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 venting systems 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 governance and 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 45 million tons of CO2 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.
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_{12}H_{26} + C_{10}H_{22}), 1.6% nitrogen (N_{2}), 0.7% carbon dioxide (CO_{2}) and trace amounts of hydrogen sulphide (H_{2}S), water (H_{2}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 region showed that sulphur dioxide (SO_{2}) 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_{2}), carbon monoxide (CO) and a variety of air pollutants, such as VOCs (which include carcinogens and air toxins), nitrogen oxides (NO_{x}), sulphur dioxide (SO_{2}), toxic heavy metals and black carbon soot. It is known that some of the products of complete combustion, such CO_{2} and H_{2}O, from flares contribute greatly to heat radiation experienced around flares [2,12]. In addition to vehicular traffic emissions (CO_{x}, HC, NO_{x}, SO_{2} 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_{2} gaseous emissions from upstream oil and gas operations in Nigeria, Obioh et al. [9] have demonstrated that CO and

| Year | Production (Mm³) | Utilization (Mm³) | Flared (Mm³) |
|------|-----------------|------------------|--------------|
| 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          | 22592.0      |
| 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      |
NO\textsubscript{x} 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\textsubscript{2}) per year, methane (CH\textsubscript{4}), 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\textsubscript{x}) and sulphur dioxide (SO\textsubscript{2}) emissions. In the presence of atmospheric compounds such as oxygen (O\textsubscript{2}) and water (H\textsubscript{2}O), NO\textsubscript{x} (NO + NO\textsubscript{2}) reacts to form nitrate ion (NO\textsubscript{3}\textsuperscript{-}) and SO\textsubscript{2} reacts to form sulphate ion (SO\textsubscript{4}\textsuperscript{2-}). Both NO\textsubscript{3}\textsuperscript{-} (from NO\textsubscript{x} emissions) and SO\textsubscript{4}\textsuperscript{2-} (from SO\textsubscript{2} 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\textsubscript{4}\textsuperscript{2-}/NO\textsubscript{3}\textsuperscript{-} in precipitation in the region. Acid rain from increased SO\textsubscript{4}\textsuperscript{2-} and NO\textsubscript{3}\textsuperscript{-} 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 SO₂, NO₂ and PM₁₀ 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 odnatum 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 mutagenic city 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 exposure 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) SO2 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 exploration 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. Oguejiofor [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.

References

[1] Buzcu-Guven, B., and R. Harriss, “Extent, impacts and remedies of global gas flaring and venting,” Carbon Management, 3 (1). 95-108, 2012.
[2] Kearns, J., K. Armstrong, L. Shirvill, E. Garland, C. Simon, and J. Monopolis, Flaring and venting in the oil and gas exploration and production industry: an overview of purpose, quantities, issues, practices and trends, vol. 2, International Association of Oil & Gas Producers, London, 2000.
[3] Christen, K., “Environmental impacts of gas flaring, venting add up,” Environmental Science & Technology, 38 (24). 480A-480A, 2004.
[4] Dung, E., L. Bomboh, and T. Agusonna, “The effects of gas flaring on crops in the Niger Delta, Nigeria,” Geojournal, 73 (4). 297-305, 2008.
[5] Uyigue, E., and M. Agho, “Coping with climate change and environmental degradation in the Niger Delta of southern
Nigeria,” Community Research and Development, Centre Benin City, 2007.

[6] Ologunorisa, T. E., “A review of the effects of gas flaring on the Niger Delta environment,” International Journal of Sustainable Development & World Ecology, 6 (3). 249-255, 2001.

[7] Brown, M. J. D. Fotheringham, T. J. Hoyes, R. M. Mortier, S. T. Orszulik, S. J. Randles, and P. M. Stroud, “Synthetic Base Fluids,” Chemistry and Technology of Lubricants, R. M. Mortier, M. F. Fox and S. T. Orszulik, eds., pp. 37-54: Springer Netherlands, 2010.

[8] Ashton-Jones, N., S. Arnott, O. Douglas, and ERA, The human ecosystems of the Niger Delta: an ERA handbook, Benin City, Nigeria: Environmental Rights Action (ERA), 1998.

[9] Obioh, I. B., A. F. Oluwole, and F. A. Akeredolu, “Non-CO2 gaseous emissions from upstream oil and gas operations in Nigeria,” Environmental Monitoring and Assessment, 31-31 (1-2). 67-72, 1994.

[10] Strosher, M., Investigations of flare gas emissions in Alberta: final report to Environment Canada Conservation and Protection, the Alberta Energy and Utilities Board, and the Canadian Association of Petroleum Producers, Calgary: Alberta Research Council, 1996.

[11] Strosher, M. T., “Characterization of emissions from diffusion flare systems,” Journal of the Air & Waste Management Association, 50 (10). 1723-1733, 2000.

[12] Schwartz, R. E., and J. W. White, “Predict radiation from flares,” Chemical Engineering Progress, 93 (7). 42-49, 1997.

[13] Ajae, E. A., and S. Anurigwo, “Land-based Sources of Pollution in the Niger Delta, Nigeria,” AMBO: A Journal of the Human Environment, 31 (5). 442-445, 2002.

[14] Scherer, P. A., A. C. Ibe, F. J. Janssen, and A. M. Lennens, “Environmental pollution in the Gulf of Guinea – a regional approach,” Marine Pollution Bulletin, 44 (7). 633-641, 2002.

[15] Isichei, A. O., and W. W. Sanford, “The Effects of Waste Gas Flares on the Surrounding Vegetation in South-Eastern Nigeria,” Journal of Applied Ecology, 13 (1). 177-187, 1976.

[16] Akinwumi, I. O., T. O. Oyebisi, and A. T. Salami, “Environmental degradation in Nigeria: implications and policy issues—a viewpoint,” International Journal of Environmental Studies, 58 (5). 585-595, 2001.

[17] Onwuka, E. C., “Oil extraction, environmental degradation and poverty in the Niger Delta region of Nigeria: a viewpoint,” International Journal of Environmental Studies, 62 (6). 655-662, 2005.

[18] Ugochukwu, C. N. C., and J. Ertel, “Negative impacts of oil exploration on biodiversity management in the Niger De area of Nigeria,” Impact Assessment and Project Appraisal, 26 (2). 139-147, 2008.

[19] Akinbami, J. F. K., I. O. Akinwumi, and A. T. Salami, “Implications of environmental degradation in Nigeria,” Natural Resources Forum, 20 (4). 319-322, 1996.

[20] Julius, O. O., “Environmental impact of gas flaring within Umutu-Ebebe gas plant in Delta State, Nigeria,” Archives of Applied Science Research, 2 (3). 272-279, 2011.

[21] Julius, O. O., “Thermal gradient due to the gas flared at umusadege marginal oil field, Umusadege-Ogbe Kwale Delta, Nigeria,” Archives of Applied Science Research, 3 (6). 280-290, 2011.

[22] Osei, J., “Thermal gradient in the vicinity of Kwale/Okpai gas plant, Delta state Nigeria: Preliminary observations,” Environmentalist, 27 (2). 311-314, 2007.

[23] Ojeh, V. N., “Sustainable Development and Gas Flaring Activities: a Case Study of Ebedei Area of Ukwuani LGA, Delta State, Nigeria,” Resources and Environment, 2 (4). 169-174, 2012.

[24] Odjugo, P. A. O., and E. J. Osemwenkhae, “Natural gas flaring affects microclimate and reduces maize (Zea mays) yield,” International Journal of Agriculture & Biology, 11 (4). 408-412, 2009.

[25] Anomoharanan, O., “Thermal Effect of Gas Flaring at Ebebei Area of Delta State, Nigeria,” The Pacific Journal of Science and Technology, 13 (2). 555-560, 2012.

[26] Anomoharanan, O., “Determination of greenhouse gas emission resulting from gas flaring activities in Nigeria,” Energy Policy, 45 (0). 666-670, 2012.

[27] Bhatia, R., and A. Wernham, “Integrating human health into environmental impact assessment: an unrealized opportunity for environmental health and justice,” Ciência & Saúde Coletiva, 14 (4). 1159-1175, 2009.

[28] Ekpo, I., and A. Obia, “The role of gas flaring in the rapid corrosion of zinc roofs in the Niger Delta Region of Nigeria,” The Environmentalist, 30 (4). 347-352, 2010.

[29] Oyeken, A., “The Nigerian Experience in Health, Safety, and Environmental Matters During Oil and Gas Exploration and Production Operations.”

[30] Gobo, A. G. Richard, and I. Ubong, “Health Impact of Gas Flares on Igwuruta/Umuzuem Communities in Rivers State,” Journal of Applied Sciences and Environmental Management, 13 (5). 27-33, 2010.

[31] Ejigun, B. C., B. B. Adeleke, I. O. Ololade, and O. Adegbuyi, “The Chemistry of Rainwater Samples Collected within Utorogu-Oil Producing Community in Niger Delta, Nigeria II,” European Journal of Scientific Research, 58 (2). 189-203, 2011.

[32] Nduka, J., O. Orisakwe, L. Ezenweke, T. Ezennwa, M. Chendo, and N. Ezeabasile, “Acid rain phenomenon in Niger Delta Region of Nigeria. Economic, Biodiversity and Public Health concern,” TheScientificWorldJournal, 8:111-818, 2008.

[33] Efe, S. I., “Spatial variation in acid and some heavy metal composition of rainwater harvesting in the oil-producing region of Nigeria,” Natural Hazards, 55 (2). 307-319, 2010.

[34] Ayamissi, A., O. Orimoogunje, T. Akinkuoluo, and A. Odiomg, “Perception on Effect of Gas Flaring on the Environment,” Research Journal of Environmental and Earth Sciences, 2 (4). 188-193, 2010.

[35] Edino, M., G. Noorof, and L. Bomborn, “Perceptions and attitudes towards gas flaring in the Niger Delta, Nigeria,” The Environmentalist, 30 (1). 67-75, 2010.

[36] Agbola, T., and T. Obaru, “Bushfire and Landcover Change in the Niger Delta,” Excerpts from a Research Report presented to the Centre for Democracy and Development, 2003.

[37] Kostik, L., M. Johnson, and G. Thomas, “University of Alberta Flare Research Project Final Report November 1996–September 2004,” University of Alberta, Department of Mechanical Engineering, 2004.

[38] Shore, D., “Making the flare safe,” Journal of Loss Prevention in the Process Industries, 9 (6). 363-381, 1996.

[39] Leahy, D. M., K. Preston, and M. Strosher, “Theoretical and observational assessments of flare efficiencies,” Journal of the Air & Waste Management Association, 51 (12). 1610-1616, 2001.

[40] Kindzierski, W. B., “Importance of human environmental exposure to hazardous air pollutants from gas flares,” Environmental Reviews, 8 (1). 41-62, 1999.

[41] Nriagu, J., “Oil Industry and the Health of Communities in the Niger Delta of Nigeria,” Encyclopedia of Environmental Health, O. N. Editor-in-Chief: Jerome, ed., pp. 240-250, Burlington: Elsevier, 2009.

[42] Christiansen, A. C., and T. Haugland, Gas Flaring and Global Public Goods, 8276134246, Fridjof Nansen Institute (FNI), Lysaker, 2009.

[43] Uzomah, V., and A. Sangodoyin, “Rainwater chemistry as influenced by atmospheric deposition of pollutants in Southern Nigeria,” Environmental Management and Health, 11 (2). 149-156, 2000.

[44] Nwankwo, C., and D. Oguguerie, “Effects of gas flaring on surface and ground waters in Delta State Nigeria,” Journal of Geology and Mining Research, 3 (5). 131-136, 2011.

[45] Stokes, P. M., “Ecological effects of acidification on primary producers in aquatic systems,” Water, Air, and Soil Pollution, 30 (1-2). 421-438, 1986.

[46] Aghalino, S., “Gas Flaring, Environmental Flaring and Abatement Measures in Nigeria, 1969-2001,” Journal of Sustainable Development in Africa, 11 (4). 219-238, 2009.

[47] Odu, C. T. I., “Degradation and Weathering of Crude Oil under Tropic Conditions,” pp. 143-152.

[48] Kuperman, R. and, C. Edwards, "Effects of Acidic Deposition on Soil Invertebrates and Microorganisms," Reviews of Environmental Contamination and Toxicology, Reviews of Environmental Contamination and Toxicology G. Ware, H. Nigg and A. Bevenue, eds., pp. 35-138: Springer New York, 1997.

[49] Pennanen, T., H. Fritze, P. Vanhala, O. Kikkilä, S. Neuvonen, and E. Baath, “Structure of a microbial community in soil after prolonged addition of low levels of simulated acid rain,” Applied and Environmental Microbiology, 64 (6). 2173-2180, 1998.

[50] Francis, A. J., “Effects of acidic precipitation and acidity on soil microbial processes,” Water, Air, and Soil Pollution, 18 (1-3). 375-394, 1992.
Killham, K., M. K. Firestone, and J. G. Mc Coll, “Acid Rain and Soil Microbial Activity: Effects and Their Mechanisms1,” Journal of Environmental Quality, 12 (1). 133-137, 1983.

Prescott, C. E., and D. Parkinson, “Effects of sulphur pollution on rates of litter decomposition in a pine forest,” Canadian Journal of Botany, 63 (8). 1436-1443, 1985.

Francis, A. J., “Acid rain effects on soil and aquatic microbial processes,” Experientia, 42 (5). 455-465, 1986.

Obia, A., “The effect of industrial air–borne pollutants on the durability of galvanized iron roofs in the tropical humid region of Nigeria,” Global Journal of Environmental Sciences, 8 (2). 89-93, 2010.

Nkwocha, E. E., and E. C. Pat-Mbano, “Effect of Gas Flaring on Buildings in the Oil Producing Rural Communities of River State, Nigeria,” African Research Review, 4 (2). 90-102, 2010.

Obia, A. E., H. E. Okon, S. A. Ekum, E. E. Eyo-Ita, and E. A. Ekpeni, “The Influence of Gas Flare Particulates and Rainfall on the Corrosion of Galvanized Steel Roofs in the Niger Delta, Nigeria,” Journal of Environmental Protection, 2 (10). 1341-1346, 2011.

Obia, A. E., H. E. Okon, S. A. Ekum, A. E. Onuegbu, and P. O. Ekeng, “The role of sulphur dioxide and gas flare particulates on the corrosion of galvanized iron roof sheets in south-south region of Nigeria,” Scientific Research and Essays, 6 (27). 5734-5740, 2011.

Lawanson, A. O., A. M. Imevbore, and V. O. Fanimokun, “The Effects of Waste-Gas Flares on the Surrounding Cassava Plantations in the Niger Delta Regions of Nigeria.”

Akpejivi, R., and P. Akamaghe, “Impact of Gas Flaring on Soil Fertility.”

Benka-Coker, M. O., and J. A. Ekundayo, “Applicability of evaluating the ability of microbes isolated from an oil spill site to degrade oil,” Environmental Monitoring and Assessment, 45 (3). 259-272, 1997.

Sojina, O. S. S., J-Z. Wang, O. O. Sonibare, and E. Y. Zeng, “Polycyclic aromatic hydrocarbons in sediments and soils from oil exploration areas of the Niger Delta, Nigeria,” Journal of Hazardous Materials, 174 (1-3). 641-647, 2010.

Ite, A. E., and K. T. Semple, “Biodegradation of petroleum hydrocarbons in contaminated soils,” Microbial Biotechnology: Energy and Environment, R. Arora, ed., pp. 250-278, Wallingford, Oxfordshire: CAB International, 2012.

Winter, F., C. Wartha, and H. Hofbauer, “NO and N2O formation during the combustion of wood, straw, malt waste and peat,” Bioresource Technology, 70 (1). 39-49, 1999.

Ana, G. R., M. K. Sridhar, and E. A. Bamgbaye, “Environmental risk factors and health outcomes in selected communities of the Niger delta area, Nigeria,” Perspectives in Public Health, 129 (4). 183-191, 2009.

Natelson, E. A., “Benzene-induced acute myeloid leukemia: A clinician's perspective,” American Journal of Hematology, 82 (9). 826-830, 2007.

Sheppard, D., W. S. Wong, C. F. Uehara, J. A. Nadel, and H. A. Boushey, “Lower threshold and greater bronchomotor responsiveness of asthmatic subjects to sulfur dioxide,” American Review of Respiratory Disease, 122 (6). 873-878, 1980.

Bethel, R. A., D. J. Erle, J. Epstein, D. Sheppard, J. A. Nadel, and H. A. Boushey, “Effect of exercise rate and route of inhalation on sulfur-dioxide-induced bronchoconstriction in asthmatic subjects,” American Review of Respiratory Disease, 128 (4). 592-596, 1983.

Kirkpatrick, M. B., D. Sheppard, J. A. Nadel, and H. A. Boushey, “Effect of the oronasal breathing route on sulfur dioxide-induced bronchoconstriction in exercising asthmatic subjects,” American Review of Respiratory Disease, 125 (6). 627-631, 1982.

Watts, J., “Doctors blame air pollution for China's asthma increases,” The Lancet, 368 (9537). 719-720, 2006.

Campbell, L., G. M. World Bank Group, Oil, and D. Chemicals, A voluntary standard for global gas flaring and venting reduction, 29555, World Bank Group, Oil, Gas, Mining and Chemicals Dept., Washington, D.C., 2004.

Madueme, S., “Economic analysis of wastages in the Nigerian gas industry,” International Journal of Engineering Science and Technology, 2 (4). 618-624, 2010.

Ngwanya, S. C., “Climate change and energy implications of gas flaring for Nigeria,” International Journal of Low Carbon Technologies, 6 (3). 193-199, 2011.

Oguejiofor, G. C., "Gas flaring in Nigeria: converting flue gas pollutants into revenue-earning fertilizer by the low-cost retrofitting of flare stations," Environmental Education & Information, 19 (2). 99, 2000.