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Evaluation of the Concentration and Distribution of Selected Air Pollutants in Some Towns in Ukwuani LGA of Delta State, Nigeria.

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Abstract

The research investigated the spatial distribution and concentrations of air pollutants, across six locations in Delta State, Nigeria which include two roadsides (Utagba-Unor junction, Obiaruku, and Umutu junction along Agbor-Abraka Road), two residential areas (Ebedei-Umueziogoli Quarters and Ebedei-Adonishaka), Ebedei-Unor near gas plant and a control site near the Ethiope River at Adonishaka. The ambient air quality of the locations were measured with Aeroqual Gas Monitoring Kit (ASTM D3249-95, 2011) with sampling done in the morning, afternoon, and evening period over seven consecutive days during the core of dry and wet seasons. The measured concentrations ranged obtained were CO (0.5 ± 0.07–3.29 ± 0.31 µg/m³), CO_2 (2.00 ± 0.04–7.39 ± 0.18 µg/m³), H_2S (0.00 ± 0.00–0.77 ± 0.12 µg/m³), NO (0.00 ± 0.00–0.83 ± 0.06 µg/m³), NO_2 (0.14 ± 0.05–4.04 ± 0.35 µg/m³), and CH_4 (0.40 ± 0.06–4.33 ± 0.35 µg/m³). CO was observed to have the highest concentrations at Ebedei-Adonishaka, while Ebedei-Unor recorded the highest concentration of CO_2, H_2S, NO, NO_2, and CH_4. Seasonal variations was observed with more pollutant during the dry season compared to wet season.

Keywords: Pollution**,** Air Pollutants, Air quality, Gas flaring, Seasonal distribution of pollutants.

Introduction

Air pollutants are compounds in the atmosphere that causes harm to humans, animals and plants. Air pollutants also cause damage to the environment and adversely affect the delicate balance of ecosystems (Evgenios et al, 2021). these substances are present in the atmosphere in various forms (solids, liquids, gases and droplets), compositions and concentrations, all of which depends on their source and prevailing environmental conditions (American Heart Association, 2010). The sources of air pollutants are broadly categorized into two main groups, natural and anthropogenic sources. Natural sources of pollutants are those found in nature, these include volcanic eruption, wildfire, dust storms, pollen, spores and others (Wimde, 2021). Anthropogenic source of air pollutants refer to pollution resulting from human activities such as agricultural practices, industrial activities, transportation, waste disposal, mining, energy production and other human activities (WHO, 2015).

Air pollutants are also classified as primary and secondary air pollutants. Primary air pollutants are pollutants that are directly discharged from specific sources into the atmosphere, these pollutants include, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S) and microorganisms. Secondary air pollutants on the other hand are formed in the atmosphere when primary pollutants chemically react. Secondary pollutants include ozone (O_3) formed from reaction of NO_x and VOCs under sunlight, sulfuric acid (H_2SO_4), sulfates, nitric acid (HNO_3), nitrates, peroxyacetyl nitrate (PAN), secondary particulate matter such as PM_{2-5} and PM_{10} and smog (Arshad et al, 2024).

While air pollutants are the substances that contaminated the atmosphere, air pollution is the introduction of these harmful substances or the excessive release of substances into the atmosphere that consequently cause harm to humans, animals, plant and the ecosystems (Bala et al, 2021; WHO, 2018). Air pollution is a critical global concern for public health and of urgent environmental importance for many years now (Zhu *et al.,* 2002), the key sources of air pollution across the globe include wastes from industrial processes, combustion of fossil fuel particularly by vehicles, agricultural activities, the use of biomass for domestic and industrial energy production, and natural sources like deforestation, and other natural environmental activities (Othman, 2010). Compounds such as carbon dioxide, nitrogen oxides, ozone and particulate matter have been linked to various human diseases most notably respiratory and cardiovascular diseases, these compounds have also been associated with plant diseases and changes in environmental conditions such as climate change and damage to ecosystems (Aliyu *et al.,* 2013). Reports from the World Health Organization (WHO) revealed that air pollution accounts for nearly 7 million deaths annually across the globe placing it among major environmental health hazards (WHO, 2014)).

In African today, the challenge of air pollution is wide spread and worsening, mainly because of mismanagement of natural and anthropogenic causes of pollution (Manisalidis, 2020), reliance in fossil fuel and biomass for energy generation (Aquila et al, 2024), deforestation (Ofremu et al, 2024), mining activities, and rapid urbanization to mention a few (Jiying et al, 2023). Amegah & Agyei-Mensah, (2017) reported that Sub-Saharan African suffers higher level of air pollution due to dependence on solid fuels in domestic uses. In Nigeria, large cities like Lagos, Kano and Port Harcourt have been reported to have dangerously high level of air pollution resulting from emissions from vehicles, industrial activities, waste burning, over population and gas flaring in the Niger Delta regions (Marais et al, 2014). The health and socio-economic implications of these pollutants in Nigeria as reported by a myriad of researcher include respiratory and cardiovascular diseases, cancer, eye irritation and infectious disease, environmental defacing, and damage of properties all of which result in huge economic losses (Pona et al, 2021). Studies released in 2020 revealed that an estimate of 11,200 premature deaths occurred in 2018 in Lagos, Nigeria due to the devastating air pollution of the city. The study also reported that pollution in Lagos state is associated with over $2.1 billion economic losses which is about 2.1% of the state's GDP. The main source of pollution in Lagos State as reported by the authors of the study include road transport, industrial emission, generator fumes, inappropriate dumping of refuse, and open burning of waste (Croitoru & Akpokodje, 2020).

The problem of air pollution in Nigeria is not only connected to the disadvantages of urbanization and industrialization. The rural communities in the country also significantly contribute to this problem, thus stirring up public and socio-economic concern from various stakeholders within and outside the country. According to Ogunro, (2024), households in both urban and rural settlement produce considerably large air pollutants as a result of the increasing dependency on biomass as primary sources of fuel. The extensive use of firewood and charcoal in domestic activities for instance is a major contributor to the growing incidence of respiratory illnesses and other health complication reported across the country (Ogunro, 2024; Akintunde *et al,*. 2024).

In the Niger Delta regions of Nigeria, air pollution is a crucial problem associated mostly with anthropogenic activities such as oil exploration and refinement, burning of biomass for fuel, and agro-industrial activities of large scale and cottage industries such as palm kernel and food processing (Glory Rechard et al, 2023). In Delta State Nigeria located in the Niger Delta region, one of the important contributor to air pollution is gas flaring. Gas flaring by definition is the controlled burning of natural gas which are by-products of oil exploration and refinement (Cheremisinoff, 2013). This industrial process is wasteful as large quantity of natural gas that could have been used for generating power is burnt. Nigeria is reported to be one of the largest gas flaring countries in the world, it is estimates that Nigeria loses about $2 million daily to gas flaring (Ezinna *et al.*, 2024). Other than the financial losses associated with this process, it also result to the releases of large quantity of toxic compounds into the atmosphere which including carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds. These pollutants contaminate water bodies, the air and soil thus leading to environmental damage, and health problems for the public and wide life (Manisalidis et al, 2020). Communities like Ebedei, Ebedei-Unor and Abraka of Delta State with close proximity to industrial sites are the ones mostly affected by air pollution, the elevated pollution level in their surrounding exacerbate environmental degradation and increases health risks. There is an urgent need for the government and other stakeholders such as environmental and health agencies to address this concern, to successfully do this require firmer implementation of effective environmental regulations tailored to suit the Nigerian society (Ojeh, 2012). However, achieving such a goal will require comprehensive studies to evaluate the distribution and concentration of air pollution in the country. Data obtained from such studies will provide invaluable insight that will help design effective targeted intervention designed to resolve the problem of air pollution and its associated consequences in Nigeria.

In this study, we focused on evaluating the distribution and concentration of air pollutants in selected towns within Ukwuani LGA of Delta State, Nigeria. Our objectives were to acquire comprehensive data on the spatial variability of air pollution and identify potential sources of air pollutants in Ukwuani LGA of Delta State and highlights the need for effective regulatory measures and sustainable practices to mitigate air quality deterioration and safeguard the well-being of the local population.

Materials & Methods

Study Area

Ukwuani Local Government Area is bounded to the North by Edo State, to the South and East by Ndokwa West and to the West by Ethiope East. (Atuma and Ojeh, 2013). Generally, two major wind systems influence the climate of Ukwuani. These are, north-east trade wind which carries cold dry air from the Sahara and the south-west trade wind which brings warm moist air from the Atlantic. The south-west wind prevails for most of the year, from March to October, while the north-east trade wind is responsible for the cold dry (Harmattan) period lasting about four months (November through February). These wind systems result in two annual distinct seasons; the rainy (wet) and dry season (Ojeh 2012).

Sample Site

Four sampling sites which include Utagba-Unor Junction in Obiaruku, Ebedei-Umueziogoli, Ebedei-Adonishaka, and Umutu Junction were selected to evaluate the distribution and concentrations of air pollutants in Ukwuani Local Government Area (LGA) of Delta State. These sites were selected due to their proximity to the gas plant at Ebedei-Unor (Fig 1). Ethiope River at Adonishaka was selected as control because of its distinct location and relatively low industrial activity. Although the experimental and control sites are within the same climatic zone, the control site is located approximately 3km away from Ebedei- Unor (gas flaring site), Ethiope River also lies outside the wind path coming through Ebedei-Unor, hence, resulting to reduce air pollution coming from the gas plant. Details about the sites are provided in table 1 below.

Table 1: Details of Sampling Sites (Using: G.P.S Model etrex 20)

S/N	Selected sites	Site Location	Distance from Gas Plant	Geographical Coordinates
1	Utagba-Unor junction Obiaruku	Road side	6 km	05°51′07.0N 006°09′82.8E
2	Umutu junction	Road side	3 km	05°54′64.2N 006°13′36.3E
3	Ebedei-Umueziogoli	Residential	4 km	05°49′55.8N 006°14′65.5E
4	Ebedei-Adonishaka	Residential	2 km	05°53′07.4N 006°12′25.7E
5	Ethiope River at Adonishaka	Control	3 km	05°53′39.4N 006°12′81.3E
6	Ebedei- Unor	Gas plant site	0 km	05°53′05.4N 006°13′01.3E

Sampling Period

Dry season samples were collected through October to December, 2014 and wet season samples were collected from May through July, 2015. Sampling was done for seven (7) days in each month above mentioned months across the six (6) sampling sites. Sampling was carried out at three consecutive period daily. Morning samples were collected between 8am and 10:30am, afternoon samples were collected by 12 noon till 3pm while evening samples were collected between 4pm and 7pm.

Sampling Procedure

Aeroqual gas detector model ASTM D3249-95, 2011 was used to carry out ambient air analysis. Specific gas probes where connected to the aeroqual gas detector, the detector was allowed to run for three (3) minutes to initialize and calibrate for data collection. Readings was taken in duplicates for three (3) minute after which the instrument is put off and the process repeated for the next reading.

Determination of Air Quality Parameters

Aeroqual gas monitoring kit was used to determine ambient air quality for each sampling location. After calibration, air is pulled into the device and diffuses through the air filter of the aeroqual gas monitor to the attached gas sensor, the sensor takes reading that is displayed on the output meter.

Statistical Analysis

All descriptive and inferential statistical analyses were done on the IBM-SPSS (IBM-SPSS, 2020).

Results

The average seasonal variations of the air pollution concentrations across the sites are illustrated in Table 2 to 7 respectively.

Table 2: Concentration and distribution of air pollutants in Utagba-Unor junction Obiaruku for dry and wet seasons

Dry Season(μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	1.16±0.13	3.74±0.34	0.00±0.00	0.02±0.00	1.16±0.13	1.33±0.33
2	0.85±0.05	3.30±0.40	0.00±0.00	0.03±0.00	0.85±0.05	1.00±0.58
3	0.57±0.07	3.79±0.08	0.00±0.00	0.02±0.00	0.57±0.07	1.67±0.33
4	0.99±0.05	4.10±0.06	0.00±0.00	0.02±0.00	0.99±0.05	0.67±0.33
5	1.00±0.04	3.86±0.03	0.00±0.00	0.02±0.01	1.00±0.04	1.00±0.58
6	1.13±0.10	3.83±0.30	0.00±0.00	0.03±0.00	1.14±0.10	1.10±0.06
7	1.11±0.10	4.53±0.19	0.00±0.00	0.03±0.01	1.02±0.01	1.40±0.21
Wet Season(μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	1.66±0.13	2.62±0.24	0.00±0.00	0.02±0.00	0.60±0.23	1.53±0.38
2	1.74±0.03	2.66±0.31	0.00±0.00	0.01±0.01	0.96±.04	2.50±0.12
3	1.85±0.01	2.07±0.02	0.00±0.00	0.00±0.00	0.98±0.02	2.60±0.23
4	1.60±0.03	2.40±0.34	0.00±0.00	0.00±0.00	1.04±0.09	2.60±0.08
5	1.69±0.01	2.14±0.23	0.00±0.00	0.00±0.00	0.95±0.10	1.67±0.12
6	1.77±0.03	2.00±0.04	0.00±0.00	0.00±0.00	0.85±0.08	1.93±0.12
7	1.84±0.03	2.10±0.05	0.00±0.00	0.00±0.00	0.14±0.05	1.50±0.17

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 0.5°51'07.0N, 006°09'82.8E

Table 2 shows the concentration and distribution of air pollutants for dry and wet seasons in Utagba-Unor junction Obiaruku.

Table 3: Concentration and distribution of air pollutants in Ebedei-Unor for dry and wet seasons

Dry Season(μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	2.44±0.31	5.67±0.03	0.37±0.04	0.50±0.06	2.47±0.19	3.60±0.15
2	2.39±0.17	6.08±0.10	0.42±0.06	0.60±0.06	2.63±0.12	3.57±0.12

3	2.26±0.10	6.20±0.02	0.44±0.05	0.67±0.09	2.80±0.06	3.77±0.09
4	2.47±0.21	6.35±0.26	0.53±0.04	0.83±0.07	3.00±0.06	4.07±0.07
5	2.96±0.07	6.87±0.08	0.60±0.11	0.83±0.03	3.07±0.33	3.80±0.06
6	2.99±0.03	7.03±0.18	0.60±0.092	0.60±0.06	2.97±0.03	3.53±0.13
7	3.35±0.32	7.39±0.02	0.58±0.07	0.57±0.09	2.97±0.09	3.57±0.20
Wet Season (μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	1.63±0.28	6.78±0.00	0.66±0.04	0.57±0.09	3.94±0.08	4.30±0.27
2	1.77±0.01	6.78±0.00	0.55±0.07	0.57±0.09	3.69±0.19	4.33±0.19
3	1.57±0.32	6.78±0.00	0.77±0.12	0.57±0.08	3.82±0.08	3.93±0.24
4	1.62±0.29	6.78±0.00	0.61±0.01	0.57±0.13	3.71±0.02	3.67±0.32
5	1.52±0.25	6.78±0.00	0.61±0.13	0.42±0.14	3.69±0.13	3.93±0.51
6	1.96±0.03	6.78±0.00	0.84±0.10	0.60±0.06	3.62±0.10	3.67±0.09
7	2.04±0.04	6.78±0.00	0.74±0.19	0.70±0.15	4.04±0.04	3.97±0.09

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 05°53′05.4N, 006°13′0.3E

Table 3 shows the concentration and distribution of air pollutants for dry and wet seasons in Ebedei-Unor.

Table 4: Concentration and distribution of air pollutants in Ebedei-Umueziogoli for dry and wet seasons

Dry Season(μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	2.06±0.25	4.02±0.10	0.03±0.01	0.01±0.01	0.95±0.03	2.53±0.18
2	1.97±0.22	4.35±0.12	0.02±0.01	0.01±0.01	0.66±0.12	2.97±0.32
3	1.82±0.11	4.36±0.01	0.02±0.01	0.01±0.01	0.44±0.05	2.57±0.03
4	1.94±0.26	4.76±0.27	0.02±0.01	0.01±0.01	0.57±0.02	2.80±0.25
5	2.36±0.10	5.17±0.08	0.03±0.01	0.01±0.01	0.61±0.10	2.43±0.26
6	2.39±0.12	5.26±0.15	0.02±0.01	0.01±0.01	0.72±0.03	2.30±0.21
7	2.10±0.39	5.55±0.04	0.03±0.01	0.01±0.01	0.62±0.06	2.57±0.20
Wet Season (μg/m^3)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	1.87±0.13	4.60±0.33	0.02±0.01	0.01±0.00	1.10±0.06	2.00±0.00

2	1.29±0.21	4.94±0.52	0.02±0.01	0.01±0.00	1.27±0.09	2.23±0.24
3	1.48±0.22	4.39±0.12	0.01±0.00	0.01±0.00	1.00±0.00	2.40±0.23
4	1.83±0.08	4.74±0.03	0.02±0.01	0.01±0.01	1.65±0.05	2.37±0.23
5	1.59±0.04	4.79±0.33	0.03±0.01	0.01±0.00	1.73±0.12	2.17±0.07
6	1.76±0.18	4.69±0.30	0.02±0.01	0.01±0.01	1.80±0.20	2.03±0.15
7	1.35±0.18	4.66±0.58	0.02±0.01	0.97±0.03	1.90±0.06	2.55±0.05

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 05°45′58N, 006°14′65.5E

Table 4 shows the concentration and distribution of air pollutants for dry and wet seasons in Ebedei-Umueziogoli

Table 5: Concentration and distribution of air pollutants in Ebedei-Adonishaka for dry and wet seasons

Dry Season (μg/m³)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	2.63±0.02	4.62±0.02	0.01±0.01	0.06±0.01	1.13±0.13	2.47±0.26
2	2.65±0.02	4.60±0.28	0.01±0.01	0.05±0.01	0.82±0.05	2.82±0.05
3	2.69±0.02	4.44±0.10	0.01±0.01	0.06±0.01	0.55±0.07	2.55±0.07
4	2.49±0.012	4.78±0.07	0.00±0.00	0.04±0.01	0.97±0.05	2.30±0.29
5	2.79±0.10	4.35±0.04	0.01±0.00	0.03±0.01	0.98±0.04	1.93±0.02
6	2.85±0.09	4.09±0.12	0.01±0.01	0.04±0.01	1.11±0.10	2.21±0.05
7	2.63±0.02	4.59±0.31	0.01±0.01	0.03±0.01	0.99±0.01	2.73±0.14
Wet Season (μg/m³)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	3.00±0.00	3.05±0.05	0.01±0.01	0.02±0.01	1.07±0.03	1.64±0.07
2	3.06±0.03	4.78±0.03	0.01±0.01	0.02±0.00	1.01±0.01	1.52±0.05
3	3.05±0.05	4.61±0.22	0.01±0.01	0.02±0.01	1.02±0.02	1.55±0.09
4	2.94±0.10	4.00±0.06	0.01±0.01	0.01±0.01	1.28±0.17	1.70±0.15
5	2.99±0.02	4.04±0.08	0.01±0.01	0.03±0.00	1.20±0.20	1.93±0.07
6	3.04±0.04	4.57±0.28	0.01±0.01	0.01±0.01	1.23±0.05	1.17±0.17
7	3.29±0.32	4.60±0.08	0.003±0.01	0.04±0.01	1.17±0.08	1.60±0.04

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 05°53′07.4N, 006°12′25.7E

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The concentration and distribution of air pollutants for dry and wet seasons for Ebedei Adonishaka is presented in Table 5.

Table 6: Concentration and distribution of air pollutants in Umutu Junction for dry and wet seasons

Dry Season(µg/m³)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	3.16±0.38	4.67±0.03	0.00±0.00	0.00±0.00	1.01±0.01	1.04±0.03
2	3.21±0.30	4.42±0.24	0.00±0.00	0.00±0.00	1.01±0.01	1.00±0.00
3	3.06±0.03	4.20±0.02	0.00±0.00	0.00±0.00	1.01±0.01	1.03±0.03
4	3.12±0.14	4.69±0.21	0.00±0.00	0.00±0.00	1.01±0.01	1.03±0.12
5	3.07±0.06	4.87±0.08	0.00±0.00	0.00±0.00	1.00±0.00	0.87±0.03
6	2.96±0.18	4.70±0.20	0.00±0.00	0.00±0.00	1.01±0.01	0.93±0.03
7	2.556±0.28	4.39±0.02	0.00±0.00	0.00±0.00	1.00±0.00	1.00±0.06
Wet Season (µg/m³)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	2.02±0.02	3.99±0.01	0.00±0.00	0.00±0.00	1.07±0.09	0.90±0.10
2	2.03±0.03	3.31±0.22	0.00±0.00	0.00±0.00	0.60±0.21	0.47±0.09
3	2.07±0.03	3.24±0.11	0.00±0.00	0.00±0.00	1.20±0.12	0.40±0.06
4	2.17±0.01	3.57±0.23	0.00±0.00	0.00±0.00	1.27±0.22	0.47±0.09
5	2.22±0.08	3.54±0.28	0.00±0.00	0.00±0.00	1.367±0.23	0.43±0.07
6	2.16±0.08	2.93±0.15	0.00±0.00	0.00±0.00	1.23±0.22	0.57±0.03
7	2.04±0.04	3.66±0.06	0.00±0.00	0.00±0.00	1.00±0.00	0.47±0.09

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 05°54′64.2, 006°13′36.3E

The concentrations and distribution of air pollutants for dry and wet seasons for Umutu junction is presented in Table 6.

Table 7: Concentration and distribution of air pollutants in Ethiope River at Adonishaka for dry and wet seasons

Dry Season(µg/m³)						
Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	2.45±0.05	4.52±0.06	0.01±0.00	0.02±0.01	1.13±0.08	0.87±0.03
2	2.51±0.05	4.27±0.12	0.01±0.01	0.01±0.01	0.68±0.04	0.90±0.01

3	2.42±0.08	4.35±0.08	0.02±0.01	0.02±0.01	0.43±0.06	0.83±0.09
4	2.60±0.03	4.30±0.15	0.00±0.00	0.02±0.02	0.81±0.12	0.83±0.03
5	2.30±0.08	4.20±0.03	0.02±0.00	0.02±0.01	1.23±0.13	0.81±0.06
6	2.61±0.17	3.65±0.42	0.01±0.00	0.01±0.00	0.92±0.04	0.84±0.03
7	2.47±0.05	4.05±0.40	0.01±0.00	0.01±0.01	0.73±0.06	0.89±0.02

Wet Season (µg/m^3)

Days	**CO**	**CO_2**	**H_2S**	**NO**	**NO_2**	**CH_4**
1	1.05±0.04	3.90±0.06	0.01±0.00	0.01±0.01	1.00±0.00	1.27±0.03
2	1.54±0.17	3.17±0.22	0.01±0.01	0.01±0.00	0.97±0.04	1.30±0.06
3	1.56±0.23	3.10±0.06	0.01±0.01	0.01±0.01	0.99±0.01	1.33±0.07
4	1.46±0.27	3.40±0.20	0.03±0.01	0.01±0.01	1.17±0.17	1.42±0.04
5	1.61±0.12	3.23±0.20	0.03±0.01	0.02±0.01	0.89±0.01	1.40±0.11
6	1.53±0.18	2.88±0.20	0.01±0.01	0.01±0.01	1.02±0.04	0.94±0.03
7	1.53±0.12	3.40±0.12	0.01±0.01	0.02±0.02	1.10±0.06	1.26±0.04

Results obtained are expressed as Mean±Standard deviation of air pollutants (CO, CO_2, H_2S, NO, NO_2, and CH_4) in the studied area. Coordinates: 05°53′39.4N, 006°12′81.3E

Table 7 shows the concentration and distribution of air pollutants for dry and wet seasons in Ethiope River at Adonishaka.

Table 8: Two-way ANOVA and Turkey significant difference Test.

Parameter	**Ethiope River at Adonishaka (control)**	**Ebedei-Umueziogoli**	**Ebedei Adonishaka**	**Umutu junction**	**Utagba-Unor junction Obiaruku**	**Ebedei- Unor**	**Days/ Time**
CO	1.98±0.09 (0.98-2.88)[abc]	1.84±0.07 (1.028-2.621)[a]	2.86±0.04 (2.45-3.16)[b]	2.56±0.08 (2-3.92)[ab]	1.35±0.07 (0.443-1.9)[c]	2.73±0.53 (0.93-2.4)[abc]	1.039
CO_2	3.74±0.093 (2.50-4.62)[a]	4.73±0.086 (3.51-5.91)[b]	4.47±0.052 (0-0.068)[b]	4.01±0.10 (2.64-5.03)[a]	3.08±0.14 (1.87-4.89)[c]	6.58±0.13 (2.26-7.42)[c]	2.855
H_2S	0.0014±0.00 (0.-0.04)[a]	0.019±0.001 (0.01-0.028)[a]	0.0029±0.000 (0-0.068)[a]	0.00±0.00 (0.00-0.00)	0.00±0.00 (0.00-0.00)	0.60±0.03 (0.3-1.00)[b]	0.989
NO	0.00115±0.00 (0-0.04)[a]	0.0047±0.00 (0.001-0.01)[a]	0.034±0.003 (0-0.07)[a]	0.00±0.00 (0.00-0.00)	0.014±0.001 (0-0.037)[a]	0.614±0.03 (0.2-0.9)[b]	1.097
NO_2	0.93±0.04 (0.321-1.5)[a]	1.008±0.07 (0.37-2)[a]	1.038±0.03 (0.415-1.62)[a]	1.056±0.04 (0.3-1.8)[a]	0.87±0.05 (0.04-1.4)[a]	3.32±0.085 (2.1-4.11)[b]	2.430

CH_4	1.06±0.04 (0.68-1.6)[a]	2.38±0.06 (1.8-3.5)[b]	2.001±0.08 (1-2.971)[c]	0.76±0.04 (0.3-1.2)[d]	1.6±0.11 (0-2.8)[e]	3.84±0.06 (3.1-4.9)[f]	0.490

Note: *Values are Mean ± Standard error; range in parenthesis. Different superscript letters in a row show significant differences ($p<0.05$) indicated by Turkey Honest Significant Difference (HSD) tests*

Discussion

The study comprehensively assessed air quality in Ukwuani Local Government Area, focusing on the influence of gas flaring. The findings highlight significant spatial, seasonal, and temporal variations in pollutant concentrations, with clear evidence of localized impacts from the gas flaring site at Ebedei-Unor. The observed trends provide valuable insights into the relationships between pollutant distribution, climatic conditions, and proximity to the gas flaring source.

The statistical data reveal critical patterns in pollutant concentrations. Carbon monoxide (CO), a key pollutant associated with incomplete combustion, was highest at Ebedei-Unor, with mean concentrations reaching 2.73 ± 0.53 µg/m³ during the dry season. By contrast, the control site (Ethiope River) recorded significantly lower CO levels, averaging 1.98 ± 0.09 µg/m³. Statistical tests indicated significant differences in CO levels across sites, underscoring the localized nature of emissions. Seasonal variations further emphasized the role of climatic factors in pollutant dispersion, with dry season concentrations consistently higher than those recorded in the wet season. This trend likely reflects reduced atmospheric mixing and rainfall during the dry season, which allow pollutants to accumulate in the atmosphere.

Carbon dioxide (CO_2), another major pollutant, followed a similar pattern, with the highest concentrations observed at Ebedei-Unor. The mean CO_2 concentration at this site was 6.58 ± 0.13 µg/m³, significantly exceeding levels recorded at other sites. The control site registered the lowest average concentration of 3.74 ± 0.09 µg/m³. These differences were statistically significant, as indicated by the two-way ANOVA results, suggesting that proximity to the gas flaring source was the primary determinant of CO_2 levels. Unlike CO, CO_2 showed less pronounced seasonal variation, likely due to its higher atmospheric persistence and broader sources, including natural respiration and other anthropogenic activities.

Methane (CH_4), a potent greenhouse gas, exhibited stark disparities between the gas flaring site and other locations. The mean concentration of CH_4 at Ebedei-Unor was 3.84 ± 0.06 µg/m³, while the control site was 1.06 ± 0.04 µg/m³. Tukey HSD test done on CH_4 levels across all the sites showed that CH_4 concentration was statistically significantly different across the sites, this is a confirmation that gas flaring is the primary source of this pollutant in the air. Also, higher CH_4 levels recorded during the dry season which is likely due to limited atmospheric dilution revealed that seasonal trends were also determinants of the CH_4 levels in the air.

Nitric oxide (NO), nitrogen dioxide (NO_2), which are the primary pollutants that forms ground-level ozone and acid rain, were largely detected at the gas flaring site. The highest NO_2 concentration of 3.32 ± 0.09 µg/m³ was recorded at Ebedei-Unor, compared to 0.93 ± 0.04 µg/m³ at the control site. NO levels showed comparable pattern, the mean concentrations was found to be 0.61

± 0.03 µg/m³ at the Ebedei-Unor while a concentration of 0.00 ± 0.00 µg/m³ at the control site. The significant differences between sites were supported by statistical analyses, highlighting the localized impact of flaring emissions. Unlike CO and CH_4, the concentrations of NO and NO_2 revealed less obvious seasonal variations, this is possibly due to their relatively short atmospheric presence and rapid transformation into secondary pollutants.

The toxic gas knows as hydrogen sulfide (H_2S) was detected only at Ebedei-Unor, the mean concentrations recorded for this gas was 0.60 ± 0.03 µg/m³ during the dry season. This observation emphasizes the site-specific nature of H_2S emissions, as it was fundamentally absent at the other sites. H_2S is indicative of incomplete combustion of gas, H_2S poses severe health hazards, which include respiratory and neurological effects for the communities living close to the flaring site.

Time-based analysis shown diurnal variations in the concentrations of the pollutants, the pollutants show higher concentrations typically in the morning and evening. This pattern is likely linked to temperature inversions, which trap pollutants near the ground during cooler periods, and reduced atmospheric mixing during these times of day. Such chronological trends underscore the dynamic nature of air pollutant dispersion and the influence of local climatic conditions.

The results clearly demonstrate that proximity to the gas flaring site is the dominant factor influencing pollutant concentrations. Ebedei-Unor consistently recorded the highest levels of all measured pollutants, highlighting the significant environmental burden imposed by gas flaring activities. The control site, located approximately 3 km away and outside the prevailing wind path, exhibited markedly lower pollutant levels, providing a baseline for comparison. Intermediate sites, such as Utagba-Unor Junction and Umutu Junction, displayed pollutant concentrations that varied with their distance and orientation relative to the flaring source.

Additionally, seasonal variations in the concentration of pollutant underline the role of climatic conditions in controlling air quality. The dry season, characterized by low humidity, reduced rainfall, and stable atmospheric conditions, support the accumulation of pollutants, which result in higher concentrations as observed in all sites. On the other hand, the frequent rainfall and turbulent atmospheric mixing of wet seasons diluted and dispersed pollutants, thereby causing lower ambient pollution concentrations. These observation align with global evidence on the seasonal dynamics of air pollution in regions affected by industrial emissions as discussed by Manju *et al.*, (2018).

The statistical analyses, including two-way ANOVA and Tukey's HSD tests, provided robust support for the observed patterns. Significant differences in pollutant concentrations across sites and seasons underscore the localized and seasonal nature of gas flaring emissions. The high F-values and low p-values gotten for almost all the pollutants is confirmatory to the fact that the differences in concentration were not arbitrary but driven by specific factors which include site proximity and climatic conditions.

The findings from this study have very important implications for public health and environmental sustainability. Heightened levels of air pollutants which include CO CO_2, NO_2, and CH_4 result in significant health risks, including neurological, respiratory and cardiovascular diseases, particularly for populations living near the gas flaring site. The presence of H_2S at Ebedei-Unor is especially concerning, as it indicates acute exposure risks for nearby residents. From an environmental perspective, high concentrations of greenhouse gases like CO_2 and CH_4 contribute to climate change, while NO_2 and NO can lead to acid rain and ecosystem degradation.

Conclusion

This research emphasize the significant effect of gas flaring on the quality of air in Ukwuani Local Government Area, Delta State, Nigeria. The distance between the gas flaring site at Ebedei-Unor and the other sample sites was the primary factor that determines the concentration of pollutant in the air. The flaring site, intermediate sites, and the control location all showed marked disparities between them. Seasonal variations was also a very strong factor as it was observed that higher pollutant levels occur during the dry season, this reflects the influence of climatic conditions on pollutant dispersion. The findings underscore the crucial need for regulatory interventions to mitigate the environmental and public health impacts of gas flaring. Addressing the root causes of pollution and employing ecological practices, stakeholders can protect susceptible communities, improve air quality, and contribute to global struggles to manage climate change.

Recommendations

To mitigate the adverse effects of gas flaring on air quality and public health, existing air quality standards for industrial operations must be enforced and strictly complied to, industries should be mandated to adopt gas flaring reduction technologies, such as gas capture and utilization systems. Health and environmental agencies should collaborate with the support of both state and federal government to develop regulatory framework that encourages the conversion of flared gas into usable energy resources. Environmental agencies should encourage industries to establish greenbelts around gas flaring sites which will be able to bioabsorb and bioaccumulate/ bioremediate the pollutants from the air. Environmental agencies should also implement air quality monitoring programs to track and identify pollutant levels and trends.

Public health initiatives like regular health assessments for individual living close to gas flaring sites should be carried out regularly. Furthermore, with the help of community leaders, health agencies should educate the locals on the danger associated with air pollution and ways to reduce exposure. And as a final resort, people living near gas flaring site should be relocated to a safe, pollution free environment.

Effecting these measures will improve the quality of air in Ukwuani and also become a standard for addressing related problems in other regions affected by gas flaring. By prioritizing sustainable practices, stakeholders can guarantee a healthier environment and a better quality of life for future generations.

Conflict of Interest

The authors declare that there are no conflict of interests in the Manuscript

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