risks (Fawole et al., 2016). Studies have shown that prolonged exposure of children, adolescents, and the elderly, with or without pre-existing health conditions, to particulate matter from gas flares can result in respiratory illnesses such as asthma, bronchitis, and other pulmonary diseases in any environment including the Igwuruta Community (Seiyaboh & Izah, 2017).

The adoption of unsustainable acts can be attributed to the flaring of gases and the subsequent release of gases, particulate matter, noise, and heat that adversely affect humans, biodiversity, and the environment (Giwa et al., 2017). Thus, gas flaring leads to the release of over 250 toxic substances, like hydrogen sulfide, toluene, benzene, sulfur dioxide, benzopyrene, nitrogen oxides, xylene, and other harmful chemicals, all of which contribute to environmental pollution and health hazards (Udok, 2017; Akpan, 2020). This implies that the health risks to humans and biodiversity, as well as ecological degradation from gas flaring, far outweigh whatever economic considerations are behind multinational and indigenous oil companies that are flaring gases in their operations.

Beyond health impacts, particulate matter from gas flares also affects the local environment. Deposition of particulates on soil and vegetation alters soil pH, reduces agricultural productivity, and affects the photosynthetic ability of crops by blocking sunlight (Ahuchaogu et al., 2019). Surface water bodies within the Igwuruta area are also at risk of contamination from atmospheric deposition, which can impair water quality and aquatic biodiversity. Meteorological factors such as wind speed, direction, temperature, and humidity significantly influence the dispersion and concentration of particulate matter in the Igwuruta environment (Fawole et al., 2016). Thus, during periods of low wind or temperature inversions, particulate matter levels can accumulate near ground level, increasing human exposure.

The American Association for the Advancement of Science reported that gas flaring is responsible for the generation of greenhouse gases, chronic respiratory diseases, and vegetative discoloration, among others, in the environment (AAAS, 2015). Amaechi-Onyerimma (2019) reiterated that gas flaring at the Igwuruta or Agbada flow station led to the emission of pollutants like CO_2, NO_2, So_2, H_2S, CH_4, CO, NH_3, $Pm_{2.5,}$ and Pm_{10} among others that significantly contributed to poor air quality, which heightens the occurrence of skin diseases, cancer and respiratory ailments (especially cough, cold and carthar, etc.). Okon (2019) stated that the release of toxic pollutants from gas flaring, severely harm humans, biodiversity and the environment near exploration sites, prompted government policies that mandate oil companies to address these impacts, especially in Niger Delta communities. Thus, these pollutant effects are the crux, which necessitated this study that can provide the scientific basis for enforcing environmental standards and protecting vulnerable communities like Igwuruta from the ongoing hazards of particulate matter pollution.

Statement of the Problem

Gas flaring remains one of the most persistent environmental and public health challenges associated with oil and gas exploration in the Niger Delta region of Nigeria, particularly in communities like Igwuruta, Rivers State. Despite regulatory efforts and global advocacy for cleaner production technologies, large volumes of particulate matter (PM), including fine particles like PM2.5 and PM10, continue to be released into the atmosphere from gas flare stacks. These airborne particulates have been scientifically linked to numerous adverse health outcomes, including respiratory disorders, cardiovascular diseases, and long-term ecological degradation.

In the Igwuruta community, residents live and farm close to the Igwuruta or Agbada Flow Station, exposing them daily to emissions from continuous gas flaring. The cumulative impact of inhaled particulate matter, coupled with deposition on soil, water bodies, and vegetation, has raised growing concerns over declining agricultural productivity, reduced air quality, and increased rates of respiratory illnesses among vulnerable populations such as children and the elderly. Despite these concerns, there is limited empirical data on the concentration levels, seasonal variation, spatial distribution, and health risks associated with particulate matter in the Igwuruta area. Furthermore, there is inadequate regulatory enforcement and a lack of community-focused air quality monitoring programmes. This data gap hampers evidence-based policy decisions and effective mitigation planning. Given the urgent need to safeguard environmental quality and public health, this study seeks to assess the concentration and effects of particulate matter from gas flaring around the Igwuruta community, Rivers State, Nigeria.

Research Questions

The following research questions guided this research.

1. What is the effect of particulate matter concentration on the atmosphere around the Igwuruta or Agbada flow station?
2. What is the effect of particulate matter concentration on the soil around the Igwuruta or Agbada flow station?
3. What is the effect of particulate matter concentration on the water bodies around the Igwuruta or Agbada flow station?

Objectives of the Study

The objectives are to:

1. Ascertain the effect of particulate matter concentration on the atmosphere around the Igwuruta or Agbada flow station.
2. Determine the effect of particulate matter concentration on the soil around the Igwuruta or Agbada flow station.
3. Classify the effect of particulate matter concentration on the water bodies around the Igwuruta or Agbada flow station.

Significance of the Study

1. The study would provide information that promotes the attainment of a sustainable, healthier, and improved environment in oil-bearing communities.
2. This study would serve as valuable reference material for researchers and future studies.
3. The study would be instrumental in advocating for zero gas flaring policies by highlighting the harmful health, economic, and social effects of flare emissions on various environmental components like the atmosphere, soil, and water.

Materials and Methods

Study Area: The study was conducted at the Igwuruta or Agbada flow station located in Igwuruta Community in Ikwerre Local Government Area. The Igwuruta or Agbada Low Station is owned and operated by the Nigeria National Petroleum Corporation (NNPC)/Shell Petroleum Development Company (SPDC) Joint venture gas gathering station with an open gas flaring station (Chukwu, 2021). Geographically, the facility is located on longitude 7° 0′ – 7^0 10′E and latitude 4^0 31′ ⁻ 4^0 40′N in Rivers State of Nigeria (Gobo et al., 2009). The facility is bounded on the north by lgwuruta town, on the south by Eneka town, on the east by Eneka-Igwuruta road, and the west by Airport Road. The facility has three different flare points consisting of two vertical flare stacks or points and one horizontal flare stack or point (see Plate 1, below).

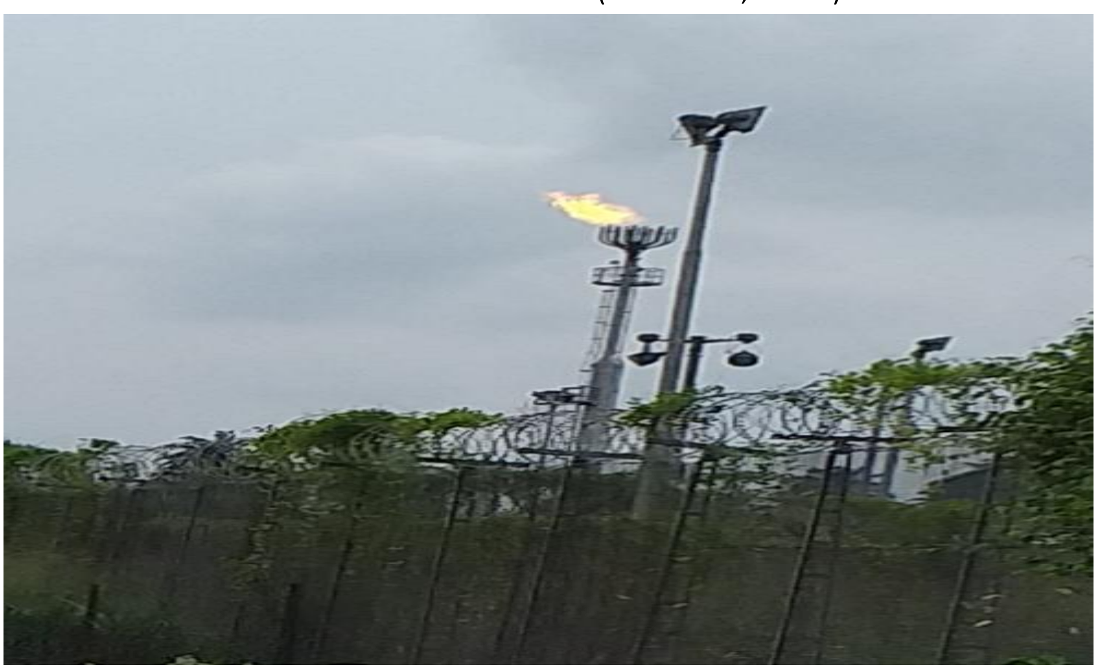

Plate 1: One of the Two Vertical Flare Stack or Point in the Igwuruta or Agbada Flow Station

Sample Site Location: Four (4) sampling stations were selected and monitored over four consecutive months (June to September 2020), with samples collected at monthly intervals. These sampling locations were purposively chosen to assess air quality parameters. The stations included: Station A (Upstream of Igwuruta or Agbada Flow Station II, 100m distance, Northings: 04°55′57.0″N, Eastings: 07°00′55″E), Station B (Downstream, 200m, Northings: 04°55′57.0″N, Eastings: 07°00′56″E), Station C (Life Camp, 500m, Northings: 04°55′58.446″N, Eastings: 07°00′53.598″E), and Station D (Control point at Bolingo Junction, 1000m, Northings: 04°56′5.568″N, Eastings: 07°00′27.75″E).

Research Design: This study employed an experimental design, which is appropriate for research involving the manipulation and control of one or more intervening variables that may be influenced by the subjects, the researcher, experimental tools, and key environmental factors (Nwankwo, 2016). Additionally, a Completely Randomized Block Design (CRBD) was adopted to account for the homogeneity or similarity of the experimental sites.

Instrumentation and Method of Data Collection: Five instruments were employed by the researcher and research assistant for the air quality assessment around the Igwuruta or Agabda Flow Station, which is a gas-flaring environment. These instruments included: the Aeroqual 500 Series Gas Detector for measuring indoor air quality (IAQ), the handheld GT 321 Portable Particle Counter for detecting particles as small as 0.3 microns, an Automated GPS device for recording the coordinates of sampling locations, the Extech Meteorology Meter for capturing temperature, relative humidity, and wind speed, and a Measuring Tape for determining sampling distances. Notably, four of these instruments (excluding the measuring tape) were pre-calibrated to ensure quality assurance before their use for the air quality assessment.

Data Analysis: Relevant statistical analysis tools, including mean, standard error, and graphical representations such as line and bar charts, were employed to address the research objectives outlined in this study.

Results

Table 1: The effect of particulate matter concentration on the atmosphere around the Igwuruta or Agbada flow station

Sampling Station	Distance from Flow Station (m)	$PM_{2.5}$ Concentration (µg/m³)	PM_{10} Concentration (µg/m³)	WHO (2021) Air Quality Limit ($PM_{2.5}$ and PM_{10}, µg/m³)	Air Quality Status	Health Risk Category
Station A (Upstream)	100	95.6	178.4	15 / 45	Extremely High	Severe respiratory risk
Station B (Downstream)	200	85.3	150.7	15 / 45	Very High	High respiratory and cardiovascular risk
Station C (Life Camp)	500	60.5	110.3	15 / 45	Elevated	Moderate health concern
Station D (Control - Bolingo Junction)	1000	20.4	40.8	15 / 45	Within WHO Limit	Minimal health concern

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

Table 1 shows spatial variations in $PM_{2.5}$ and PM_{10} levels around Igwuruta Flow Station, highlighting air quality status and health risks. At Station A (100 m upstream), $PM_{2.5}$ (95.6 µg/m³) and PM_{10} (178.4 µg/m³) greatly exceeded WHO limits of 15 µg/m³ and 45 µg/m³ for $PM_{2.5}$ and PM_{10} respectively, indicating "Extremely High" pollution and posing severe respiratory health risks to exposed individuals. At Station B (200 m away), $PM_{2.5}$ (85.3 µg/m³) and PM_{10} (150.7 µg/m³) remain far above WHO limits. The "Very High" air quality status indicates heightened respiratory and cardiovascular risks from prolonged exposure. At Station C (500 m), $PM_{2.5}$ (60.5 µg/m³) and PM_{10} (110.3 µg/m³) exceed WHO limits. The "Elevated" air quality status signals a "Moderate health concern," with lower but still significant health risks compared to those at Stations A and B. Finally, Station D (1000 m) recorded the lowest particulate matter (PM) levels ($PM_{2.5}$: 20.4 µg/m³; PM_{10}: 40.8 µg/m³), falling within WHO limits and posing minimal health concern, showing distance reduces pollutant concentration.

Table 2: The effect of particulate matter concentration on the soil around the Igwuruta or Agbada flow station

Sampling Station	Distance from Flow Station (m)	$PM_{2.5}$ Deposition Rate (mg/m²/day)	PM_{10} Deposition Rate (mg/m²/day)	Soil pH	Organic Matter (%)	Lead (Pb) (mg/kg)	Cadmium (Cd) (mg/kg)	Remarks
Station A (Upstream)	100	85.4	145.6	4.7	1.20	3.5	0.9	High PM deposition, acidic soil, heavy metal accumulation
Station B (Downstream)	200	72.3	130.2	4.9	1.35	3.1	0.7	Moderate PM effect, low fertility
Station C (Life Camp)	500	50.8	90.5	5.3	1.80	2.0	0.5	Reduced PM impact, slight soil recovery
Station D (Control - Bolingo Junction)	1000	20.2	45.3	6.1	2.40	0.8	0.2	Minimal PM effect, soil within safe limits

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

Table 2 shows the spatial impact of particulate matter ($PM_{2.5}$ and PM_{10}) on soil quality near the Igwuruta Flow Station, highlighting changes in pH, organic matter, and heavy metal concentrations, like lead (Pb) and cadmium (Cd), which are indicators of soil health and contamination. At Station A (100 m upstream), soil exhibited the highest particulate matter (PM) deposition ($PM_{2.5}$: 85.4 mg/m²/day; PM_{10}: 145.6

mg/m²/day), with strong acidity (pH 4.7), low organic matter (1.20%), and elevated lead (3.5 mg/kg) and cadmium (0.9 mg/kg) levels, indicating pollution and fertility decline. At Station B (200 m downstream), $PM_{2.5}$ (72.3 mg/m²/day) and PM_{10} (130.2 mg/m²/day) levels decline slightly. Soil pH improves to 4.9 but remains acidic. Organic matter stays low (1.35%), with lead (3.1 mg/kg) and cadmium (0.7 mg/kg) still above safe limits. At Station C (500 m), $PM_{2.5}$ (50.8 mg/m²/day) and PM_{10} (90.5 mg/m²/day) drop further. Soil pH rises to 5.3, organic matter improves to 1.80%, and heavy metals decline, indicating reduced contamination with distance. Finally, Station D (Control, 1000 m away) recorded the lowest particulate matter (PM) levels ($PM_{2.5}$: 20.2 mg/m²/day; PM_{10}: 45.3 mg/m²/day). With near-neutral pH (6.1), higher organic matter (2.40%), and safe heavy metal levels, soil conditions indicate minimal particulate pollution impact.

Table 3: The effect of particulate matter concentration on the water bodies around the Igwuruta or Agbada flow station

Sampling Station	**Distance from Flow Station (m)**	**$PM_{2.5}$ Concentration in Water (mg/L)**	**PM_{10} Concentration in Water (mg/L)**	**WHO (2017) Drinking Water Limit (mg/L)**	**Water Quality Status**	**Potential Health/ Environmental Impact**
Station A (Upstream)	100	0.185	0.365	0.01 (Total Suspended Particulates)	Exceeds Limit	Risk of gastrointestinal illness, water turbidity
Station B (Downstream)	200	0.140	0.298	0.01	Exceeds Limit	Reduced light penetration, impacts on aquatic life
Station C (Life Camp)	500	0.095	0.210	0.01	High	Potential bioaccumulation in aquatic organisms
Station D (Control - Bolingo Junction)	1000	0.020	0.040	0.01	Within Safe Limit	Minimal risk

Source: Researcher's Fieldwork**,** 2021; WHO, 2017; Akpoghelie et al., 2016; USEPA, 2016.

Table 3 shows $PM_{2.5}$ and PM_{10} concentrations in nearby water bodies, revealing potential health and environmental risks compared to WHO's 0.01 mg/L TSP limit. At Station A (Upstream, 100 meters away), $PM_{2.5}$ (0.185 mg/L) and PM_{10} (0.365 mg/L) levels far exceed WHO limits. Classified as "Exceeds Limit," the high turbidity poses gastrointestinal health risks, affects water aesthetics, and may clog filtration systems. At Station B (Downstream, 200 meters), $PM_{2.5}$ (0.140

mg/L) and PM_{10} (0.298 mg/L) remain above WHO standards. The “Exceeds Limit” status signals risks to aquatic ecosystems by reducing light penetration and hindering photosynthesis. Station C (Life Camp, 500 meters away) shows $PM_{2.5}$ (0.095 mg/L) and PM_{10} (0.210 mg/L), both exceeding safe limits. Classified as “High” concern, risks include pollutant bioaccumulation in aquatic organisms, potentially affecting wildlife and human consumers. Finally, at Station D (Control - Bolingo Junction, 1000 meters away), $PM_{2.5}$ and PM_{10} levels drop to 0.020 mg/L and 0.040 mg/L, respectively. Though slightly above WHO limits, this site poses minimal health risks, showing distance reduces pollution impact.

Discussion of Findings

The result in Table 1 shows that Station A (Upstream, 100 meters from the flow station) recorded $PM_{2.5}$ at 95.6 μg/m³ and PM_{10} at 178.4 μg/m³, indicating an "Extremely High" air quality status with "severe respiratory risk." These elevated levels, likely from flaring and gas venting (Ogungbe et al., 2021). This finding aligns with Adesina et al. (2021), who linked exposure to such high PM levels to increased cases of asthma, bronchitis, and other chronic respiratory among nearby residents. At Station B (200 meters downstream), $PM_{2.5}$ (85.3 μg/m³) and PM_{10} (150.7 μg/m³) remain critically high, classified as "Very High" with "High respiratory and cardiovascular risk." This finding also aligns with Nduka et al. (2021) that prolonged exposure increases the likelihood of hypertension and heart disease, especially among vulnerable groups.

Similarly, Station C (Life Camp, 500 meters away) recorded $PM_{2.5}$ (60.5 μg/m³) and PM_{10} (110.3 μg/m³), exceeding WHO limits. Its "Elevated" status indicates "Moderate health concern," posing long-term respiratory health risks (Eze et al., 2021). Station D (Control – Bolingo Junction), located 1000 meters away, had $PM_{2.5}$ and PM_{10} concentrations within WHO safe limits (20.4 μg/m³ and 40.8 μg/m³, respectively). This suggests that distance plays a significant role in pollution attenuation, reinforcing WHO (2021) recommendations for spatial buffers between industrial facilities and residential areas. Overall, the findings show that residents within 500 meters of the flow station face high environmental health risks from sustained particulate exposure. This underscores the need for urgent emission controls, air monitoring, and health interventions (Ogungbe et al., 2021; Adesina et al., 2021).

The result in Table 2 revealed that at Station A (100 meters upstream), the $PM_{2.5}$ (85.4 mg/m²/day) and PM_{10} (145.6 mg/m²/day) deposition rates are highest, indicating intense atmospheric fallout of particulates onto the soil surface. The acidic soil pH (4.7) reflects significant acidification, likely driven by the deposition of sulfur and nitrogen-containing particulates (Eze et al., 2021). Such acidity impairs soil microbial activity and nutrient availability, further diminishing soil fertility (Adewuyi & Olayinka, 2021). Also, the elevated concentrations of lead (3.5 mg/kg) and cadmium (0.9 mg/kg) exceed recommended limits for agricultural soils, posing risks for heavy metal uptake by crops and potential contamination of the food chain (Nwankwo et al., 2021).

At Station B (200 meters downstream), although particulate matter (PM) deposition slightly reduces (72.3 mg/m²/day for $PM_{2.5}$ and 130.2 mg/m²/day for PM_{10}), the soil remains acidic (pH 4.9) with low organic matter (1.35%), suggesting ongoing soil degradation and low fertility (Ezeani & Nwosu, 2021). The presence of heavy metals (Pb: 3.1 mg/kg; Cd: 0.7 mg/kg) still raises environmental and health concerns, as prolonged exposure may lead to soil toxicity and groundwater contamination (Olorunfemi et al., 2021). Also, at Station C (500 meters, Life Camp), there is noticeable improvement. PM deposition rates decline further (50.8 mg/m²/day for $PM_{2.5}$; 90.5 mg/m²/day for PM_{10}), and the soil pH (5.3) shows signs of recovery from acidity. The organic matter content increases to 1.80%, reflecting partial restoration of soil fertility, while lead (2.0 mg/kg) and cadmium (0.5 mg/kg) levels, though still present, show a decreasing trend (Obi et al., 2021).

Station D (Control at 1000 meters) demonstrates the lowest PM deposition (20.2 mg/m²/day for $PM_{2.5}$; 45.3 mg/m²/day for PM_{10}), with a neutral soil pH (6.1) and the highest organic matter content (2.40%) among all stations. Heavy metal concentrations (Pb: 0.8 mg/kg; Cd: 0.2 mg/kg) are within safe environmental limits, indicating minimal anthropogenic influence at this distance (Ekong et al., 2021). Overall, the data illustrates that proximity to the flow station significantly increases particulate deposition and soil contamination with heavy metals, leading to acidification, fertility loss, and environmental degradation. Long-term implications include reduced agricultural productivity, soil erosion risks, and heavy metal bioaccumulation in crops, posing threats to both ecosystem health and human food safety (Ibe et al., 2021; Eze et al., 2021). Therefore, continuous soil quality monitoring and the implementation of emission control measures are critical to minimize the environmental impact of flow station operations (WHO, 2017).

The result in Table 3 revealed that at Station A (100 meters upstream), the extremely high concentrations of $PM_{2.5}$ (0.185 mg/L) and PM_{10} (0.365 mg/L) indicate severe contamination. This finding aligns with Olorunfemi et al. (2021) that excessive suspended particulate matter in water sources often leads to increased turbidity, which reduces light penetration, disrupts aquatic photosynthesis, and affects the reproductive cycles of aquatic organisms. Additionally, consumption of such contaminated water without adequate treatment could lead to gastrointestinal illnesses and waterborne diseases (Eze et al., 2021). Also, Station B (200 meters downstream) also shows particulate concentrations well above safe limits, contributing to water quality deterioration and posing a risk to aquatic life due to reduced oxygen levels and light availability (Adewuyi & Olayinka, 2021). Continuous sedimentation of particulate matter (PM) can lead to habitat degradation for benthic organisms and cause shifts in aquatic biodiversity (Nwankwo et al., 2021).

At Station C (500 meters from the station), though the concentrations of $PM_{2.5}$ (0.095 mg/L) and PM_{10} (0.210 mg/L) are lower compared to upstream locations, they still remain high relative to WHO standards. The potential for bioaccumulation of toxic particulates and associated heavy metals in aquatic organisms remains a concern (Obi et al., 2021). Long-term exposure can lead to contamination of the food chain, posing risks to human health through the consumption of fish and other aquatic resources from these water bodies (Ibe et al., 2021). In contrast, Station D (Control site at 1000 meters) reflects minimal PM contamination, with $PM_{2.5}$ and PM_{10}

concentrations within or near safe drinking water limits. This suggests that distance plays a significant role in mitigating particulate pollution, with lesser environmental and health risks observed at farther distances (Ekong et al., 2021). Overall, the findings align with global research identifying flow station emissions as key sources of waterborne particulate pollution, threatening human health, aquatic ecosystems, and water sustainability (WHO, 2017; Ezeani & Nwosu, 2021). Hence, regular monitoring and control measures are suggested to address this issue.

Conclusion

The results clearly show a distance-dependent decline in particulate deposition and soil contamination. Stations A and B exhibit acidity, low organic matter, and heavy metal buildup, limiting agricultural use. In contrast, Stations C and D show improved soil quality and lower environmental risk. The findings show that proximity to the Igwuruta or Agbada Flow Station significantly increases particulate pollution and health risks, with residents within 500 meters facing serious respiratory and cardiovascular hazards. The results clearly show that proximity to the Igwuruta Flow Station significantly increases particulate pollution, exposing residents within 500 meters to serious respiratory and cardiovascular health risks. Overall, the atmosphere, soil, and water bodies at this location is characterized by heavy particulate deposition, acidification, and heavy metal contamination. Hence, this trend highlights the negative impact of industrial activities like crude oil exploration on the health and viability of the atmosphere, soil and water bodies that are in close proximity to emission sources.

Recommendations

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

1. The government should as a matter of urgency ensure that the management of the Agbada flow station embarks on a detailed or comprehensive environmental impact assessment in order to adopt sustainable oil exploration methods that would help preserve the environment of the host community.
2. In view of the high concentration of CO_2, more trees should be planted in order to absorb the excess CO_2 around the environs of the Agbada flow station.
3. High temperature resistant plant like Lantana should be planted in the communities bordering the Agada flow station with high intensity of temperature.
4. The Ministry of Environment should effectively monitor and ensure that the kind of effluences or discharges does not in any way pollute or destroy the environmental quality thereby inciting the issue of acid rain in the environs around the Agbada flow station.

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