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Effect of Gas Flaring on Human Well-Being and Environment in Obodo-Ugwa, Ndokwa West, Local Government Area, Delta State, Nigeria

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Abstract

This study investigates the effect of gas flaring on human wellbeing and environment in Obodo-ugwa, Ndokwa West LGA, Delta State. The study used primary and secondary source of data. Water samples from wells, river and boreholes and soil samples were collected and analyzed using standard procedure. Landsat images for the years 2003, 2013 and 2023 were obtained from United States Geological Survey (USGS) online resources to assess the impact of oil spill on biodiversity (vegetation) using the Normalized Difference Vegetation Index (NDVI) in ARCGIS 10.6. The study administered 232 copies of questionnaires to compliment the data. The result of the findings revealed that the mean surface water (river) turbidity 16.00 NTU was 11.5% above the NSDWQ standard of 5.0., while the DO was 3.3% higher than the NSDWQ standard. The Biological Oxygen Demand (BOD) for Well water (A and B), borehole, and the river water were 9.8mg/L (96%), 9.9mg/L (98%), 7.7mg/L (54%) and 10.2mg/L (104%) higher than the Nigeria Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) Standard. For Chemical Oxygen Demand (COD), all water sources were above both the WHODWQ and NSDWQ. The soil analysis revealed manganese 4.53mg/kg (7.60%) above the Food and Agriculture Organization (FAO) limits of 4.21kg/kg, copper 7.60mg/kg (111.11%) above the 3.60mg/kg FAO limit. The NDVI result shows 80% deterioration vegetation health including farm land as only patches of healthy vegetation on the periphery as evident from 2003, 2013 and 2023 where the highest greenness index ranged from 0.26 to 0.34 in 2023, indicating that over the period of study, the forest in these areas have been degraded to mere shrubs. The study recommend that the Federal Government should enforce existing laws and provide alternative energy source to mitigate the effect of gas flaring on the people and salvage the environment.

Keywords: Biodiversity; Gas flaring; Human-Wellbeing; Ndokwa; Obodo-Ugwa

Abbreviations: USGS: United States Geological Survey; NSDWQ: Nigeria Standard for Drinking Water Quality; WHO: World Health Organization; BOD: Biological Oxygen Demand; APG: Associated Petroleum Gas; OD: dissolved oxygen; NDVI: Normalized Difference Vegetation Index; COD: Chemical Oxygen Demand; TDS: Total Dissolved Solids; ERDAS: Earth Resource Data Analysis System; VOCs: Volatile Organic Compound.

Introduction

Gas flaring is the combustion of natural gas mixed with oil during oil extraction process, which poses significant threats to both human wellbeing and the environment [1]. Gas flaring involves burning off natural gas associated with crude oil when there is insufficient infrastructure to capture or utilize the gas. The process releases pollutants such as carbon dioxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds into the atmosphere. Additionally, the process generates unpleasant noise, unbearable heat, smoke, and carbon monoxide, contributing to global warming that is resulting to climate change and negatively impacting both the health of the people, biodiversity and the entire environment [2].

Gas flaring occurs in the oil and natural gas sector when light hydrocarbon, particularly methane is flared for economic and technical reasons. In 2018, 145 billion m^3 of gas was flared worldwide [3]. This result in the emission of 350 million tons of CO_2, equivalent to 1% of the global carbon dioxide emission associated with the combustion of fossil fuels [4]. The burning of this excess gas comes from the production of fossil fuel and derivatives, mainly 90% from the upstream processing or extraction stage [5].

The flaring of natural gas is typically carried out using flare stacks, elevated structures that release the gas into the atmosphere. This practice is a byproduct of oil drilling, where gas is often wasted rather than being repurposed or reinjected into the reservoir for storage. Studies indicate that gas flaring causes air and water pollution, harming aquatic life, crops, vegetation, and human health. The flare zones, extending up to 0.5 km from the stack base, becomes unsuitable for human habitation due to high temperatures, noise, and light pollution. This elevated temperature affects not only humans but also the entire ecosystem, including fauna and flora [6].

The impact of gas flaring extends to both local and global levels, with direct emissions of sulfur dioxide and nitrogen into the atmosphere at temperatures as high as 1,600^{o}C [7]. Nigeria, being the sixth (6th) largest oil producer globally and the seventh (7th)-largest gas reserve holder, ranks fifth (5th) in gas flaring worldwide [8]. This calls for the urgent need for attention and remediation to mitigate environmental degradation to protect endangered species [8].

Oil exploration began in Nigeria in 1958. Subsequently, oil exploration extended across the 75,000 km^2 expanse of the Niger Delta. Notably, the practice of flaring and venting Associated Petroleum Gas (APG) in the region has been identified as a significant contributor, releasing approximately 35 million metric tons of greenhouse gases annually, posing a substantial environmental concern for both Nigeria and the global community [9].

Studies by Ite AE and Ibok UJ [10] reported that the Niger Delta alone flares about 2.5 billion cubic feet of gas daily, emitting various anthropogenic gases and hazardous substances, including carcinogens and heavy metals. The impact of gas flaring on human health and the environment as reported by Gobo AE, et al. [11] and Lee C, et al. [12] reveals the need for urgent attention. Ogwu CE, et al. [1] attributed the major issues in the Niger Delta to the oil and gas industries' non-compliance with environmental laws and government policies on gas flaring.

Obodo-Ugwa the study area situated in the Ndokwa Local Government Area of Delta State, with a population of around 3,000 people, serves as a microcosm of the broader challenges faced by communities in the Niger Delta region of Nigeria. The detrimental effects of gas flaring on both the environment and residents are evident in this small community. The abundant biodiversity in the region is rapidly declining, and the overall health of the community is deteriorating, likely due to the environmental consequences of prolonged exposure to gas flaring.

Gas flaring has the potential to disrupt the socio-economic fabric of the community by impacting agriculture, fisheries, and local livelihoods [13]. The economic consequences and potential displacement of residents due to adverse effects on their means of sustenance need to be investigated within the local context. The persistent challenges associated with gas flaring in the Niger Delta region, particularly in small communities like Obodo-Ugwa, despite extensive research efforts and recommendations aimed at addressing the issue and the regrettable non implementation by the Nigerian government and multinational oil companies is a source of concern in the study area. This situation is exacerbated by the global concern over Nigeria's significant contribution to carbon dioxide emissions and greenhouse gases.

Despite being a global concern, the specific impact of gas flaring on this local community remains inadequately addressed. Gas flaring is a common practice in the oil and gas industry located in Obodo-Ugwa community and poses significant threats to human wellbeing and the environment. This study examines the environmental impact of gas flaring in Obodo-ugwa, Ndokwa West LGA, Delta State Nigeria. The focus is on investigating the impact of gas flaring on human well-being and the environment in the study area where not much studies has been conducted to date.

Theoretical Framework

This study is anchored on the theory of environmental justice which is often attributed to Dr. Robert Bullard, often referred to as the "father of environmental justice." Robert Bullard is a prominent scholar and activist who has written extensively on the intersection of race, poverty, and the environment. The concept of environmental justice emerged in the 1970s and 1980s as a response to the disproportionate burden of environmental pollution and degradation experienced by marginalized communities, particularly communities of color and low-income. Poor and vulnerable communities often face environmental injustices, leaving them unable to combat or reverse detrimental trends, thereby further marginalizing them in society. Mohai P and Saha R [14] stress that calls for environmental justice essentially demand fair governance in affected regions. Mehta L, et al. [15] expanded the discussion of social justice beyond distribution to include recognition of differences, political participation and good governance.

This study uses the concept of social justice to examine environmental and ecological justice in Obodo-Ugwa, Ndokwa West Delta State in the Niger Delta region where gas flaring poses challenges for local impoverished communities. Sobrasuaipiri S [16] refers to the situation in the Niger Delta as a "Nigerian Environmental Apocalypse," and the region's distributional issues are labeled as "Resource Curse," impacting oil-producing communities negatively.

The environmental justice theory, focusing on multinational oil corporations' impact on the environment, incorporates a broader social justice discourse, including social recognition, participation, and distributional issues. Schlosberg D [17] argues that incorporating recognition and participation as justice issues can unite human and nature-focused movements for environmental justice.

The degradation caused by gas flaring in the Niger Delta contributes to further poverty, affecting the exercise of basic rights [18]. As ecosystem functions decline, the poor, who bear minimal responsibility, suffer the most, impacting their lives and livelihoods. Martin A, et al. [19] suggest emphasizing general concepts of equality in advocating for environmental justice in the Niger Delta.

Schlosberg D [17] underscores the importance of refining the understanding of environmental injustice mechanisms. Environmental justice has been applied in various issues, such as gas flaring, transportation, energy development, and water quality in the Niger Delta movement. Mehta L, et al. [15] propose a capability approach to justice, highlighting its utility in addressing the relationship between the environment, human needs, and ecosystem functioning.

The lack of governance undermines ecological support systems, leading to injustice for both humans and non-humans. Walker G [20] criticizes environmental justice studies for being insufficient in revealing inequalities and understanding the underlying processes, while Schlosberg D [17] contends that the approach provides a broad framework to comprehend the demands of environmental justice movements.

Description of the Study Area

Obodo-Ugwa is located in Ndokwa West Local Government Area of Delta State, Nigeria with headquarters in Kwale (Utagba-Ogbe) town. Ndokwa West Local Government Area has an area of 816km^2 and a population of 149,325 people according to the 2006 census [21] while Obodo-Ugwa has a population of around 3,000 people. It is located between latitude 6° 09'N and 6° 29'N of the equator and longitude 5°30'E and 6°03'E of the Greenwich meridian at an elevation of zero (0) meters above sea level as shown in Figure 1.

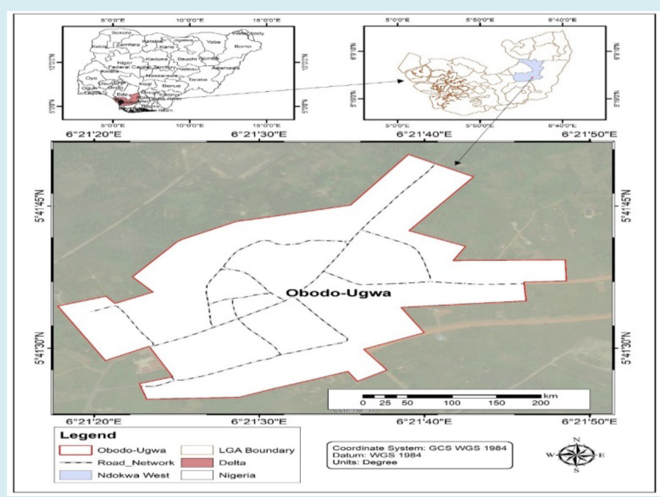

Figure 1: Map of the study area [22].

The climate of Obodo-ugwa is a sub-tropical humid climate based on Koppen's climatic classification scheme. It has an average temperature of 27.6°C. It receives about 256cm^3 of rainfall with about 314.12 rainy days (86.06% of the time) annually [23]. The entire Obodo-ugwa has approximately 50.8799 (13.94%) days of no rainfall annually [23]. The vegetation is a tropical rain forest with moist evergreen vegetation and tall trees. Unfortunately, the natural vegetation has been altered greatly by anthropogenic activities such as agricultural activities, oil exploration and constructions that reduced the natural vegetation of tropical rain forest to forest islands [24].

Obodo-Ugwa is a flat low-lying community with an elevation close to sea level in Niger Delta region. The terrain is characterized by network of rivers, creeks, and swamps. The area is intersected by numerous waterways, including the Ase, Tamer, and Umi Rivers, all of which drain into the larger Niger River system. The region has ecosystem that support diverse wildlife [25]. The flat relief and extensive waterways also make the area prone to flooding during the rainy season, which impact the local community and agriculture [26]. The study area is underlain by sedimentary rocks, primarily composed of sand stone, shale, and clay that were deposited by the Niger river and its distributaries [27]. This sedimentary deposited have been shaped by the process of erosion, transportation and deposition associated with the vast river system in the region [28].

Obodo-Ugwa is an important oil-producing community in the Niger Delta region with oil companies such as Agip Oil Company, Sterling Global Company, Mid-western Company and many others [21]. Farming is the major economic activities there, which is done at subsistence level, though there are a few commercial holdings especially for tree crop production such as oil palm trees. Crops such as plantain, cassava, maize, yam, okro, pepper and vegetable are the main food crops grown in the study area. Forestry, mining and hunting are part of the other primary activates done [27]. The people of Obodo-Ugwa also sees the forest as their sources of woods for building, source of energy (fuel wood) and herbs from the forest for local medication. They engaged in different Agricultural activities as their source of livelihood. There are also civil servants, politicians and laborers as skilled and unskilled workers. The people of Obodo-Ugwa are majorly self-employed (motorcycles, vehicles and bicycle).

Figure 2: (a),(b),(c),(d) Gas Flaring in the study area[22].

Materials and Methods

The survey research design was adopted in this study. This involved field observation and collection of water samples for laboratory analysis. Structured questionnaires were used to elicit information from members of the community on the impact of gas flaring on human wellbeing and the environment. Additionally, landsat data for 2003, 2013, and 2023 were used to assess the impact of gas flaring on the local flora. The satellite imagery was used to compute the normalized difference vegetation index (NDVI). NDVI quantifies the amount of vegetation greenness based on the principle that green vegetation during photosynthesis absorbs radiation in the visible band of the electromagnetic spectrum. On the other hand, near infrared is strongly reflected by the plant [29]. The near infrared is computed using the formula;

$$NDVI=\frac{(NIR\text{-}RED)}{(NIR+RED)} \qquad (1)$$

Where,
NIR= Near Infrared Reflectance Value
RED= Red Reflectance Value

The NDVI values were calculated. The result of NDVI ranging from -1 to +1 with higher values indicating healthier vegetation (close to 1) and lower values indicating less vegetation or non-vegetated area (close to -1). The metadata information of the landsat data used are shown in Table 1.

Dataset	Date	Resolution
LANDSAT 7 ETM+	30-12-2003	30 meters
LANDSAT 8 OLI	23-12-2013	30 meters
LANDSAT 8 OLI	29-12-2023	30 meters

Table 1: Meta Data Information of the Satellite Images used [22].

The water quality assessment focused on river, two well water designated as (W1) and (W2), one borehole (B), and one river (R). The collected samples were placed in clean plastic bottles, stored at room temperature, and transported to the laboratory within a five-day period for physicochemical analysis, while the soil sample was collected from the farm area of the community in a plastic container and was also taken to the laboratory for analysis. The samples were analyzed at the laboratory of the Department of Chemistry, Faculty of Chemical Sciences, Ahmadu Bello University, Zaria, Nigeria.

The study employs standard water quality test to determine the physicochemical parameters of the water samples. The parameters analyzed include physicochemical and heavy metal concentrations in the samples. The physicochemical parameters included Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), pH, Turbidity, Salinity, and Electrical Conductivity (EC). The heavy metals analyzed are manganese (Mn), cadmium (Cd), copper (Cu), lead (Pb), cobalt (Co), chromium (Cr), iron (Fe), nickel (Ni) and zinc (Zn). The values of these heavy metals were compared with the WHO and National Standard for Water Quality / permissible limit for portable water.

The study administered 232 copies of questionnaire randomly to respondents in ten (10) different quarters in the study area as indicated in Table 2.

An inferential statistic such as the Analysis of Variance was used to compute the difference in the calculated values and the WHO values for both water samples and the soil samples, while a simple percentage was uses for demographic data.

The satellite imageries were processed using Earth Resource Data Analysis System (ERDAS) software. The post-classification comparison technique was employed to detect changes. To calculate changes in land cover types for each study year (2003, 2013, and 2023), a table was developed indicating areas in square kilometers and percentage chanjuges for each land cover type. Percentage change was computed by dividing observed change by the sum of changes and multiplying by 100.

$$\text{Percentage change} = \frac{\text{Observed change} \times 100}{\text{Sum of change}}$$

Quarters	No. of Questionnaire
Ogbe Uku	22
Ogb-e Udala	18
Ogbe Ulade	27
Ogbe Ofu	25
Ogbe Oluji	21
Ogbe Okolari	19
Ogbe Oba	26
Ogbe Akpu	20
Ogbe Igbuduedem	28
Ogbe Okpofu	26
Total	232

Table 2: Table showing Questionnaire distributed among different quarters in the community [22].

Result of the Findings

Demographic Characteristics of the Respondents

Demography	Subgroup	Frequency	Valid percentage
Age	18-30	35	15
	31-45 Years	74	32
	46-60	74	32
	>60 Year	49	21
	Total	232	100.00%
Gender	Males	122	53
	Females	110	47
	Total	232	100.00%

Social Status	Lowest class(No Education)	154	65
	Low class(Prim Education)	58	25
	Mid Class(Secondary Education)	18	8
	High Class(Tertiary Education)	2	2
	Total	232	100.00%
Source of livelihood	Farming	225	97
	Personal Business	5	2
	Civil Servants	2	1
	Others	0	0
	Total	232	100.00%

Table 3: Demographic Characteristics of the Respondents [22].

The finding of the study in Table 3 reveals that 32% of the respondent was within the age of 31-45years and 32% are 36-60years. Table 3 shows that 53% of the respondents were male and 47% female. In terms of educational attainment, Table 3 reveals that 65% of the respondents have no formal schooling, while primary education accounted for 25.0%, secondary education 8.0% and tertiary education 2.0%. This educational profile suggests a substantial reliance on farming as the primary source of livelihood for the majority of the population. Given this context, the impact of gas flaring on human well-being and the environment in Obodo-Ugwa is multifaceted. The pervasive dependence on farming makes the community particularly vulnerable to the adverse effects of gas flaring, with potential consequences on agricultural productivity and the overall health of the population. The Table 3 reveals 97% of the respondents depend on farming for their livelihood, 2% on their personal business and 1% are civil servants.

Given that the majority of the population in Obodo-Ugwa relies on farming, any adverse effects on agriculture and vegetation due to gas flaring can directly impact the livelihoods and well-being of the community members. Reduced crop yields, soil degradation, and potential health hazards from exposure to air pollutants can all contribute to a decline in the overall quality of life of the people in the local communities.

Figure 3: (a), (b), (c), (d) Local communities interacted with the findings of the study on the sources of drinking water in the study area is presented in Table 4.

Sources of Drinking Water	Frequency	Percentage (100)
River/Stream	80	34.5
Well	76	32.8
Borehole	76	32.8
Total	232	100

Table 4: Sources of drinking water in the study area [22].

The result in Table 4 reveals that 34.5% of the respondents claimed that their sources of drinking water are River/Stream, 32.8% well and borehole sources respectively. The high proportion of the population depending on surface water for drinking water indicates more susceptibility to pollution by gas flaring when viewed in light of Smith and Johnson's [30] comprehensive exploration of the enduring consequences of gas flaring on water quality in regions associated with oil production.

The findings of the study on the health impact of gas flaring in the study area are presented in Table 5. From Table 5, it can be seen that 20.7% of the respondents claimed that the health impact is fatigue and headache, 20.3% claimed experiencing nausea, 16.8% claimed heart disease, 6.5% reproductive problems and 1.7% cancer.

Question	Value	Frequency	Percentage
Health issues	Fatigue	48	20.7
	Headache	48	20.7
	Nausea	47	20.3
	Respiratory Problems	39	16.8
	Heart Disease	31	13.4
	Reproductive Problems	15	6.50
	Cancer	4	1.70
	Total	232	100

Table 5: Health impact of gas flaring [22].

Effect of Gas Flaring on Human Wellbeing

Gas flaring has harmful effect on the health of the of the people who lived and work in the gas flare zone, that is those who live within the community which is also the study area; flared gas release different poisonous chemicals into the atmosphere, including but not limited to nitrogen dioxide, sulphur dioxide, volatile organic compound (VOCs) such as hydrogen sulfide, benzene, toluene, and benzene. The people of Obodo-Ugwa have suffered different kinds of health challenges as a result of continuous emission of these toxic gases as presented by the result below.

Niger delta is the highest oil producers in Nigeria and by implication the highest in Africa, since Nigeria is rated the highest oil producing country in Africa yet the region and the people have suffered neglect by the Government, environmental degradation, loss in economic and social values. The environment is deteriorating as well as the health of the people. According to Agochi O [31], the flaring of gas produces a continuous blazing fire burning day and night, exposing the people to excessive toxics that jeopardize their health. Natural gas flared into the air contain poisonous substance such as dioxins, benzene, toluene, nitrogen and SO_2. The health impact of air pollution spread across a wide area, and those who rely on locally produced food, either from their own farm or purchase in the market risk serious contamination. This study discovered that 98% of the people in the study site were suffering from health challenges ranging from heart disease, respiratory problem, cancer, reproductive problem. nausea, headache and fatigue. Emma AE [32] and Giwa SO, et al. [33] shows that short time human exposure to NO_2 can cause breathing complication, increase exacerbation of asthma and other respiratory problems. The people of Obodo-Ugwa, from this study showed that they have prevalence of gas flared related diseases.

The Effect of Gas Flaring on Drinking Water Quality

The result of the physico-chemical and heavy metals in drinking water sources of the community is presented in Table 6.

From Table 6, the pH of the water samples ranges from 6.26 to 6.42 and are within the permissible water quality limit. The water samples from the study site had COD ranging from 60.90mg/L to 88.00mg/L are below the WHO and NSDWQ standard 196mg/L and 5.0mg/L (Table 6). The high value shows a high amount of pollution in the water. The Biological Oxygen Demand (BOD) of all the water samples in this study area ranges from 7.70mg/L to 9.90mg/L which is beyond the WHO/NSDWQ permissible limit and suggest a very high amount of organic pollutants, such as nutrients or organic matters. High BOD level result to water pollution, decreased oxygen levels. A decrease in the oxygen level in aquatic environment can have serious consequences for aquatic life. Oxygen is essential for many organism including fish, invertebrates and plants. The results in Table 6 show that the turbidity ranges from 7.4 to 16NTU which is above the threshold of WHO and NSDWQ. The turbidity of all the water samples indicates the presence of pollutant in the water that is harmful for human consumption. The results in Table 6 further showed that the electrical conductivity of the water samples ranges from 32.0 to 46.8 µS/cm which are below 1000 µS/cm NSDWQ. This result corroborated the findings of Effiong S and Etowa UE [34] on impact of gas flaring on water quality in Obiakpu Egbema, Imo State which reported EC values of 30.90µS/cm – 40.40µS/cm compared with 22.00µS/cm – 23.00µS/cm of non- gas flared source.

S/N	Sample	DO (mg/L)	BOD (mg/L)	COD (mg/L)	pH	EC (µs/con)	Sal (%)	TDS (mg/L)	Turbidity (NTU)
1	Well Water (A)	4.9	9.8	78.3	6.26	38.6	0	18.9	7.5
2	Well Water (B)	5.1	9.9	81.1	6.47	40.4	0	19.3	7.4
3	Borehole	3.8	7.7	60.9	6.42	46.8	0	23.8	7.1
4	River	6.2	10.2	88	6.31	32	0	16	16
5	WHO Limit	6.50-8.00	2	196	6.5-8.5	-	-	-	1.00-5.00
6	NSDWQ	6	5	5	6.5-8.5	1000	-	500	5

Table 6: Physico-chemical parameters of water sample in the study area [22].

The dissolved oxygen (DO) levels in the water samples ranges between 4.90, 5.10, 3.80, and 6.20 mg/L. This is a source of concerns because it falls below the WHO/NSDWQ permissible limit. The result of the analysis of heavy metal constituents in the drinking water sources of Obodo-ugwa is presented in Table 7.

Parameter	Well (W1)	Well (W2)	River (R)	Borehole (B)	WHO Limit	NSDWQ	Remark
Manganese	-0.01	0.2	0.18	0.13	0.5	0.2	Negative
Cadmium	-0.06	0.03	-0.01	-0.02	0.003	0.003	Negative
Copper	0.06	0.03	0.06	0.08	2	1	Negative
Lead	0.28	0.31	0.24	0.27	0.01	0.01	Positive
Cobalt	0.02	0.02	-0.02	-0.13	0.005	0.005	Positive
Chromium	-0.49	0,30	-0.65	-0.19	0.05	0.05	Positive
Iron	1.26	1.65	1.45	1.06	1	0.3	Positive
Nickle	-0.05	-0.04	0.02	-0.09	0.02	0.001	Negative
Zinc	0.26	0.32	0.28	0.28	5	3	Negative

Table 7: Determination of Heavy Metal Constituents in the Drinking Water Sources [22].

The results in Table 7 shows that the concentration of manganese in drinking water sources ranges between -0.1 to 0.2mg/l which is within the WHO and NSDWQ limit (0.5 and 0.2 respectively). The result in Table 7 also shows no traces of cadmium in the water samples with -0.03 to -0.01. The result further reveals that the copper in the water sample ranges from 0.03-0.08. mg cu/l which were within WHO / NSDWQ permissible limits of 2.0 and 1.0mg cu/l respectively. Table 7 reveals that lead (Pl) ranging from 0.31 to 0.28 in all the water samples were above the threshold of the WHO / NSDWQ permissible limit of 0.01, thereby placing the lives of the people living in the community and who depend on those water sources at risk. Children and infants are particularly vulnerable to health issues associated with Pb exposure. An estimated intake of lead (Pb) to about 3.8 µg/day for infants and up to 10 µg/day for adults is derived from a 5 µg/l concentration of lead (Pb) WHO [35]. Health problems resulting from Pb exposure are diverse, encompassing neurological effects in both children and adults, as well as renal, cardiovascular, hematological, immunological, and reproductive effects [36].

The result in Table 7 reveals that there is no cobalt in the water samples with values of -0.02 to 0.02. The value of Cr in the water samples was 0.34 which is high compare to the WHO and NSDWQ standard of 0.05. This indicates that the potential for pollution occurs due to the poisonous gas emitted during gas flaring. Table 7 reveals high concentration of iron (Fe) of 1.2mg/l to 1.6mg/l which is above the threshold of 1.0 and 0.30mg/l WHO/ NSDWQ standard. The Table 7 also shows nickel to be within the WHO/NSDWQ permissible limit. The results in Table 7 showed zinc (Zn) concentration of 0.25mg/l to 0. 27 mg/l which is within the WHO/NSDWQ permissible limit.

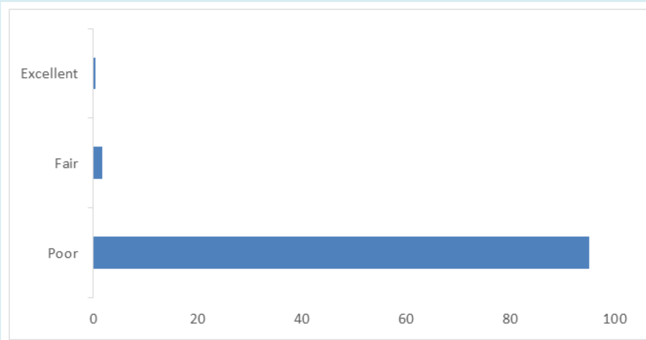

Figure 4: Respondents perception of the quality of drinking water source in the study area [22].

The findings of the study in Figure 4 reveals that 95% of the respondents claimed that the drinking water source in the study area is poor, 3.8% claimed it is fair, and 1.2% their sources of drinking water quality as excellent. This data implies an overwhelming perception of poor quality of drinking water source within the host community, suggesting potential health and well-being risks. Smith and Johnson [30] had reported consequences of gas flaring on water quality in regions associated with oil production. Their empirical study meticulously examines the prolonged impact of gas flaring activities on water bodies in these areas, revealing compelling results that establish a clear correlation between gas flaring and key water quality parameters. These parameters include chemical composition, microbial content, and overall ecological health. The findings emphasize the persistent and substantial influence of gas flaring on water quality, extending beyond immediate concerns and posing potential threats to aquatic ecosystems and communities relying on these water sources. The empirical evidence presented by Smith and Johnson contributes significant insights to understanding the environmental implications of industrial practices in oil-producing regions. Their results underscore the importance of informed decision-making in environmental management, advocating for sustainable practices and regulatory measures to mitigate the adverse effects of gas flaring on water quality in such areas [30].

Effect of Gas Flaring on Soil Quality

The result of the findings on the effect of gas flaring on soil quality is presented in Table 8.

S/N	Parameters	Soil mg/kg	WHO standard NSDWQ mg/kg
1	Manganese (Mn)	4.53	4.21
2	Cadmium (cd)	-0.4	3.00-8.00
3	Copper (Cu)	7.6	3.6
4	Lead (Pb)	100	600
5	Cobalt (Co)	0.6	1.00-17.00
6	Chromium (Cr)	-6.6	0.3
7	Iron (Fe)	92.5	0.40-1.03
8	Nicked (Ni)	0.625	20
9	Zinc (Zn)	9.12	10

Table 8: The effect of gas flaring on soil of Obodo-ugwa community [22].

The result of the findings in Table 8 reveals that manganese (Mn) concentration in the soil sample collected from study area was surpassing the Food and Agricultural Organization (FAO) standard for manganese in soil which is set at 4.21 mg/l. The elevated manganese levels are indicative of potential contamination resulting from gas flaring activities in the area. While manganese is an essential nutrient, exceeding permissible levels poses health risks. Chronic exposure may lead to neurotoxicity, impacting the nervous system and potentially causing neurological disorders, cognitive impairments, and developmental issues, especially in vulnerable populations like children and pregnant women.

The measured value of cadmium (Cd) in the soil samples from the study area was 0.4mg/l, while the FAO standard for cadmium in soil ranges from 3.00-8.00 mg/l. This indicates that the cadmium level in the soil is low. The Table 8 reveal that copper (Cu) in the soil sample had high concentration of 7.60mg/l surpassing the FAO standard of 3.60 mg/l. This excess copper in the soil by 4.00 mg/l, raises significant environmental and health concerns. The elevated copper levels suggest potential environmental pollution and pose a risk to ecosystems. Chronic exposure to such high copper levels may adversely affect the health of local residents, potentially impacting respiratory and nervous systems. Table 8 further reveal the presence of lead (Pb) concentration of

10.0 mg/l in the study area. The elevated lead (Pb) levels pose significant health risks to both the environment and individuals residing in or around the affected area. Chronic exposure to lead in soil can lead to various health issues, including neurological and developmental problems, especially in children. Given the proximity to a gas flaring site, there is an increased likelihood of lead (Pb) being released into the environment through air and soil contamination, amplifying the health implications. The findings of the study in Table 8 shows cobalt (Co) concentration of 0.60 mg/l. Table 8 reveal iron (Fe) concentration of 92.5 mg/l. This elevated iron level suggests a potential environmental issue with implications for both plant growth and water quality. High iron concentrations in the soil may adversely affect agricultural productivity and contribute to groundwater contamination, posing risks to both aquatic ecosystems and drinking water sources. The health implications include the potential for increased human exposure to iron through the consumption of crops grown in contaminated soil, which could lead to issues such as iron toxicity affecting organs like the liver and heart. The Table 8 also reveals the presence of Nickel (Ni) 0.625 mg/l. The zinc concentration in the soil sample from the study area is measured at 9.12 mg/l, while the FAO standard for zinc in soil is set at 10.00 mg/l. The measured zinc levels are below the FAO standard, indicating that, in this specific case, gas flaring activities may not be significantly impacting zinc levels in the soil.

Effect of Gas Flaring on Vegetation Health

This section presents the result of the effect of gas flaring on vegetation health through the Normalized Difference Vegetation Index (NDVI) as shown in Figure 5.

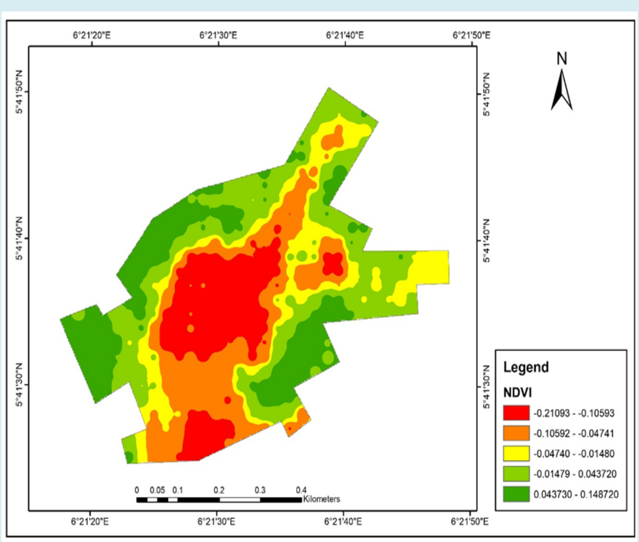

Figure 5: NDVI for Obodo-Ugwa, 2003 [22].

The NDVI result in Figure 5 indicate the vegetation health in Obodo-Ugwa community, with each color range representing different levels of vegetation density. The values between -0.21 and -0.16, indicate non-vegetated areas, such as water bodies, bare soil, or built–up urban surfaces. Values between -0.16 and -0.11 also suggests non-vegetation or sparely vegetated areas, such as spare shrubs or grasslands. Values between -0.11 and -0.05; still represent non-vegetated or sparsely vegetated areas. Values between - 0,05 and 0,04; This range represents areas with minimal to moderate vegetation cover, including sparsely vegetation or areas with limited greenery. Values between 0.04 – 0.15 indicate moderate to dense vegetation cover, such as croplands, orchards, or moderately dense forests.

The NDVI result for 2003 suggest a mix of non-vegetated areas, sparse vegetation areas, and some moderate vegetation cover. The result for 2013 as shown in Figure 6.

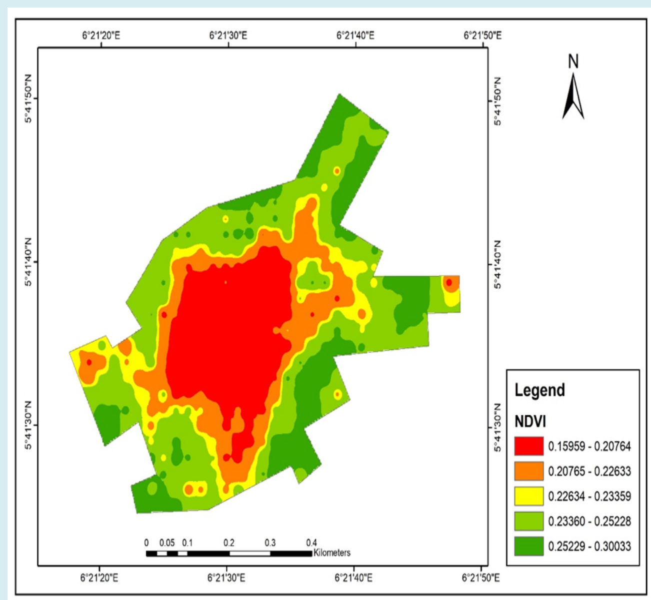

Figure 6: NDVI for Obodo-Ugwa, 2013[22].

The NDVI result for 2013 indicates a range of values from 0.15959 to 0.30033. NDVI values between 0,15959b and 0.20764 suggest areas with little or no vegetation, which signify a depletion of the vegetation in the study area as a result of gas flaring activities. However, there were still area with moderate vegetation cover with values between 0.20765 and 0.25228. The highest values in the range (0.2529 to 0.30033) which indicate very high dense vegetation across the study area. This also account for the long time communal crisis in the area which was responsible for low human activities particularly gas flaring. The NDVI result for 2023 is shown in Figure 7.

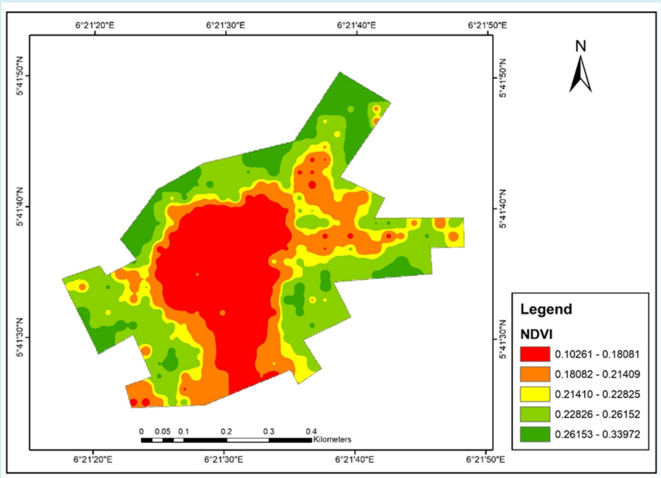

Figure 7: NDVI for Obodo-Ugwa, 2023 [22].

The NDVI result for 2023 indicates a range of values from 0.10261 to 0.33972. The values between 0.10261 and 0.18082 suggest areas with little or moderate vegetation, while values between 0.18082 and 0.22825 represent moderate to dense vegetation. The highest values in the range (0.22826 to 0.33972) indicate areas with very dense vegetation cover. Overall, the NDVI result for 2023 suggest a range of vegetation density across the area of interest, with some areas showing increased vegetation com pare to the 2013 result and this could be as a result of long standing communal crisis in the area that result to low gas flaring activities [37].

Conclusion

This study has examined the effect of gas flaring on human well-being and environment in Obodo-Ugwa, Ndokwa West, Local Government Area Delta State, Nigeria. The findings of the study revealed that gas flaring has had an adverse effect on the health of the people and the environment in the study area especially the quality of their sources of drinking water, soil and vegetation. The result of the physicochemical analysis indicates the presence of some heavy metals in the drinking water sources and soil samples of the study area. The NDVI result shows 80% deterioration in vegetation health including farm land as only patches of healthy vegetation on the periphery as evident from 2003, 2013 and 2023 where the highest greenness index ranged from 0.26 to 0.34 in 2023, indicating that over the period of study, the forest in these areas have been degraded to mere shrubs.

Recommendations

Based on the findings of the study, the following recommendations are made:

- There is need for Nigerian government to demonstrate commitment to zero flare which is a win for the global climate change issue. This will enable the country to use the flared gas for production of synthetic fuels (gasoline, kerosene, diesel, fuel oil) which is a win for the quest for cleaner transportation energy.
- Government should take proactive measures to safeguard water sources by implementing measures that will treat and purify water sources that have been contaminated by gas flaring activities. encouraging the use of the gas that is flared such as generation of electricity that is considered a win for employing efficient water treatment machine to provide clean drinking water, standard water for the fish farming aqua-culture ponds, production of chemical for drugs production and creation of jobs for operating the facilities thereby improving the quality of life in the affected areas.
- Production of liquefied petroleum gases (LPG) in place of gas flaring can replace fire wood thereby protecting the physical environment. This will go a long way in providing sustainable solutions to the problem of gas flaring in the affected communities.
- Government should undertake afforestation programs to restore vegetation and biodiversity in areas affected by gas flaring. Nigerian government will need to consider the proposed global solution approaches that emphasizes real-time monetization of associated petroleum gas (APG) flaring, using on-site skid mounted units/modular.
- The government and multinational oil companies should consider investing in community-driven initiatives that will mitigate the far-reaching impacts of gas flaring on both human populations and the natural environment.
- With the continuous gas flaring activity in the study area, there will be need for periodic monitoring of soil, water and vegetation in the study area. Measures should be put in place to minimize or mitigate the release of pollutants from gas flaring activities into the environment.
- Government may need to enforce the adoption of cleaner technologies by the multinational oil companies operating in the study area. Government need to support the development of modular refineries that can convert the entire flare stream from a location to any of the most required variety of products.

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