

# Gas Flaring and Venting Associated with Petroleum Exploration and Production in the Nigeria's Niger Delta

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**Abstract** Global flaring and venting of petroleum-associated gas is a significant source of greenhouse gas emissions and airborne contaminants that has proven difficult to mitigate over the years. In the petroleum industry, poor efficiency in the flare systems often result in incomplete combustion which produces a variety of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and inorganic contaminants. Over the past fifty years, gas flaring and venting associated with petroleum exploration and production in the Nigeria's Niger Delta has continue to generate complex consequences in terms of energy, human health, natural environment, socio-economic environment and sustainable development. In some oil-producing host communities, most flaring and ventingsystems are located in close proximity to residential areas and/or farmlands; and the resultant emissions potentially contribute to global warming as well as somelocal and/or regional adverse environmental impacts. There are emerging facts in an attempt to understand the effect of flaring and venting practices and the complex interactions of thermal pollution, organic and inorganic contaminants emission in the environment. This review discusses environmental contamination, adverse human health consequences, socio-economic problems, degradation of host communities and other associated impacts of flaring and venting of associated gas in the petroleum industry in the Niger Delta. Effective understanding of the overall impact of associated gas flaring and venting in the petroleum industry is important for effective management of the energy resources, environmental risk mitigation, implementation of good governanceand sustainable development.

**Keywords:** petroleum, natural gas, flaring, venting, emissions, environment, Niger Delta, Nigeria

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## 1. Introduction

Gas flaring and venting associated with petroleum exploration and production in the Nigeria's Niger Delta commenced in 1956 following the discovery of oil and gas resources in commercial quantity. Flaring and venting of associated natural gas are widely used in the petroleum industry to dispose of associated natural gases for safety reasons during petroleum development operations and/or where no infrastructure exists to bring it to market. Associated natural gas, which is a by-product of petroleum production, is burned on reaching the surface with a process called flaring or by being released into the atmosphere without burning through venting [1,2]. The flaring and venting of petroleum associated gas has been dramatically curbed in developed countries [3]. For example, Norway has adopted flaring reduction measures and introduced a carbon tax, which penalizes companies for flaring or venting gas. However, Nigeria's penalty for gas flaring and venting seems too low to either influence the practice or curb emissions. Gas flaring practices has been preferred means of disposing associated or waste gas

by various petroleum exploration and production companies operating in the Nigeria's Niger Delta for the past five decades (Table 1). In some cases, venting may be preferred discharge option depending on factors such as safety, local noise impacts, chemical composition and toxicity of the associated gases. However, re-injection of associated natural gas into the ground for potential future harvesting [4] and liquefaction of natural gas for energy supply could serve as an alternative means of disposal.

The Nigerian government has policy and regulations on its books (since 1979) regulating gas flaring in the petroleum sector and by the 1979 Associated Gas Re-injection Act, no oil company was permitted to flare gas after January 1984 without ministerial authorization. However, these flaring policy and regulations were not properly enforced, and Nigeria flares over 75 % of the associated gas it produces and this represents a pollution equivalent to 45million tons of CO<sub>2</sub> per day. Currently, there are over 123 flaring sites in the Niger Delta region and Nigeria has been regarded as one of the highest emitter of greenhouse gases in Africa [5]. In the developed countries, several attention and corrective measures have been adopted to address the problems associated with these remarkable wastes with significant economic value

and considerable environmental costs. Nigeria, the highest producer of gas in Africa, has been ranked among some of the highest gas flaring countries across the world along with Russia and Iraq. Over the past fifty years, petroleum exploration and production companies have done little to stop gas flaring in the Nigeria's Niger delta and there is slow pace of adoption of modern technology for utilization of petroleum-associated gas that could help curb flaring and venting in the region. However, empirical studies on the impact of gas flaring on the physical, chemical, biological, atmospheric, soil and social environment have not been adequately documented [6]. Although the total environmental costs are yet to be adequately quantified, the effects of flaring and venting of gas associated with petroleum exploration and production are multifaceted and complex in nature.

**Table 1. Amount of gas production, utilization and flared in Nigeria from 1970 – 2011 (data and information sourced from the Nigerian National Petroleum Corporation (NNPC), Department of Petroleum Resources (DPR) and Central Bank of Nigeria (CBN) Estimates)**

Year	Production (Mm <sup>3</sup> )	Utilization (Mm <sup>3</sup> )	Flared (Mm <sup>3</sup> )
1970	8029.0	72.0	7957.0
1971	12975.0	185.0	12790.0
1972	17122.0	274.0	16848.0
1973	21882.0	395.0	21487.0
1974	27170.0	394.0	26776.0
1975	18656.0	323.0	18333.0
1976	21276.0	659.0	20617.0
1977	21924.0	972.0	20952.0
1978	21306.0	1866.0	19440.0
1979	27619.0	1546.0	26073.0
1980	24551.0	1647.0	22904.0
1981	17113.0	2951.0	14162.0
1982	15382.0	3442.0	11940.0
1983	15192.0	3244.0	11948.0
1984	16255.0	3438.0	12817.0
1985	18569.0	3723.0	14846.0
1986	18739.0	1822.0	13917.0
1987	17085.0	4794.0	12291.0
1988	20253.0	5516.0	14737.0
1989	25053.0	6323.0	18730.0
1990	28163.0	6343.0	21820.0
1991	31588.0	7000.0	24588.0
1992	32464.0	7058.0	25406.0
1993	33444.6	7536.2	25908.4
1994	32793.0	6577.0	26216.0
1995	32980.0	6910.0	26070.0
1996	36970.0	10150.0	26820.0
1997	36754.8	10207.0	26547.8
1998	36036.6	10886.5	25150.1
1999	35856.4	12664.6	23191.8
2000	47537.0	21945.0	25592.0
2001	57530.0	29639.7	27890.3
2002	101976.1	26203.4	75772.7
2003	53379.0	30583.0	22796.0
2004	69748.0	45156.0	24592.0
2005	58247.0	34818.0	23429.0
2006	57753.7	39374.8	18376.9
2007	65936.5	43188.4	22748.1
2008	66640.8	48796.0	17844.8
2009	41534.2	28076.5	13457.2
2010	58006.0	44506.6	13499.3
2011	55099.1	38898.2	16200.5

This review examines the complex environmental, potential human health risks and socio-economic impacts of flaring and venting of petroleum-associated gas, and discharges of associated hazardous atmospheric contaminants from the petroleum industry in the Niger Delta.

## 2. Chemical Composition of Petroleum-associated Gas and Emissions from Flare Systems

Natural gas is a mixture of hydrocarbons which consist of 95% methane, 2.5% ethane, 0.2% propane, 0.06% butane and 0.02% some higher alkanes (C<sub>5</sub>H<sub>12</sub> + C<sub>10</sub>H<sub>22</sub>), 1.6% nitrogen (N<sub>2</sub>), 0.7% carbon dioxide (CO<sub>2</sub>) and trace amounts of hydrogen sulphide (H<sub>2</sub>S), water (H<sub>2</sub>O) as well as other trace gaseous impurities and non-combustible components. According to Brown et al. [7], composition of natural gas associated with crude petroleum mainly consists of methane and other gaseous components vary with the individual production oil field with a very broad description of the composition of natural gas. Nigerian natural gas can be roughly described as 90% methane, with 1.5 – 2.0% carbon dioxide, 3.9 – 5.3% ethane, 1.2 – 3.4% propane, 1.4 – 2.4% heavier hydrocarbons and trace amount of sulphur [8]. Although Nigerian natural gas are classified 'sweet' due to its low sulphur contents, the results of a study on flaring operation in the Niger Delta regionshowed that sulphur dioxide (SO<sub>2</sub>) is one of the products of natural gas flare in Nigeria [9]. Apart from other anthropogenic sources, flaring and venting process associated petroleum exploitation and production operations in the Niger Delta have discharged significant amount of emissions into the environment over the past five decades.

Gas flare and vent systems in the petroleum exploration and production facilities, power generation and hydrocarbon contamination are the main sources of anthropogenic inputs to the terrestrial environment in the Niger Delta. According to Strosher [10], predominant hydrocarbon compounds recently measured 5 m above a low-sulphur content (sweet) gas flame include various VOCs and PAHs. In most cases, the most abundant hydrocarbon compounds found in any of the emissions examined in the field flare testing include benzene, styrene, ethynyl benzene, ethynyl-methyl benzenes, toluene, xylenes, ace naphthalene, biphenyl, and fluorene [11]. Flaring of associated gas mainly emits carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO) and a variety of air pollutants, such as VOCs (which include carcinogens and air toxics), nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), toxic heavy metals and black carbon soot. It is known that some of the products of complete combustion, such CO<sub>2</sub> and H<sub>2</sub>O, from flares contribute greatly to heat radiation experienced around flares [2,12]. In addition to vehicular traffic emissions (CO<sub>x</sub>, HC, NO<sub>x</sub>, SO<sub>2</sub> and particulate matters), emissions from gas flaring and venting systems in the oil-producing Niger Delta mainly contribute to atmospheric pollution in the South-South geopolitical zone of Nigeria [13,14]. From the study of non CO<sub>2</sub> gaseous emissions from upstream oil and gas operations in Nigeria, Obioh et al. [9] have demonstrated that CO and

NO<sub>x</sub> emissions from flare systems are an order of magnitude higher than other sources in the petroleum industry. Further, the effects of gaseous emissions resulting from gas flares on vegetation in Nigeria and the resultant acid rains resulting from gaseous compounds emissions has been identified as a major problem [15]. Several researchers have reviewed the effect of oil extraction and the extent of environmental degradation in Nigeria [16,17,18,19].

### 3. Effects of Gas Flaring and Venting in the Niger Delta

Gas flaring and venting systems in the petroleum exploration and production operations are stationary sources of atmospheric contaminants that have several consequences on the regional and global environment. Some of the effects of petroleum associated gas flaring and venting systems in the oil-producing Niger Delta region include greenhouse effect, increase in temperature or thermal gradient [20-26], human health problems [27,28,29,30], poor agricultural yields [4], acid rain/acidification of aquatic environment [31,32] and changes in the ecosystem [33]. In the Nigeria's Niger Delta, there are widespread perceptions that gas flaring and venting practices in the petroleum industry contribute to several human health, environmental and socio-economic problems in the region [34,35]. This section will discuss some of the issues associated with flaring and venting of petroleum associated gases in the oil and gas industries in the 9 oil-producing states in the Nigeria's Niger Delta.

#### 3.1. Atmospheric Effect

Atmospheric effect associated with emissions from flaring and venting in the oil and gas industry are generally influenced by a number of factors, including flare/vent design, operating conditions and chemical composition of petroleum-associated gas. From an operational perspective, some 45.8 billion kilowatts of heat are discharged into the atmosphere of the Niger Delta from combustion of 1.8 billion cubic feet of gas everyday [36]. The performance of combustion is largely impacted by the energy density of the flare gas stream, design of the flare system, composition of flare gas, and environmental conditions such as ambient temperature, wind speed, and wind direction [11,37,38,39]. However, since the combustion efficiency depends on wind speeds, stack exit velocity, stoichiometric mixing ratios, and heating value, the flaring in reality is rarely successful in the achievement of complete combustion [39]. It is known that incomplete combustion of these gases produces a variety of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) [37,40]. Therefore, environmental issues associated with emissions from the flare and/or vent systems depends on the combustion efficiency and the amount of organic contaminants depend on the chemical composition of the associated gas sources.

In the Niger Delta, flaring and venting of associated gas contributes approximately 35 million metric tons of carbon dioxide (CO<sub>2</sub>) per year, methane (CH<sub>4</sub>), a large

number of hydrocarbons and other forms of green-house gases (GHG) into the atmosphere. For example, methane constitutes approximately 86% of the natural gas, and because of the low burning efficiency of the flares, greater percentage of the associated gas released is methane that has a higher global warming potential [41]. These emissions increase the concentration of green-house gases (GHG) in the atmosphere, which in turn contributes to global warming [42]. Due to the large number of hydrocarbons in the Niger Delta atmosphere, there are large numbers of possible reactions in the photochemical smog in the region and emissions from flare and vent systems has implicated regional and/or global environment. In a study, Ayansina et al. [34] assessed the adverse effect of gas flaring on the environment and the potential benefits of its reduction on the local economy and the environment at large. The data from the study suggested that gas flaring contributes to global climate change and has significant negative impacts on the environment [34]. It is evident that gas flaring has contributed significantly to poor environmental and human health quality around the vicinity of the flares and overall environmental degradation in the region.

#### 3.2. Chemical, Biological and Physical Effect

Acid precipitation or acid rain is one of the major environmental problems that have characterized the oil-producing Niger Delta in recent times and causes significant impacts on freshwater, coastal and mangrove ecosystems. While there are various sources of anthropogenic contaminants, flaring of petroleum-associated gas and combustion of fossil fuel are the main sources of oxides of nitrogen (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) emissions. In the presence of atmospheric compounds such as oxygen (O<sub>2</sub>) and water (H<sub>2</sub>O), NO<sub>x</sub> (NO + NO<sub>2</sub>) reacts to form nitrate ion (NO<sub>3</sub><sup>-</sup>) and SO<sub>2</sub> reacts to form sulphate ion (SO<sub>4</sub><sup>2-</sup>). Both NO<sub>3</sub><sup>-</sup> (from NO<sub>x</sub> emissions) and SO<sub>4</sub><sup>2-</sup> (from SO<sub>2</sub> emissions) contribute significantly to acid rain. There is widespread acid rain in the Niger Delta region [31,32,33,43,44], however, there is no information on the relative ratio of SO<sub>4</sub><sup>2-</sup>/NO<sub>3</sub><sup>-</sup> in precipitation in the region. Acid rain from increased SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub> concentrations is evident in the pH values that range from 4.98 – 5.15 and mean value of 5.06 [33]. According to Efe [33], rain water acidity (pH) varied significantly ( $P > 0.05$ ) and it decreases with increasing distance from gas flare sites throughout the period of study.

Acid precipitation may contribute to local and regional environmental problems such as acidification that leads to a reduction in species richness [45], impact on agriculture and forests [42] and other physical infrastructure [46]. When leaves are frequently bathed in acid precipitation their protective waxy coating can wear away and this can lead to reduction in photosynthesis in plants. Odu [47] observed that oil deposited on leaves of plants, penetrates the leaves and reduces transpiration and photosynthesis and that leaves become yellow where oil pollution is light. Although the detrimental effects of acidic deposition on plants and other organisms were made in Europe more than 300 year ago [48], there are limited scientific research on the effects of acid rain on soil and aquatic microbial processes in the Niger Delta. Both direct and

indirect soil-mediated effects of an increased acid load on the size, composition and activity of the soil microbes have been reported in some studies [49,50,51]. Further, there are effects of acid rain precipitation on microbe-mediated changes in soil processes, such as litter decomposition [52] and the function of the decomposer community may lead to imbalances in nutrient cycling and productivity of the ecosystem. Although changes in C-availability in the exposed soils are reported, changes in the supply of N are evaluated as the major mechanism through which simulated acid rain affects soil microbial activity [51]. The effects of acid rain on soil and aquatic microbial processes have been critically reviewed [53].

Acid precipitation phenomenon in the Nigeria's Niger Delta region has raised environmental, economic, biodiversity and public health concerns over the past years. The negative environmental problem such as rapid corrosion of corrugated iron roofs (galvanized iron sheet) witnessed in the oil-producing communities in the Niger Delta have been linked to acid rain in some studies [28,54,55,56,57]. In a study, Ekpoh and Obia [28] demonstrated that acid rain causes rapid corrosion of zinc roofs in the in the three experimental sites that were located near pollution sources such as gas flare station or sea aerosols in the Niger Delta relative to the controlled site that was located far away from pollution sources. Further, building degradation have been attributed to the major pollutants such as SO<sub>2</sub>, NO<sub>2</sub> and PM<sub>10</sub> that may have caused the observed impacts (corrosion of roof tops, colouration of walls, leakage of roof tops, etc.) due to their toxic properties [55,57]. Although the impacts of gas flaring on built environment are limited, there are several consequences associated with flaring and venting of petroleum-associated gas during petroleum resources exploitation and production. Further, acid rain in the oil-producing host communities in the Niger Delta can also contribute to the microclimate degradation, poor soil fertility and agricultural yield.

### 3.3. Impact on Plant and Microclimate Degradation

Gas flaring is the major source of thermal pollution, which causes a distinct microclimate around the vicinity of oil and gas exploration and production operations. In addition, the toxicity of contaminant mixtures from gas flare and vent systems could affect some aquatic organisms by changing their phylogenetic position and reduction in their relative sensitivity as the intensity of gas flares increases. The impact of gas flaring on plant and vegetation growth was first studied by Isichei and Sanford [15]. It was observed that air, soil and leaf temperatures increased and relative humidity of the air decreased within 110m from the flare sites. According to Isichei and Sanford [15] the leaf chlorophyll content and intern ode length of *Eupatorium odmatum* decreased with increasing distance to the flares, and flowering of this short-day plant was suppressed in the area of the flares. It is common perception by peasant farmers in the Niger Delta region that gas flaring and microclimate change are the major cause of poor agricultural yield in the region. The retardation of tuber yield of *Manihot esculenta* Crantz was investigated [58] and cassava tubers decreased in length and in weight as the distance from the flares systems

decreased. According to Lawanson et al. [58], the high levels of amino acids and sugar in tubers closer to the flares suggest reduced synthesis, or increased degradation of tuber proteins and insoluble carbohydrates, respectively. Therefore, it was suggested that gas flaring, most probably through their effect on the surrounding soil temperature, reduce the quantity and quality of cassava crop yield.

Gas flaring does not only result in the destruction of vegetation, wild life and ecological change in the ecosystem, but it also significantly affects the microclimate, biological and physico-chemical properties of soils in close proximity to the flare sites. In a study, Dung et al. [4] investigated the spatial variability effects of gas flaring on the growth and development of cassava (*Manihot esculenta*), waterleaf (*Talinum triangulare*), and pepper (*Piper* spp.) crops commonly cultivated in the Niger Delta, Nigeria. The results suggest that a spatial gradient exists in the effects of gas flares on crop development [4]. This study attributed increased temperatures around the gas flare as the most likely cause of crop retardation in this region. In a further study, Odjugo and Osemwenkhae [24] observed that the air temperature, soil temperature at 5 cm and 10 cm depths increased as one moves closer to the flare site. Therefore, the environmental impacts associated with flaring are mainly regional and local, but to some extent also global. The regional increases in temperature (thermal gradient) around gas flaring facilities have been reported [20,21,22,24,25]. It has been suggested that increase in temperature associated with gas flare contributed to low agricultural productivity and cause changes in the natural ecosystem.

The physico-chemical properties of soil, air and soil temperatures, rainfall and relative humidity around some flare sites have been investigated in some studies [20,21,22,24,59]. In a study, Odjugo and Osemwenkhae [24] investigated the physiological parameters such as germination rate, growth rate, leaf area index (LAI) and product yield of maize (*Zea mays*). The induced microclimatic condition impacted on the soil and reduced the yield of maize by 76.4%, 70.2% and 58.2% at 500m, 1km and 2km, respectively [24]. The modified microenvironment in terms of air and soil temperatures of the flare site, relative humidity, soil moisture and other soil chemical properties actually affected not only maize germination, but also the growth and agricultural yield [24]. It is known that thermal pollution from gas flares affects the microbial populations [60], which participate in organic matter decomposition and nitrogen formation process resulting in a decline in organic matter and total nitrogen, as well as microbial populations, humid (top soil) formation, nutrient availability and soil fertility. Therefore, gas flaring impacts adversely on soil fertility and biogeochemical nutrient cycles [59] and the negative effects of physico-chemical properties of the soil subsequently impact on some crops due to modification of the microclimate in the region.

### 3.4. Soil Contamination

Apart from thermal pollution associated with gas flaring, which alters the microenvironment, flue gas dispersion and emissions from the flare systems discharges various organic and inorganic contaminants

into the atmosphere. Assessment of the PAH compound ratios, phenanthrene/anthracene and fluoranthene/pyrene, suggested that predominant present of PAHs of pyrogenic sources in surface soils is an indication that oil leakage and/or gas flaring contributes to soil contamination [61]. It is widely known that soil and sediments have become the ultimate sink for most petroleum contaminants, such as benzene, toluene, ethyl benzene, and xylenes (BTEX), aliphatic and polycyclic aromatic hydrocarbons (PAHs). According to Ite and Semple [62], PAHs containing from two to five fused aromatic rings are of significant concern because of the mutagenicity and carcinogenicity of several of these compounds and tendency to bioaccumulate in organic tissues due to their lipophilic character and electrochemical stability. However, indigenous soil microbes possess the inherent ability to transform organic contaminants into less toxic or non-toxic end products, thereby mitigating or eliminating contamination from the environment [62]. Organic contaminants present in the environment may have adverse effects on the several ecological receptors and thus undermine sustainable development with adverse socio-impacts. Therefore, there is urgent need for more research on the effect of gas flaring on the different environmental compartments in the Niger Delta.

### 3.5. Human Health Risks

Gas flaring in the Niger Delta has resulted in thermal radiation, flue gas dispersion and emissions from the flare systems have produce considerable amounts of air pollutants for the past fifty years. The efficiency of gas flare systems are mainly impacted by the energy density of the flare gas stream, design of the flare system, composition of flare gas, and environmental conditions such as ambient temperature, wind speed, and wind direction [37,38]. According to Nriagu [41], the inefficient technology in the flare systems means that many of them burn without sufficient oxygen or with small amounts of oil mixed in with the gas, creating soot that is deposited on nearby land and buildings and inhaled by local residents. The mixture of toxic substances emitted from flares containing benzene particles pose severe health risks exposes to host communities in the oil-producing Niger Delta. The background level concentration of the products of incomplete combustion depended on the distance from the source. Exposure to hazardous air pollutants emitted during incomplete combustion of gas flare is known to cause human health risks such as cancer, neurological, reproductive and developmental effects [40]. There are numerous adverse health consequences complaints among several people who live in close proximity to gas flare facilities in the Niger Delta. According to Edino et al. [35], most gas flaring systems in Nigeria's Niger Delta are located in close proximity to communities and the residents perceive gas flaring as hazardous to health, environment and general well-being of the community.

Gas flaring can produce nitrogen oxides along with the fine particulates that can trigger the reported respiratory problems among children near gas flares, but this problem has not been fully studied in the region [41]. Nitrogen monoxide (NO), which is one of the oxides of nitrogen generated from natural gas combustion, is a harmful

pollutant causing direct injuries of the respiratory organs and it is the precursors for acid rain and ground level ozone [63]. Few researches have even linked VOC such as benzene with increased chances of developing leukemia [64,65]. Some studies have suggested links between gas flaring and health problems in the communities [27,28,29,30]. In a recent study, Gobo et al. [30] examined the relationship between human exposure to toxicological factors in the environment arising from gas flares and the development of various human health related conditions in selected host communities in the Niger Delta. The data from the study showed a greater frequency of disease types such as asthma, cough, breathing difficulty, eye and skin irritation in the study area (Igwuruta/Umuechem) with a long history of gas flaring compared to community (Ayama) with no flaring history [30]. Some clinical studies have demonstrated the rapid onset of bronchoconstriction in asthma patients exposed to relatively low (0.25 – 0.5 ppm) SO<sub>2</sub> levels [66,67,68]. The link between asthma and industrialization, in particular, increases in asthma cases in China has been attributed to air pollution [69]. Therefore, the threat to human health posed by pollution due to gas flaring cannot be undermined and there may be extensive human health effects associated with oil pollution in the Niger Delta.

Flue gas dispersion, emissions from the flare systems and atmospheric deposition of pollutants have influenced rainwater chemistry in the Nigeria's Niger Delta [31,32,43,44]. The findings from some studies suggest that rainwater from most industrial cities of Nigeria are tending towards acidity and if gas flaring and venting activities are not checked, there is a tendency of increasing acidic rainwater in the Delta regions [32,43]. It is a common practice by many residents in the rural communities to harvest rainwater by capturing runoffs from rooftops for drinking, cooking, laundry and other domestic purposes. Apart from causing serious health problems such as skin cancers and lesions via dermal exposure, the ingestion of contaminated water – 'acid rain' can alter pH of the stomach, leach the mucous membrane of the intestinal walls and cause stomach ulcers. Further, a greater number of people in the rural communities may be exposed to the risk of elevated levels of petroleum hydrocarbon contaminant mixtures, PAHs, and toxic metals (especially vanadium) via harvested rainwater usage. Despite the fact that there are other sources of atmospheric contamination in the Niger Delta, contamination of rainwater with contaminant mixtures from atmospheric deposition in the region could pose potential health risk to human health. Therefore, there may be health risks associated with exposure to flue gas and hazardous air pollutants in harvested drinking rainwater that have been contaminated during atmospheric precipitation in the Niger Delta.

### 3.6. Socio-economic Problems

Oil companies in Nigeria flare about 2.5 billion cubic feet of gas every day and the extent of economic loss due to gas flaring and venting in Nigeria is estimated at \$2.5 billion annually [70]. In a recent study, Anomohanran [26] has estimated that Nigeria loose an estimated revenue of 17 billion dollars (2.65 trillion naira) to gas flaring annually. Gas flaring is a great waste of energy resource

that causes economic loss due to poor management of investment opportunities to the petroleum sector and wastes of potential contribution to gross national income of the nation. Despite the enormous economic benefits that would accrue to the country from harnessing this energy resource [1,19,71], gas flaring and venting of associated gas resulting from petroleum exploration and production in the Niger Delta region has remained significantly high over the past five decades. Petroleum exploration and production in the Nigeria's Niger Delta have significantly contributed toward the nation's development, however, environmental contamination associated with upstream and downstream operations have resulted in various socio-economic development issues. For example, gas flaring and venting have had several negative consequences on plants, microorganisms, human health and safety, cultural, social and economic environments at large. The effects of increasing petroleum resources exploitation and other socio-economic activities would be difficult to quantify because of their diffuse nature [14].

From an economic perspective, the flaring and venting of petroleum-associated gas is a colossal waste to the communities when most of the household are using firewood (fuel-wood) as fuel for cooking. If natural gas flared at various oil facilities in the Niger Delta are put to domestic uses, the energy resource would have provided significant amount of energy sourced from fuel-wood in Nigeria [72] and would have help reduce deforestation linked to fuel-wood consumption. Gas flaring and venting is among the major problem associated with oil exploration and production activities in the Niger Delta, which have not been effectively regulated and impacts negatively on the environment, health, physiology and psychology of the host communities. For example, increase in temperature or thermal gradient resulting from the gas flare systems in some communities has undesirable effect on human health in the natural environment and affect socio-economic activities of the inhabitants with close proximity to the flare systems [20,21,22,23]. Several farmers have attributed thermal gradient from gas flaring practices to poor agricultural yields and the affected communities suffer loss of vegetation [4,24]; and adverse human health [27,28,29,30]. Therefore, the consequences of gas flaring in the environment have adverse effects on the inhabitants and also undermine sustainable development of the Niger Delta region [23].

The flaring of associated gas from petroleum exploration, production and processing continues to generate insidious environmental and energy consequences against efforts toward sustainable development for Nigeria. The preservation of the environment is an essential factor for sustainable development and poverty reduction, therefore, there needs to develop environment friendly approach for utilization of associated natural gas in the region. Oguejio for [73] have suggested a blueprint for a low-cost retrofit at flare installations for the conversion of flue gas pollutants into revenue-yielding fertilizer is shown, as it provides the basis for the economy of the process technology conceptualized by this work. Therefore, there is need for education and training of the personnel to create awareness of related problems in order to achieve effective environmental, human health and safety.

According to Oyekan [29], there is a further need for industrial training on preventive maintenance of existing facilities and on the installation of adequate safety and pollution control equipment on the oil production and handling facilities. The socio-economic problems and environmental consequences of emission of carbon dioxide, methane gas and other emissions from flare and vent systems can be mitigated by adopting various sustainable approaches.

## 4. Conclusions

This review has shown that flaring and venting of petroleum-associated gas in the petroleum industry in the Niger Delta has clearly impacted on the natural environment, human health, socio-economic environment and caused degradation of host communities. There are serious environmental effects on the human and other species, soil, water and vegetation resources in the Niger Delta region and several studies have call for the extinction of gas flaring. Although the Nigerian government established the Nigeria Liquefied Natural Gas plant which delivered its first cargo in 1999, the attempt to stop the flaring of associated gas is not yet effective and the government have been unable to implement strict regulations to curb the practice. In Nigeria, gas flaring attracts special interest because of lack of the social responsibility on the part of major oil firms toward gas conservation, poor governance and lack of environmental compliance. Considering the past and present levels of atmospheric contamination, it is important to understanding the long- and short-term impacts of gas flaring and venting on the different environmental compartments and components of the ecosystem. Therefore, effective understanding of the overall impact of the exploration and production of the petroleum hydrocarbon resources in the petroleum industry is important for the effective management of the energy resources, environmental risk mitigation, implementation of good governance and sustainable development. Further, information on potential human health effects associated with gas flaring and venting from the oil industry operations in the Niger Delta may contribute towards evidence informed decision-making (EIDM) in public health.

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