



Gas Flaring, and Its Environmental Impact in Ekpan Community, Delta State, Nigeria

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Abstract: In the Ekpan settlement of the Uvwie local government area, Delta state, Nigeria, a study on gas flaring and its effects on the environment was carried out. It was found that hazardous gases have been released into the environment because of air pollution caused by the combustion of methane and other hazardous flue gases during the manufacturing and processing of hydrocarbons. Industrial flue gas flare-ups cause several problems and are harmful to public health and the environment. This study investigated the pH of rainwater, as well as air pollutants (NO₂, SO₂, CO₂, CO, and suspended particle matter). During the dry and wet seasons, samples of air and rainwater were collected at different distances around exposure sites, and they were then examined using established techniques for the air contaminants. Descriptive statistical tools such as mean and standard deviation were used to analyze the variance and degree of effect of pollutants. The obtained results showed that the mean CO₂ concentrations in the dry and wet seasons were, respectively, 0.036 ppm and 0.26 ppm and that the pH of rainwater in the wet season was 6.82, both of which were within the safe limits, indicating that there were little to no negative effects on the environment. However, the average concentrations of suspended particulate matter in dry and wet seasons respectively were 7.92 mg/m₃ and 5.95 mg/m₃, NO₂ was 0.15ppm and 0.10ppm, SO₂ was 0.72ppm and 0.10ppm, CO was 11.20ppm and 10.24ppm, and CO₂ 0.036ppm and 0.26ppm. The pH of rainwater was 6.02 for the dry season which exceeded the acceptable ambient air limits set by the DPR (2002) and FMENV (1991), while during the wet season, the pH was 6.82. This study suggested that the activity of continuous gas flaring is one of the main causes of high concentrations of these air pollutants within the examined community. The findings further suggested that the numerous environmental, socioeconomic, and political issues within Ekpan were linked to the effects of gas flaring. This study suggests that the challenges caused by gas flares for the Ekpan community are good enough grounds to stop the practice of gas flaring in the area and the government needs to enact strict legislation with penalties for defaulters. The study finally recommended that flared gas could be refined and reused.

Keywords: Gas Flaring, Emission, Crude Oil, Air Pollution, Policy, Ekpan, Niger Delta

1. Introduction

The cities and villages of Ekpan, Batan, and Escravos surround the Niger Delta, which is in southern Nigeria [1]. Fishing and farming are the main economic drivers in this area

[2]. A region known as the Niger Delta is where Nigeria's vast supply of natural resources, including petroleum and natural gas, is located [3]. The Niger Delta is equipped with a diverse marine ecosystem recognized as one of the top producers of aquatic food, with access to Lake Chad and the Atlantic Ocean

via numerous rivers [2, 3]. Due to decades of excessive natural gas and petroleum drilling, exploration, and production, a lack of planning to use these natural resources wisely and with the least possible negative environmental effects, and the underlying and secondary pollutants/damage associated with these activities, coastal and oceanic inhabitants are in danger of going extinct [4]. Natural gas flare-ups and sanitary sewage overflow runoff are among several elements that worsen the local environment and increase the amount of pollutants polluting the water and air in the Niger Delta region [5].

An elevated vertical conveyance of burning gas seen next to the presence of oil and gas wells, refineries, rigs, chemical factories, landfills, and natural gas plants is referred to as a gas flare, also known as a gas stack [6]. Waste gas that would otherwise be impractical to use. An elevated vertical conveyance of burning gas seen next to the presence of oil and gas wells, refineries, rigs, chemical factories, landfills, and natural gas plants is referred to as a gas flare, also known as a gas stack [6]. Waste gas that would otherwise be impractical to use or transport is eliminated with this method. When necessary, they are the equipment. Flared gas sometimes serves as a safety mechanism for non-waste gases. This prevents the over-pressurization of the gas processing machinery. Additionally, the flare system aids in burning through the whole stock of gas in an emergency [7, 8]. During the burning of used oil-gas-water or oil-gas solutions, a large amount of hydrocarbons are released. Flaring is an ineffectual process operation because it releases raw fuel that is bad for the environment due to external factors that affect combustion and inefficient burning, and these fuels are harmful to the environment [9]. Flaring natural gas occurs in both offshore and onshore wells [10]. While some may consider it as a safety measure, most often it is done as a way to get rid of extra gas. Its goal is to make it easier to lower the pressure in the well. Natural gas flaring in Nigeria contributes about 1 percent to global CO₂ emissions, which has serious environmental consequences [11]. Table A1 shows the composition of typical flue gas, and in its composition, elements that are known to be dangerous to the environment when emitted in a large quantity are contained.

The amount of natural gas that has been flared over the past 20 years has stayed constant at 100 billion cubic meters per year, 80 percent of the polluting the environment and needlessly depleting valuable natural gas [11]. The Vietnam Rang Dong Project, the Kyoto Protocol, and efforts made by the World Bank in coordination with the government of Norway are just a few examples of partnerships between the government and the oil industry to decrease or stop natural gas flaring [12].

According to [11], the following problems have become prevalent in the Ekpan community over the last several decades.

Firstly, the persistent release of harmful gases into the Ekpan community from industrial activities has become a thing of concern. These gases are continuously flared all-day e.g., carbon dioxide, methane, propane, ethane, etc., which accumulate into major environmental hazards such as climate

change, global warming, acid rain, infertile soil, health-related problems such as infertility, constant headaches, eye diseases, cardiovascular and respiratory diseases, etc. Inadequate facilities for proper management of harmful/waste also contribute to the increase in gas flaring [13, 14]. No appropriate law has been given by the government against this act, and the ones given out are not monitored properly. There is little or no health care for victims of the impact of gas flare-ups in the Ekpan neighborhood. This establishes the foundation for looking at current data on gas flaring in society, monitoring the amount of contaminants due to gas flaring released into the Ekpan community, and looking into whether CO₂, CO, and associated contaminants comply with the Department of Petroleum Resources Environmental Standards or Guidelines for the oil and gas industry, as well as other relevant guidelines, and suggesting/elaborating potential solutions for reducing the detrimental effects of gas flaring.

2. Review of Related Literature

2.1. Gas Flaring: A Global Trend

In the literature, gas flaring is defined in a number of different ways. The combustion of natural gases produced by the extraction of crude oil into the atmosphere is referred to as gas flaring [5]. It has also been described as the intricate and irrational burning and emission of surplus hydrocarbons, including a significant amount of carbon monoxide, soot, and greenhouse gases, in association with the production of crude oil and gas [15]. The method of burning off undesired, combustible gases in the open air has sometimes been referred to as "gas flaring" [16]. Because gas flaring emits a cocktail of toxic substances that are harmful to people, plants, animals, and the entire physical environment, it is also an anthropogenic activity that contributes to the wasteful emission of greenhouse gases (GHGs) that contribute to global warming, the disequilibrium of the earth, unpredictable weather changes, and significant natural disasters [17]. However, despite this plethora of definitions, the descriptions all agree that it is an activity that is peculiar to crude oil production either on-shore or off-shore, and its emission is harmful to the environment.

Geologists are aware that some of the richest oil and natural gas resources coexist and when natural gas is brought to the surface in an area without the necessary infrastructure to use it, such gas is flared. Unwanted gases were continuously burnt off at various oil and gas facilities from Saudi Arabia to Texas during the 1960s and 1970s [7]. At its peak, the practice contributed 0.5% of the global carbon dioxide emissions, or about 110 million metric tons per year, to the environment. Since then, the practice has become less common, partly because of businesses realizing the gas's commercial value. When the detrimental effects of burning the gas were more understood and initiatives to minimize CO₂ emissions that cause climate change started, pressure to reduce flaring rose. However, flaring is frequent in Nigeria, where the estimated

daily gas burn rate is over 2.5 billion SCF, or 40% of the country's total gas production [18]. Globally, the gas wasted through flare gas emissions can supply one-third of the annual natural gas needs of the European Union [19, 20].

2.2. Green House Gas Emission

The greenhouse effect is caused by greenhouse gases, which are atmospheric gases that trap heat waves coming from the sunlight in the earth's atmosphere [21]. The need to reduce the problem of greenhouse gas emissions and climate change have become two of the most crucial policy concerns that the world economy must address. The warming of a planet's or moon's surface caused by the existence of atmospheric gases that may simultaneously absorb and emit infrared light is known as the greenhouse effect. Thus, the surface-troposphere system is kept cool by greenhouse gases. The greenhouse effect was first reliably tested by John Tyndall in 1858 after it was identified by Joseph Fourier in 1824, but Svante Arrhenius conducted the first qualitative research on it in 1896. Since Svante Arrhenius' groundbreaking work in the 1980s, the scientific underpinning for climate change has received widespread recognition [7].

These greenhouse gases are produced by a variety of human activities, such as energy use, gas flare emissions, power plant emissions, changes in land use (including deforestation), and agricultural operations. Because of their symmetry, they can vibrate in the infrared range, and these vibrations generate momentary charge separation. They can both emit and absorb infrared light thanks to their dipole moment. Finding a solution to the problem there is essential due to the high rate of green gas emissions from oil-powered power plants and gas flares within the Niger Delta region, which increases the present worries about global climate change [7].

It has been established that the high concentration of synthetic gases, such as Hallons-carbons & Chlorine/Chloro-Fluoro-Carbons (CFC), which are some of the byproducts of gas flaring, contributes to the destruction of the ozone layer. This allows UV radiation to reach the surface of the earth [22]. As a result, it is widely acknowledged that gas flaring plays a significant role in fostering the destruction of the ozone layer.

In contrast to CH₄, which provides 4 - 9% (~1.8 ppm) of the total greenhouse gas emissions, gas flaring produces 9 - 26% (~400 ppm) of the total greenhouse gas emissions [23, 24]. Today's unprecedented rate of global climate change is mostly caused by growing emissions of greenhouse gases like atmospheric CO₂ [24]. The temperature can dramatically affect animal habitats and food sources because it is the primary predictor of creature life phases, such as plant germination and flowering. This might have a severe effect on the richness of species and ecosystems globally. Because global climate change affects biological and physical habitats simultaneously, depending on how it interacts with other environmental factors, it can have both direct and indirect effects on biodiversity [25]. In order to adapt to climate change, ecosystems and other living creatures must modify their habitats, alter their life cycles, or develop new physical

traits [26]. The principal documented impacts of climate change on ecosystems and biodiversity are as follows:

2.2.1. Loss of Biodiversity and Species Extinction

The rate of species extinction has dramatically increased because of climate change [25, 27]. The expected biodiversity nature of Earth has significantly decreased, with 10% to 30% of bird, mammal, and amphibian species in danger of extinction [28].

2.2.2. Phenology Alterations

Numerous species of both animals and plants have shown changes in phenology (the duration of the growing season or the timing of natural processes like reproduction in some species) [29]. For instance, warmer temperatures have caused some plant species to flower earlier [30] and the spruce budworm to lay more eggs than usual [31].

2.2.3. Changes to the Geographic Range

Climate change compels organisms to adapt or migrate in response, which alters species' geographic ranges [26, 32]. As the temperature climbed, for some animals and plants, the northern limits shifted further north [33, 34].

2.2.4. Changes in Ecosystem Functions and Services

Biodiversity and ecosystem stability are closely related. Increased greenhouse gas emissions from biodiversity loss brought on by land use and climate change could exacerbate climate change [35]. Increases in biodiversity, on the other hand, can improve carbon sequestration and ecosystem productivity and possibly mitigate the adverse effects of climate change.

2.3. Human Health

The fact that dangerous air pollutants are inhaled when gases are flared, gas flaring has a negative impact on human health. On the other hand, these contaminants harm human health by producing cancer and problems in the nervous system, reproduction, and development [23]. There have also been reports of skin issues, lung damage, and birth defects in children [36, 37]. Hydrocarbons that are not completely burned have been found to affect hematological parameters. These modifications have a detrimental impact on blood and blood-forming cells, resulting in anemia leukemia, and pancytopenia [5].

2.4. Reasons Behind Flaring

Generally, aside from placing the alibi refineries put up for flaring gases and the negatives this activity presents, it does not in all cases correlate to pass the expected logical test. The gas in oil wells sometimes contains a vast amount of highly toxic hydrogen sulfide (H₂S); hence for the safety of the workers and the facility, it is safer to burn it into the air [38]. However, this is only a parochial excuse that ensures the safety of the facility workers but leaves the entire atmosphere in jeopardy. In addition, there is a lack of a market for this gas right away and ineffective regulation of flaring activities, which all contribute to the growth of this practice [39, 40].

2.4.1. *Knowing the Characteristics of Upstream Process*

Knowing and understanding the upstream processes, especially their responses during upset conditions, is crucial for a suitable analyzer system design. With the flare gas probe, crucial activities include extreme sample circumstances and sample take-off. These unsettling characteristics can be identified, enabling correct anticipation in system design. Sulfur recovery units and amine treaters are necessary for most gas treatment facilities and refineries that employ sour (acidic) feedstock. These units are crucial for environmental management even though they are not frequently the "money-makers" of a refinery or gas plant. The most frequent extreme changes in feedstock, a lack of maintenance, improper operation, and a lack of process competence in these units are the main reasons for the fouling and plugging of analyzer systems. The existence of heat-stable salts, most frequently elementary sulfur, and ammonia salts are two classic examples. Usually, these are the species that are to blame for fouling and plugging.

2.4.2. *Knowing the Precise Analytical Needs*

Making a successful analytical specification requires skill. Sadly, there are times when important parts of the analysis are missing, or at worse, a specification is just a "Copy & Paste" of design defects from other projects. In a proper specification, the objective of the analysis is given first, then its justification, and finally its significance. These standards serve as the foundation for choosing the right analyzer and designing the right system. Despite the equality on paper or the license, each procedure is distinct. Environmental factors, feedstock, local requirements, etc. will have an impact on how Process units operate. For instance, energy efficiency, legislation, product quality, management, the environment, safety, or process dependability are a few examples of the reasons for analysis. The purpose of analysis includes, for instance, monitoring, control, alert, or trip. The criticality of analysis might be due to safety, process, environment, quality, or non-critical requirements.

2.5. *Reasons Behind Flaring*

Petroleum regularly contributes more than 14% of Nigeria's GDP, 95% of its exports, and significantly more than 80% of the country's annual income [41, 42]. The Niger Delta region currently has over 100 gas flaring sites, some of which have been in operation for more than 40 years. In Nigeria, the Niger-Delta spans an area of around 70,000 square kilometers (as palpable in the encircled portion in figure 2) and houses Nigeria's gas reserve which is estimated to be about 120 trillion cubic feet [43]. 17% of the total gases in production in Nigeria is re-injected, 33% is converted for commercial purposes and the 50% left is burnt-out through gas flaring [44]. Nigeria flares an estimated amount of the highest production rates of any OPEC member country or state are two billion cubic feet per day and 17 bm^3 annually and evidently the biggest flaring country after Russia [45]. Additionally, it has been calculated that Nigerian gas flaring contributes to the country's annual emissions of 12 million

tonnes of methane and 35 million tonnes of carbon dioxide [46]. Due to Nigeria's poor flare stack investments, enormous amounts of gas, mainly methane, have been flared. There have been numerous oil spills that have damaged the delta and intensified the violence in the area since the beginning of crude oil exploitation there in the 1950s. Even though gas flaring was declared unlawful in 1984, the government has consistently broken its commitments to put an end to the practice. The London-based nonprofit "On Our Radar" examined the viability of the government's recent pledge to end gas flaring by 2020 [47]. It employed Rory Hodgson, a geospatial data expert, to analyze and quantify gas flare hotspots using infrared data. As of late 2017, "The satellite data seems to point to a significant increase in the amount of radiant heat emitted by gas flares in Nigeria," according to Hodgson. A NOAA satellite that began taking infrared observations in 2012 provided the data. The most recent figures for gas flaring in Nigeria come from 2018. According to the data, Hodgson claims that there 2018 saw more gas flares burning than the previous five years combined. This is contrary to the general trend, which shows that gas flaring has significantly decreased in recent decades as seen in table A2. According to data from July 2018 from the Global Gas Flaring Reduction Partnership, Nigeria ranks sixth as the largest gas-flaring nation in the world (see figure A2). It is commonly acknowledged that gas flaring wastes energy and increases atmospheric carbon emissions. Due to the incomplete combustion caused by flaring, significant volumes of soot and carbon monoxide are created, aggravating the problem of air pollution.

2.5.1. *Burning Money*

"Burning gas costs money," In fact, On Our Radar had earlier predicted about \$770 million in lost income for just the year 2016 using a gas price of about \$2.49 per gallon that year [47]. In a country where 27% of the population lacks access to energy, locals are concerned about waste. Global warming is significantly exacerbated by gas flaring. Nigeria's emissions from flaring in 2016 were calculated by the US Environmental Protection Agency to be equal to more than 3.5 million passenger automobiles operated for an entire year. To extract gas, however, infrastructure is required, and this costs money right once. The Nigerian government must exert more effort to persuade oil and gas corporations to construct the essential infrastructure for the gas to be captured and used [48, 49]. Infrastructure may be built to harness natural gas and use it as a source of income.

"Flaring gas is burning money", In fact, On Our Radar calculated that lost income for just the year 2016 would total \$770 million at a petrol price of \$2.49 a gallon [47]. Residents are worried about waste in a nation where, according to the World Bank, 27% of people lack access to electricity. Another big factor in global warming is gas flaring. The greenhouse gas calculator, according to estimates from the US Environmental Protection Agency, Nigeria's 2016 emissions from flaring were equivalent to more than 3.5 million passenger vehicles driven for a whole year. However,

infrastructure is needed to capture the gas, and this is an immediate expense. The Nigerian government needs to do more to persuade oil and gas companies to build the necessary infrastructure to capture and use the gas [14, 48]. Necessary infrastructure may be developed to harness natural gas and turn it into a cash Company/cow.

2.5.2. Looming Deadlines

Previously, Nigeria gave itself till 2020 to stop the recurrent flare-ups. Nothing on the ground indicated a plausible 2020 date, according to the statement. Bjorn Hamso, program manager for the World Bank's Global Gas Flaring Reduction Partnership (GGFR), was more upbeat. He noted that "a number of nations, including Nigeria, are making progress." However, much more work needs to be done to stop the current regular flaring. Shell Nigeria is responsible for the majority of the oil extraction in the Niger Delta. It belongs to the GGFR as well. The Shell Petroleum Development Company (SPDC), commonly known as Shell Nigeria, told DW that it was collaborating closely with the Nigerian government to put an end to gas flaring. All new SPDC JV facilities have been built since 2000 with the goal of reducing ongoing related gas flaring, and a multi-year program to develop technology for capturing related gas from older facilities has been successfully completed concurrently.

The quantity of gas produced and flared in the country from 2003 to 2012 is shown in Table 2A. Nigeria is a substantial producer of crude oil and has the sixth-largest proven natural gas resource. Natural gas was generated by the sixteen oil firms in 2011 to a total of 2404.40 BSCF. Of this amount, 1,781.37 BSCF (or 74% of it) was used, while 619.03 BSCF (or 26%) was flared. This presents a problem that needs to be investigated at the local, national, and international levels.

2.6. Economic Effect of Gas Flaring

Aside from the collateral damage gas flaring brings to man and his environment; it also presents huge economic loss to any country where it is practiced. This gas, however, has huge economic value, in that, it can be refined and converted to domestic use and generate electricity. Countries in Southeast Asia have been able to reduce these flared gases by 2.6 million tons and converted them to the generation of additional electric power. Reviews so far indicate that countries like Nigeria are losing significantly as a result of gas flaring in terms of their economies, environments, and health; as a result, this study will concentrate on the Ekpan community as shown in figure A1 which is an area known for flaring activities to identify the full level of the impact and suggest potential policy interventions.

3. Methodology

The following air pollutant parameters: CO, CO₂, SO₂, NO₂, and SPM were considered effective impact indicators of the condition of the surrounding air and rainwater sample from its surrounding based on reviewed works of literature. Table 1 shows the critical information on the nature of the air composition of Ekpan community before the establishment of

the refinery or petrochemical plant in Warri which is perceived to be the source of major air pollution within the environment.

Table 1. Composition of Air within Ekpan Community prior the establishment of Warri refinery/ petrochemical Plant.

| Element | Weight (%) | Volume (%) | Volume (PPM) | Molecular Weight of the element |
|-----------------|------------|------------------------|--------------|---------------------------------|
| N ₂ | 75.47000 | 78.08000 | 780790.000 | 28.01 |
| O ₂ | 23.20000 | 20.95000 | 209445.000 | 32.00 |
| Ar | 1.28000 | 0.93000 | 9339.000 | 39.95 |
| CO ₂ | 0.06200 | 0.04000 | 404.000 | 44.01 |
| Ne | 0.00120 | 0.00180 | 18.210 | 20.18 |
| He | 0.00007 | 0.00050 | 5.240 | 4.00 |
| Kr | 0.00030 | 0.00010 | 1.140 | 83.80 |
| H ₂ | Negligible | 0.00005 | 0.500 | 2.02 |
| Xe | 0.00004 | 8.7 x 10 ⁻⁶ | 0.087 | 131.30 |

Note: the table shows the composition of Ekpan atmosphere before the establishment of industrial platforms, and the data suggested a good atmosphere before later being polluted [49, 50]

Sulfur dioxide (SO₂), which has a concentration of about 1.0 parts per million (ppm), Methane (CH₄), which has a concentration of about 2.0 ppm, Nitrous oxide (N₂O), which has a concentration of about 0.5 ppm, Ozone (O₃), which has a concentration of 0 - 0.07 ppm, Nitrogen dioxide (NO₂), which has a concentration of about 0.02 ppm, Iodine (I₂), which has a concentration of 0.01 ppm, Ammonia (NH₃) which could be from 0 to a traced ppm, and Carbon monoxide (CO) which could also be from 0 to a traced ppm, are all components that could be present in the air [51, 52].

Flue gases come from the indirect (pyrolysis and gasification) or direct (incineration) oxidation of intermediate syngas or refuse-derived fuel (RDF), and they are mixes of combustion products containing water vapor, particulates, carbon dioxide, acidic gases, and heavy metals. Oxides of carbon, sulfur, and nitrogen as well as fly ash, other contaminants, and water vapor may be present in the flue gas.

Petrochemical and refineries industries employ flares as crucial safety equipment. Excess hydrocarbon gases that can't be recycled or recovered are safely burned there. Excess gases are burned off during flaring by combining them with air, steam, and or other gases, which results in the production of carbon dioxide and water vapor.



Figure 1. GX-2012 Portable One-to-Five Gas Monitor with Inbuilt Sampling Pump.

Figure 1 monitors the Lower Explosive Limit (LEL), percent volume of methane, oxygen, carbon monoxide, and

hydrogen sulfide. It also has a 0 - 100% volume methane option, an internal sample drawing pump with a 15-meter range, visual, vibration, and audible alarms, an auto-ranging display of percent volume and percent LEL, a calibration reminder with lock-out option, an automatic backlight during alarms, a quick charge (completes charge in 90 mins), a High impact protective rubber over-moulding, Alarm latching or non-latching, Glove-friendly big buttons, data tracking for up to 600 hours with alarm trends, single or auto-calibration, STEL and TWA readings that have a lunch break mode.

3.1. Experimental Procedure

First, the field area in Ekpan received numerous visits. First-hand or direct observation of the surroundings was used to collect data. Different samples were gathered at varying distances from the gas flare position, and careful measurement and experimentation were done. The air quality and flare-related rainwater were the variables that were tracked at each sampling location.

3.1.1. Air Quality

(i). Field Sampling

Using the gaseous emission analyzer GX-2012 model, air samples from the study location were taken over a three-month period (February to April 2019). The sampler was positioned 200, 300, and 400 meters away from the flare point, and the average values were compared to the ambient air quality standard for Nigeria.

(ii). Working Principle of the Gaseous Emission Analyzer

The gaseous emission analyzer GX 2012 model is a portable digital hand-held air monitor used to measure air pollutants. It was connected to the main source of electric power until the batteries were fully charged, then it was tested to ensure that the equipment was in top working condition for the in-situ data collection. At each sampling point, the equipment case was opened, and the probe was mounted on its stand, then the height was adjusted before it was switched on by pressing the 'On' button, the equipment vibrates as it was turned on and the digital display then show "GX 2012" after that it shows "stabilizing". It remains in that position for a minute before reading the concentrations of the parameters present in the environment where it is being used at that moment and displaying the results on the screen. CO, CO₂, SO₂, NO₂, and SPM were thought to be excellent impact indicators of the condition of the surrounding and ambient air. The particle monitor (HAZ-dust skc model) was used to measure the concentration of suspended particulate matter (SPM) in the air. Throughout this inquiry, all values were

acquired during the investigation on-site.

3.1.2. Rainwater Analysis

Since gas flaring is associated with acid rain, samples of rainwater were taken to check the pH and gauge the contamination of the atmosphere. Due to their low metallic content and non-polar surfaces, two-liter plastic bottles and a clean plastic basin were used to collect rainwater samples. To guarantee that no foreign soluble substances that were originally in the container contaminated the samples, all basins and bottles were properly rinsed or cleaned using the collected rainwater. Away from the flare point, the samplers were positioned 200, 300, and 400 meters. The basins were kept elevated above the ground outside, unobstructed by any trees or rooftops. As soon as the water had accumulated in the basins, it was promptly transferred to the plastic bottle, sealed, and sent to the lab for testing. The pH of the rainwater was measured using a Benchtop Jenway pH meter model 3071, and the results were shown on the screen and recorded.

3.2. Method of Data Analysis

To obtain the mean and standard deviation of the measured values, Equations (1) and (2) were used.

The mean was examined as follows.

$$X = (\sum x)/n \quad (1)$$

Where Σ = Sum of the sampled data

n = Total number of data that were attainable

x = Value of each observation

X = mean

In equation 2 the standard deviation was calculated using the mathematical model.

$$S.D = \sqrt{(\sum (X^2 - x^2)) / n} \quad (2)$$

Where, Σ = sum of sampled data, n = sample size, x = value for each observation made, X = mean, $\sqrt{}$ = square root, while S. D = standard deviation

4. Result and Discussion

Parameter values from the study of air pollutants and rainfall samples collected in Ekpan from February to April 2019 were calculated for the dry and rainy seasons and are shown in tables 2 and 3. Tables 4 and 5 reveal the mean values and deviations that were found in this inquiry, and table 6 compares them to the Nigerian Ambient Air Quality Standard recommendations.

Table 2. Air Sampling during the dry season at Ekpan.

| S/N | Location | Month | SPM | NO ₂ | SO ₂ | CO | CO ₂ | pH |
|-----|---------------------|----------|-------|-----------------|-----------------|-------|-----------------|------|
| 1 | A (200m from flare) | February | 8.875 | 0.2 | 1.4 | 14.30 | 0.10 | 5.90 |
| | | March | 7.998 | 0.2 | 0.8 | 10.70 | 0.01 | 6.10 |
| 2 | B (300m from flare) | February | 8.404 | 0.1 | 0.8 | 12.70 | 0.10 | 5.80 |
| | | March | 7.104 | 0.1 | 0.3 | 11.60 | 0.01 | 6.20 |
| 3 | C (400m from flare) | February | 8.375 | 0.1 | 0.8 | 10.30 | 0.01 | 5.90 |
| | | March | 6.773 | 0.2 | 0.2 | 10.01 | 0.01 | 6.23 |

Table 3. Air Sampling during the Wet season at Ekpan.

| S/N | Location | Month | SPM | NO ₂ | SO ₂ | CO | CO ₂ | pH |
|-----|----------|-------|-------|-----------------|-----------------|-------|-----------------|------|
| 1 | A (200m) | APRIL | 6.104 | 0.1 | 0.1 | 10.00 | 0.30 | 6.88 |
| 2 | B (300m) | APRIL | 5.973 | 0.1 | 0.1 | 9.92 | 0.26 | 6.86 |
| 3 | C (400m) | APRIL | 5.773 | 0.1 | 0.1 | 10.8 | 0.22 | 6.92 |

Table 4. Mean and S. D of pollutants during the dry season at Ekpan.

| Parameters | 200m | 300m | 400m | Mean | S. D |
|-----------------|---------|--------|-------|---------|-------|
| SPM | 8.4365 | 7.754 | 7.574 | 7.9215 | ±0.37 |
| NO ₂ | 0.2000 | 0.100 | 0.15 | 0.1500 | ±0.04 |
| SO ₂ | 1.1000 | 0.550 | 0.50 | 0.7200 | ±0.27 |
| CO | 12.5000 | 12.250 | 8.85 | 11.2000 | ±1.66 |
| CO ₂ | 0.0500 | 0.050 | 0.01 | 0.0360 | ±0.04 |
| pH | 6.0000 | 6.000 | 6.07 | 6.0230 | ±0.03 |

Note: S. D represents Standard Deviation

Table 5. Mean and S. D of pollutants during the Wet season at Ekpan.

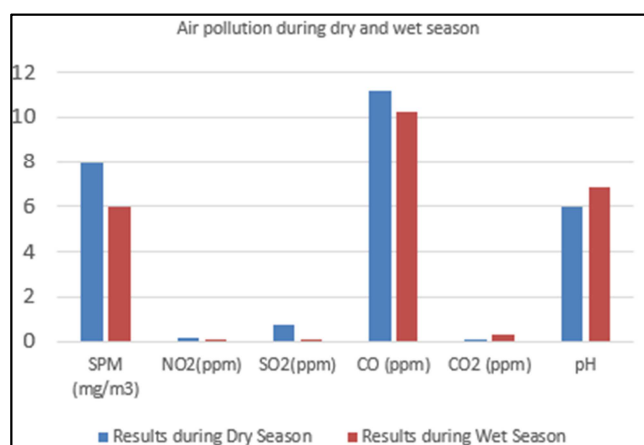
| Parameters | 200m | 300m | 400m | Mean | S. D |
|-----------------|-------|-------|-------|-------|--------|
| SPM | 6.104 | 5.973 | 5.773 | 5.95 | ±0.14 |
| NO ₂ | 0.1 | 0.1 | 0.1 | 0.1 | 0 |
| SO ₂ | 0.1 | 0.1 | 0.1 | 0.1 | 0 |
| CO | 10 | 9.92 | 10.8 | 10.24 | ±0.39 |
| CO ₂ | 0.30 | 0.26 | 0.22 | 0.26 | ±0.034 |
| pH | 6.88 | 6.86 | 6.74 | 6.82 | ±0.06 |

Note: S. D represents Standard Deviation

Table 6. Comparison of results with FMENV and DPR standards [12, 13].

| Parameter | Results | | FMENV, 1991, DPR 2002 Standards |
|--------------------------|------------|------------|------------------------------------|
| | Dry Season | Wet Season | |
| SPM (mg/m ³) | 7.92 | 5.95 | 1.15 |
| NO ₂ (ppm) | 0.15 | 0.10 | 0.05 |
| SO ₂ (ppm) | 0.72 | 0.10 | 0.01 |
| CO (ppm) | 11.20 | 10.24 | 10 |
| CO ₂ (ppm) | 0.036 | 0.26 | 35 |
| pH | 6.02 | 6.82 | 6.5-8.5 |

Note: DPR means Department of Petroleum Resources, presently Nigerian Upstream Regulatory Commission [14], while FMENV means Federal Ministry of Environment. The standard used was from the regulations of 1991 (for FMENV) and 2002 (for DPR)

**Figure 2.** Statistics of air pollutants due to gas flare in Ekpan.

Summary of Air Pollution Statistics of Ekpan

The term "suspended particulate matter" (SPM) refers to a broad category of finely divided particles that might enter the

atmosphere as a result of combustion, natural or industrial processes. The average SPM concentration in the air was greater than the FMENV standard of 1.15 mg/m³, at 7.92 mg/m³ and 5.95 mg/m³, respectively. The standard deviations of 0.37 and 0.14 for the dry and wet seasons, respectively, further indicated that the ecosystem is more at risk during the dry season than it is during the rainy season due to higher SPM variations and swings. Furthermore, given that both the means and S. D. s of the rainy season are lower than those of the dry season, it is plausible to conclude that rain contributes to lessening the impacts of air pollution. As previously noted the presence of high SPMs is a challenge for the environmental sustainability and public health in this area due to the smoke and soot from the stack of the gas flares.

The mean dry season value of 0.15 ppm and the standard deviation of 0.04 for the samples' measurements of NO₂ were greater than the mean wet season value of 0.1 ppm and the standard deviation of 0. It exceeded the limit when compared to the FMENV standard of 0.05 ppm. This may be caused by ongoing gas flares, fuel burning, and dust production as a result of reduced rainfall, even during the wet season.

According to the results of the samples' analysis, the mean SO₂ concentrations throughout the dry and rainy seasons, respectively, were 0.72 ppm and 0.27 ppm, and 0.1 ppm and 0 ppm, respectively. It was found that the concentration of SO₂ was above the limit when compared to the regulatory standards due to ongoing gas flaring in the area, which may contain a significant amount of incompletely stripped soured gas components (for example, H₂S), as previously stated as a reason behind flaring by [38], as well as human activities like refuse burning, etc. Statistics also revealed a significant seasonal fluctuation in the mean values.

With a mean concentration of 11.20 ppm and a standard deviation of 1.66 for the dry season and 10.24 ppm and a standard deviation of 0.39 for the rainy season, respectively, the CO readings collected also demonstrated seasonal fluctuation. The high mean values can be explained by the incomplete combustion of the gas flared and a sign of the area's pollution due to the existence of CO emissions, which supports assertions in the review that Nigeria's carbon emissions are on the rise. Additionally, the dry season's higher mean and S. D. values imply that atmospheric pollution has a greater geographic spread than it does during the rainy season, and that rain may be able to clean up contaminated areas. Last but not least, the average levels for the dry and rainy seasons were both higher than the standard permitted value, further indicating that the ecosystem and its inhabitants are at risk owing to exposure to too much CO.

When compared to the FMENV standard of 10ppm, the mean CO₂ content in the air was below the limit at 0.036ppm with a standard deviation of 0.04 and at 0.26ppm with a

standard deviation of 0.034 for the dry and rainy seasons, respectively. As a result, the area was not at risk with respect to CO₂. This provides more evidence that incomplete combustion, which results in the release of more CO gases than CO₂ gases, is the primary cause of flared gases.

As a result, for the dry and wet seasons, respectively, the mean pH value of the samples was 6.02 with a standard deviation of 0.03 and 6.82 with a standard deviation of 0.06 units. Due to the dry season value being outside the FMENV drinking water restriction of 6.5-8.5, it was evident that the rainfall under study is acidic. Oxides of carbon, that have been dispersed into the atmosphere from gas flares together with other compounds such as oxides of sulfur, nitric acid, and carbonic acids, could have caused acidity because of their constant presence. But the wet season value was within the FMENV drinking water limit. These findings support the views of [13, 14] on the presence of acid rain in Nigeria and the root causes being the irrational flaring of gas.

Statistically, from the discussions above on individual parameters, the mean values varied significantly from season to season and from regulatory standards, which is alarming and can be linked to several factors that are specific to that parameter, this supports the stands of [39, 40] that regulations are not met, and further flares might lead to troubling future implications. Additionally, tables 2 and 3 implied that the impact of gas flaring declines the further you are from the source, implying that residents closer to the source are more affected than those further away and this can be relied upon in environmental planning policies. Also, using models or correlations such as equation 1A the quantity of gas emitted from a plant can be ascertained and with this, plans on how to utilize flare gas instead of burning can be made. In general, it is noticed that there is a significant difference between the nature of air before the establishment of a refinery as shown in the prior section and highlighted in table 1 and the findings of this study, therefore, this study has produced useful information that the government can use to improve environmental protection and policies for sustainability in line with the UN's sustainable development objectives.

5. Conclusion and Recommendations

5.1. Conclusion

The results of this study indicate that the impacts of gas flaring on the Ekpan community are not only an abstract idea or a concept; rather, they may be connected to actual factual facts. With mean values of CO, SO₂, NO₂, pH, and suspended particle matter that exceed the ambient air quality guidelines. As a result, it is possible to draw the conclusion that the Ekpan community is dealing with a major environmental problem that requires immediate attention in order to mitigate its long-term repercussions. Furthermore, the study revealed that there are seasonal variations linked to the impact of flaring, therefore, a broader study can be done within this area and across other parts of the region considering more parameters

to come up with policies that will consider these variations while setting policies and standards for environmental emissions. Lastly, the reviews that informed this study suggested that the value of flared gases is underutilized within Nigeria, therefore it will be apt to channel them into economically advantageous investments rather than cause more environmental harm.

5.2. Recommendations

Natural gas produced in conjunction with oil accumulations is known as associated gas. It can either be found dissolved in oil or as a cap of free gas on top of the oil in a reservoir. It is flared because it will ignite or explode if the gas is not used or flared throughout the production process. Nigeria discharged 1,252.26 trillion cubic feet of natural gas into the atmosphere between 2016 and 2020 [15]. The gas is made up of methane and several natural gas liquids, such as propane, ethane, pentane, and butane. Natural gas liquids are highly valuable and can be utilized for a variety of purposes, including as raw solvents, and feedstock for the synthesis of different liquid fuels and chemicals. The following are advised for the efficient or total exploitation of associated gas:

- 1) Stakeholders such as the government and other important parties should support small businesses that utilize associated gases, by establishing NGL extraction plants, and other support programs that will improve utilization. Additionally, businesses that produce electricity, fertilizer, aluminum, steel, and other minor businesses can be urged to use the purported flared gases as their primary fuel source.
- 2) The government should make sure that, despite missing its initial goals, the strategy to increase domestic gas consumption and end countrywide flaring is still carried out. Businesses that miss the deadline should be subject to substantially greater fines.
- 3) The government needs to support natural gas distribution infrastructure being owned independently from the companies that supply the gas and distribute it via pipes for sale to residential and commercial customers in a particular region. Additionally, gas might be delivered to customers who might not be close enough or within easy reach of the current gas facilities as compressed natural gas (CNG).
- 4) Gas usage should be promoted as a primary energy source for domestic usage and businesses since it will significantly minimize gas flare-ups and address the issue of deforestation.
- 5) It is important to look into current technologies that are in use around the globe that encourages gas utilization, such as gas-to-liquid conversion technology and Mason power plants.
- 6) To guarantee that the price is fair for both the consumer and the supplier, allowances should be made in operating agreements, fiscal policies, and gas pricing plans. As a result, investments will prosper; consequently, harnessing flared gas should be considered an economic proposition.

- 7) To use gas for industrial purposes, oil companies should establish gas collection facilities throughout all of their fields and a pipeline network connecting gas stations to processing facilities.
- 8) Oil companies should strive to inject gas back into the

ground and should selectively close oil wells that generate large amounts of gas.

Seasonal influences on flaring and settlement location should be considered in policymaking as flaring can be linked to both parameters.

Appendix



Figure A1. Map of Delta State showing Ekpan community.

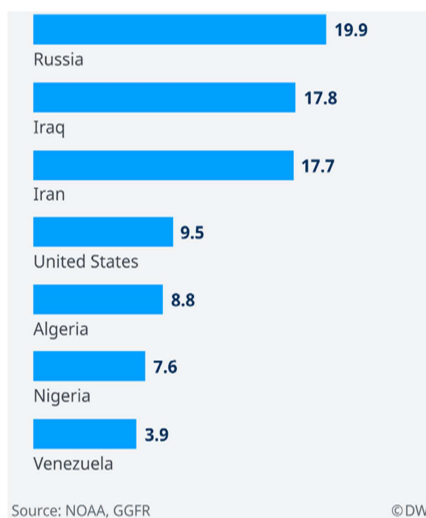


Figure A2. Top 7 gas-flaring countries in 2017 in billion cubic meters (NOAA & GGFR, 2017).

Table A1. Flue Gas Compositions at a Fossil Fuel Plant.

| Gas flaring constituent | Gas composition | Flue gas % | | |
|-------------------------|--------------------------------|------------|----------|----------|
| | | Min. (%) | Max. (%) | Avg. (%) |
| Methane | CH ₄ | 7.170 | 82.000 | 43.600 |
| Ethane | C ₂ H ₆ | 0.550 | 13.100 | 3.660 |
| Propane | C ₃ H ₈ | 2.040 | 64.200 | 20.300 |
| n-Butane | C ₄ H ₁₀ | 0.199 | 28.300 | 2.780 |
| Isobutane | C ₄ H ₁₀ | 1.330 | 57.600 | 14.300 |
| n-Pentane | C ₅ H ₁₂ | 0.008 | 3.390 | 0.266 |
| Isopentane | C ₅ H ₁₂ | 0.096 | 4.710 | 0.530 |
| Neo-Pentane | C ₅ H ₁₂ | 0.000 | 0.342 | 0.017 |
| n-Hexane | C ₆ H ₁₄ | 0.026 | 3.530 | 0.635 |
| Ethylene | C ₂ H ₄ | 0.081 | 3.200 | 1.050 |
| Propylene | C ₃ H ₆ | 0.000 | 42.500 | 2.730 |
| 1-Butene | C ₄ H ₈ | 0.000 | 14.700 | 0.696 |
| Carbon monoxide | CO | 0.000 | 2.850 | 0.713 |
| Carbon dioxide | CO ₂ | 0.023 | 3.800 | 0.256 |
| Water | H ₂ O | 0.000 | 14.700 | 1.140 |
| Oxygen | O ₂ | 0.019 | 5.430 | 0.357 |
| Nitrogen | N ₂ | 0.073 | 32.20 | 1.300 |
| Hydrogen sulfide | H ₂ S | 0.000 | 3.800 | 0.256 |

| Gas flaring constituent | Gas composition | Flue gas % | | |
|-------------------------|-----------------|------------|----------|----------|
| | | Min. (%) | Max. (%) | Avg. (%) |
| Hydrogen | H ₂ | 0.000 | 37.600 | 5.540 |
| Nitrogen oxides, | NO _x | 0.089 | 36.200 | 1.390 |
| Sulfur dioxide | SO ₂ | 0.068 | 24.600 | 0.479 |

Note: Gas's worth is essentially determined by how well it heats a space to determine the economic value of flared gas and match it with an appropriate procedure or disposal. It is crucial to know its composition. For instance, the H₂S level of the gas is the most important factor for transport in the upstream pipeline network. Gas is deemed sour if it has 10 mol/kmol or more H₂S. Source: Eman (2015)

Table A2. Gas produced and flared in the Ijaw area between 2003-2012.

| Years | Gas Utilized (mm ³) | Gas flared (mm ³) |
|-------|---------------------------------|-------------------------------|
| 2003 | 10000 | 30000 |
| 2004 | 15000 | 50000 |
| 2005 | 34000 | 23000 |
| 2006 | 36000 | 28000 |
| 2007 | 39000 | 25000 |
| 2008 | 41000 | 15000 |
| 2009 | 47000 | 12000 |
| 2010 | 52000 | 10000 |
| 2011 | 55000 | 7000 |
| 2012 | 59,000 | 5,000 |

Note: The table shows a gradual decline in the gas flared. The ratio of gas flared to gas utilized has steadily declined to show that lesser and lesser metric tons of gas is being flared. This may be attributed to better practice or increased effort to capture the gas. Source: [16].

Correlation for calculating gas emissions from a power plant

$$EM_{gas} (MT) = EF(\text{[Kg]}_{gas/kWh}) \times P(MW) \times CF(\%) \times T(year) \times MT/kg \times h/year \quad (A1)$$

EF = Emission factor, P = Nameplate capacity of the power plant, CF = Capacity factor (%), T = time, and the units are MT = million metric tons (10⁹ kg), MW = million watts, kWh = Kilowatts, kWh = Kilowatt. hour, kg = kilogram.

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