This work gives a bigger picture of gas flaring in Nigeria with emphasis on emissions emitted into the immediate environment from the flared gas. Gas flaring activities and its associated problems in the Niger Delta region of Nigeria is of great concern to the global and local communities. Emissions from gas flaring sites in the region of the country in view consist of particles outside the conventional greenhouse gases and obnoxious gases which impact the region negatively. Black carbon (BC) is the major component of particulate matter emitted during the burning of fossil fuel, biomass and biofuel. BC is a climate forcer with a global warming potential of 900 and ranked second only to carbon dioxide, which is the main global warming agent. Inventory of emissions released into the atmosphere due to flaring of gas in the country is lacking and this book for the first time presents a well-documented information in this regard. BC emissions from flared gas for the period of 49 years (1965-2013) were estimated and reported accordingly. Also, the effects of BC on the well-being of the inhabitants of this region is discussed in this book.

Solomon Giwa

Emission Inventory for Gas Flaring in Nigeria

Baseline Black Carbon Emission Inventory for Gas Flaring in the Niger Delta Region of Nigeria

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DEDICATION

This work is dedicated to God Almighty, the Alpha and the Omega of life, the Source of all wisdom, knowledge, understanding and power.

Abstract

Obnoxious gases, particulates and enormous heat are released during gas flaring activities which are the primary cause of environmental pollution and human health problem. Black carbon (BC) is an aerosol formed from the incomplete combustion of fossil fuel, biomass and biofuel. The focus of this present study is to provide baseline emission inventory for the amounts of BC released into the atmosphere through gas flaring in the Niger Delta region for a period of 49 years (1965 - 2013); spanning five decades. Emission factors and volume of gas flared for each year for a 49-year period were sourced from literature and were employed to empirically estimate the amounts of BC emitted. For this period in view, 55% of the gas produced was flared (895.01 billion cubic metres) releasing a colossal amount of 4.56×10^5 tons (4.11×10^8 tons CO_2 equivalent) of BC into the environment. It was observed that the amounts of BC released into the environment increased progressively (5.06×104 to 1.27×10^5 tons) for the first decade (1965-1974) of gas flaring to the fourth decade (1995-2004) with a significant reduction (8.74×10^4 tons) in the amounts of BC emitted in the fifth decade (2005-2013). The financial implication of the gas flared and the emission of BC associated with it under the period in view is estimated to be $132.57 billion. This value comprises of $126.46 billion and $6.17 billion as the cost of gas flared (at 0.141$/cubic metre) and carbon credit tax (at $15 per ton) of BC emitted in the environment. Of the proffered probable solutions to reducing BC emission via gas flaring in the country, the principal solution lies in the increased utilization of the gas domestically and the market expansion for the exportation of the gas.

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CHAPTER ONE

1.0 INTRODUCTION

The burning of fossil fuel (coal, oil and gas) has led to the warming up of the environment through the emissions of carbon dioxide (CO_2) as the main greenhouse gas. Nigeria is one of the highest emitter of greenhouse gases in Africa and among the highest CO_2 emitters in the world (Orimoogunje et al., 2010). One of the environmental problems associated with crude oil exploration and exploitation in Nigeria is linked to gas flaring. Atmospheric contaminants from gas flaring include oxides of nitrogen, carbon and sulphur (NO_x, CO_2, CO, SO_x), particulate matter, hydrocarbons and ash, photochemical oxidants, and hydrogen sulphide (H_2S) (Orimoogunje et al., 2010). Nigeria is one of the world's biggest flarer of Associated Gas with many gas flaring points that release over 23 billion cubic metres (bcm) of gas per annum *(*Nkwocha and Pat-Mbano, 2010*)*. The Niger Delta is endowed with an estimated reserve of about 23 billion barrels of oil and 183 trillion cubic feet (tcf) of natural gas. The largest flaring activities occur in the Niger Delta region of Nigeria which covers an area of about 75,000 km^2 (Sonibare et al., 2008). It is generally accepted that flaring and venting of gas contribute significantly to greenhouse gas emissions coupled with negative impacts on the environment (Ologunorisa, 2001).

Black carbon (BC) emissions are caused by incomplete combustion of fossil fuels, biofuels and biomass. BC is the most strongly light-absorbing component of particulate matter (PM). A particle (aerosol) rather than a greenhouse gas, it is the second largest climate forcer in today's atmosphere, following carbon dioxide (Bond et al., 2013). BC's contribution to global warming is approximately 70% of carbon dioxide's contribution. Although BC remains in the atmosphere for only a few days, one gram of BC warms the atmosphere several hundred times more during its short lifetime than one gram of carbon dioxide does during 100 years. Total global emissions of BC using bottom-up inventory methods are 7500 Gg yr^{-1} in the year 2000 with an uncertainty range of 2000 to 29000 (Bond et al., 2013).

This present study was aimed at providing a baseline BC emission inventory from the gas flaring activities in Nigeria for the past 49 years and to assess the health implications of this obnoxious act, and hence, to proffer possible solutions to this unending problem. It is worth noting that to the best of our knowledge, no national, regional and sectoral inventory exists for BC emissions in Nigeria and most importantly, that of gas flaring in the Niger Delta region.

1.1 Statement of Problems

Flaring of gas in the Niger Delta area of Nigeria is known to contribute negatively to the immediate and global environment. The combustion of natural gas is associated with the emission of gases, particulates and heat. These gases, in particular, the greenhouse gases contribute significantly to global warming and climate change while the particulates (particulate matters, black carbon, organic carbon etc) have seriously impacts on the immediate environment, especially, the local inhabitants.

Studies have reported gas flaring to having serious economic, social and health implications for Nigeria and the world in general, due to its negative environmental degradation and its contribution to climate change (Ologunorisa, 2001; Abdulkareem, 2005; Edino et al., 2010; Orimoogunje et al., 2010; Omokaro, 2009; World Bank, 2007). Gas flaring is also reported to cause acid rain within the flare's microenvironment (Ologunorisa, 2001; Odjugo and Osemwenkhae, 2009). Another impact of gas flaring reported is the destruction of vegetation, wild life and ecological destabilization (Ologunorisa, 2001; Abdulkareem, 2005; Odjugo and Osemwenkhae, 2009). Gas flaring is found to have significantly affected the health of the inhabitants around oil rich zones causing ailments like respiratory problems, skin disorders, intestinal diseases, child deformities and other health risks (Ologunorisa, 2001; Madueme, 2010; Odjugo and Osemwenkhae, 2009).

1.2 Objectives of Study

The primary purpose of conducting this study was to estimate the quantity of BC emitted into the environment of the Niger Delta region of Nigeria, where the notorious act of gas flaring is continuously perpetuated. A 49-year period of gas flaring in the region was investigated for the emission of BC. Inventories of emissions from gas flaring in the region is lacking in the country and thus, the reason for this work.

1.3 Justification of Study

Gas flaring is likely one of the largest sources of BC emissions from the oil and gas sector. This practice, although increasingly controlled in many countries, persists in many regions, the most notable being the Niger Delta region in Nigeria and West Siberia in Russia (Levitsky, 2011). Fast action deems necessary for BC mitigation in order to slow global and regional warming and improve the health and air quality of poor rural and urban areas throughout the world. BC emissions inventory as carried out in this work is to promote awareness on the impacts of BC on the environment and the well-being of people in this region. In addition, the inventory is to provide tool in form of information on the estimated emission of BC in the region that will enable government, international communities and bodies to address the adverse effects of BC and at large the incessant gas flaring in this part of the country.

1.4 Limitations

Though the knowledge on BC emissions from gas flaring is very limited, this work therefore estimated BC emissions via flared gas empirically based on emission factors reported by researchers on this subject. Experimental investigation of BC emissions could not be carried out due to lack of funding and the high cost of instrumentation required for this work. Future work in this regard is keenly being looked up to.

1.5 Layout of Work

This work is presented in five chapters. Chapter two is the introduction; chapter three is the methodology; chapter four is inventory of black carbon emissions; while chapter five is the conclusion.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 What is Gas Flaring?

Gas flaring is the combustion of associated gas produced with crude oil or from gas fields. Flaring is a high-temperature oxidation process used to burn combustible components, mostly hydrocarbons, of waste gases from industrial operations. Smoking results from combustion, depending upon waste gas components, and the quantity and distribution of combustion air. Flaring is the common practice of burning off unwanted, flammable gases via combustion in an open-atmosphere, non-premixed flame. This gas may be deemed uneconomic to process (i.e. if it is far from a gas pipeline or if it is 'sour' and contains trace amounts of toxic H_2S) or it may occur due to leakages, purges, or an emergency release of gas in a facility. Typical gas flaring site is shown in Figure 2.1.

Figure 2.1: Gas flaring stack in Niger Delta region of Nigeria

2.2 Overview of Gas Flaring

The impact of gas flaring is both of local and global concern. Gas flaring is one of the most challenging energy and environmental problems facing the world today whether regionally or globally. It is a multi-billion dollar waste of natural resource, a local environmental devastation, and a global energy and environmental crisis which has persisted for decades. Studies have reported gas flaring to having serious economic, social and health implications for Nigeria and the world in general, due to its negative environmental degradation and its significant contribution to climate change (Ologunorisa, 2001; Abdulkareem, 2005; Edino et al., 2010; Orimoogunje et al., 2010; Omokaro, 2009; World Bank, 2007).

2.2.1 Global Gas Flaring

Gas flaring is one of the most demanding and important energy and environmental problems currently facing the world. The fact is, around 150 bcm of natural gas are flared in the world each year, representing a 15 to 20 billion dollar waste of resources and a 260 to 400 million metric ton contribution to global greenhouse gas emissions (Farina, 2011). Annual global flaring is equivalent to about 30 percent of the total yearly gas requirements of the entire European Union, or the annual residential gas consumption in the United States. In some instances, flaring negatively affects the livelihood and quality of life for local populations, frequently raising political stakes for governments and petroleum production companies (Farina, 2011).

Flaring is a technique used extensively in the oil and gas industry to burn unwanted flammable gases. Oxidation of the gas can preclude emissions of methane (a potent greenhouse gas); however, flaring creates other pollutant emissions such as particulate matter (PM) in the form of soot or black carbon (BC). As of the end of 2011, 150×10^9 cm (5.3×10^{12} cf) of associated gas are flared annually. That is equivalent to about 25 percent of the annual natural gas consumption in the United States or about 30 percent of the annual gas consumption in the European Union (Rao and Krishna, 2012). As of 2010, 10 countries accounted for 70% of the flaring, and twenty for 85%. The top ten leading contributors to world gas flaring in 2010 were (in declining order): Russia (26%), Nigeria (11%), Iran (8%), Iraq (7%), Algeria (4%), Angola (3%), Kazakhstan (3%), Libya (3%), Saudi Arabia (3%) and Venezuela (2%) (Rao and Krishna, 2012).

2.2.2 Local Gas Flaring

The Niger Delta region (as presented in Figure 2.2) covers 20,000 km² within wetlands of 70,000 km² formed largely by sediment deposition. Home to 20 million people and 40 different ethnic groups, this floodplain makes up 7.5% of Nigeria's total land mass (Tawari et al., 2012). It is the largest wetland and maintains the third-largest drainage basin in Africa. The Delta's environment can be divided into four ecological zones: coastal barrier islands, mangrove swamp forests, freshwater swamps and lowland rainforests (Tawari et al., 2012). This exceptionally well-endowed ecosystem contains one of the highest concentrations of biodiversity on the planet, in addition to supporting copious flora and fauna, arable terrain that can sustain a wide variety of crops, lumber or agricultural trees and more species of freshwater fish than any ecosystem in West Africa (Tawari et al., 2012).

The local and regional problem of environmentally unethical gas flaring is predominant in developing nations like Nigeria and has contributed considerably to the degradation of the environment. The Niger Delta region's biodiversity is under grave threat owning to the rapid rate of environmental degradation caused by oil and gas exploration activities. Gas flaring is also reported to cause acid rain within the flare's microenvironment (Ologunorisa, 2001; Odjugo and Osemwenkhae, 2009). Another impact of gas flaring reported is the destruction of vegetation, wild life and ecological destabilization (Ologunorisa, 2001; Abdulkareem, 2005; Odjugo and Osemwenkhae, 2009).

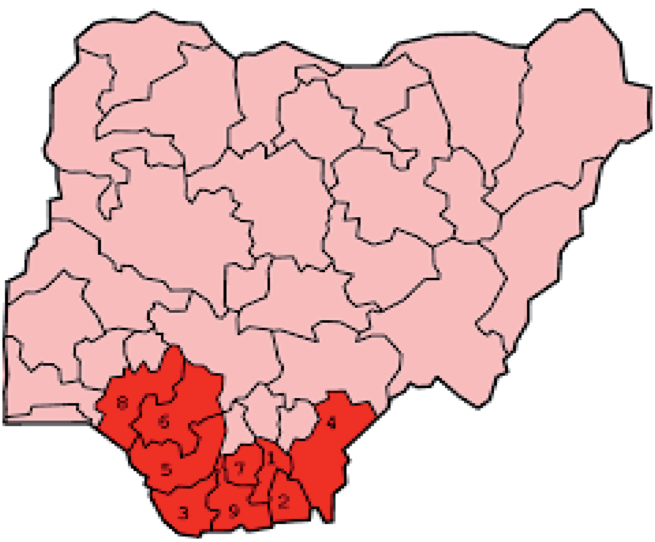

Figure 2.2: Nine states in Nigeria making up the Niger Delta region

2.3 Gas Flaring in Nigeria

The exploration and production of natural gas in Nigeria is accidental to the exploitation of crude oil. Gas flaring has been a contentious issue in Nigeria right from the beginning of commercial exploitation of crude oil in the country. The gas that is flared in the oil fields of the Niger Delta is called associated gas because it comes out of the earth along with the target crude oil and is separated from the crude so as to make the commodity useful. The separated gas could be handled in a number of ways. It could be harnessed for use as liquefied natural gas. Secondly, it could be re-injected into the earth where it came from. Thirdly, it could be vented or flared. Flaring of gas has been considered blameworthy because of its effects, its profligacy and its incessant method. Gas flaring is a miserable metaphor for a wasteful nation like Nigeria that eats her chickens and the eggs and yet expects more eggs in future (Bassey, 2008). Satellite images indicating gas flaring sites in the Niger Delta region is shown in Figure 2.3.

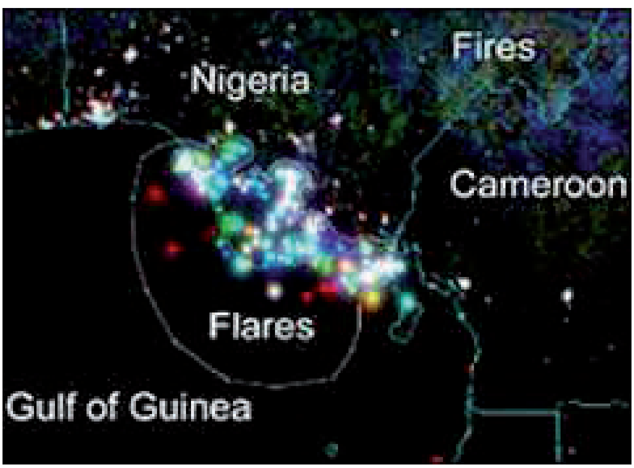

Figure 2.3: Satellite image of gas flaring sites in the Niger Delta region of Nigeria

2.3.1 Historical Background

The discovery of gas in Nigeria is as old as that of oil, but little or no attention has been directed at this energy source. From November 1938, practically the whole country was covered by a concession granted to the then Shell D"Arcy to explore for petroleum resources. The company made the first discovery of gas in 1956 at Afam in the Niger Delta. Also, in the same year, another major discovery was made at Saku also in the Niger Delta with a reserve of 3.5 tcf (Anthony and Anyadiegwu, 2013).

Table 2.1: Proved natural gas reserves as at end of 2012

		Proved reserves at the end 2012			
	Total world	6614.1	187.3	100.0%	55.7
S/N	Country	Trillion cubic feet	Trillion cubic metres	Share of total	R/P ratio
1	Iran	1187.3	33.6	18.0%	>100
2	Russian Federation	1162.5	32.9	17.6%	55.6
3	Qatar	885.1	25.1	13.4%	>100
4	Turkmenistan	618.1	17.5	9.3%	>100
5	USA	300.0	8.5	4.5%	12.5
6	Saudi Arabia	290.8	8.2	4.4%	80.1
7	United Arab Emirates	215.1	6.1	3.3%	>100
8	Venezuela	196.4	5.6	3.0%	>100
9	**Nigeria**	**182.0**	**5.2**	**2.8%**	**>100**
10	Algeria	159.1	4.5	2.4%	55.3
11	Australia	132.8	3.8	2.0%	76.6
12	Iraq	126.7	3.6	1.9%	>100
13	China	109.3	3.1	1.7%	28.9
14	Indonesia	103.3	2.9	1.6%	41.2
15	Norway	73.8	2.1	1.1%	18.2
16	Egypt	72.0	2.0	1.1%	33.5
17	Canada	70.0	2.0	1.1%	12.7
18	Kuwait	63.0	1.8	1.0%	>100
19	Libya	54.6	1.5	0.8%	>100
20	India	47.0	1.3	0.7%	33.1
21	Malaysia	46.8	1.3	0.7%	20.3
22	Kazakhstan	45.7	1.3	0.7%	65.6
23	Uzbekistan	39.7	1.1	0.6%	19.7
24	Netherlands	36.7	1.0	0.6%	16.3
25	Oman	33.5	0.9	0.5%	32.8
Sum of top 25 countries	6251.3	176.9	94.8%		
Rest of the world	362.8	10.4	5.2%		

Source: BP Statistical Review of World Energy June, 2013

Nigeria is the largest oil producer in Africa with most of the oil-producing land located in the Niger Delta region. Shell, one of the largest oil producers in Nigeria, first discovered crude oil in Nigeria in the 1950s (Ukala, 2011). One of the devastating consequences of oil drilling in the Niger Delta region is gas flaring. As crude oil is extracted from the ground, associated gases are released.

According to Nwaoha and Wood, 2014, Nigeria's current proven natural gas reserves stood at approximately 182 tcf, making the country's gas reserves the ninth largest in the world (Table 2.1), and hold about 2.8% of total global reserves. Gas flaring has commenced since the petroleum exploration in the Niger delta area of Nigeria in 1956 (Ologunorisa, 2001). In 2004, a total amount of 160 bcm of gas was flared, of which Nigeria flared over 14% and ranked second only to Russia (Elvidge et al., 2009; World Bank, 2007). This quantity of gas is enough to meet Nigeria's energy needs and leave a healthy balance for export. Through this obnoxious act, the country has lost about $72 billion in revenues for the period 1970-2006 or about $2.5 billion annually (Bassey, 2008). All these go up in smoke yearly, leaving death and destruction in its path. Globally, the absence of an efficient regulatory framework, inaccessibility to domestic and international markets and limited finances to carry out gas flaring reduction projects are key reasons for the continuous flaring of gas (World Bank, 2002). However, in Nigeria, all these reasons appear to hold true in addition to inadequate capabilities and overlapping responsibilities of government institutions, unclear operational procedures and political instability and corruption (Edino et al., 2010; Ishisone, 2004; Omakaro, 2009; World Bank, 2002).

2.3.2 Government Policies and Legislations

In the early 1960s, the Nigerian government recognized gas flaring as a potential problem associated with oil production and thus took steps in phasing out gas flaring. It enacted a number of regulations for monitoring flaring volumes and enforcing operational procedures. The introduction of these regulatory policies for more than 20 years ago has mostly been unsuccessful in achieving their set objectives. According to Abdulkareem (2005), these policies and regulations are very poor and inefficient due to the fact that the government puts profits maximisation ahead of the environment and the welfare of its people. Another reason responsible for the failure of these policies is the very insignificant fines imposed as a penalty for gas flaring which the multi-national oil companies are more than willing to pay as it is more economical to flare and pay fine than to stop flaring of gas (Ishisone, 2004). Listed below are several regulations on gas flaring from its inception till date;

- **1969 - Petroleum (Drilling and Production) Act and Regulations:** This encouraged the use of associated gas, by exempting multi-national oil companies from the payment of royalties (ICF 2006).
- **1979 - Associated Gas Re-injection Act (AGRA):** This act prohibited flaring of associated gas after January 1, 1984 without the permission from the Minister of Petroleum. Consequently, about 75% of gas is flared, whereas approximately 12% is re-injected. Since about 90% of Nigeria's foreign exchange comes from oil revenue, the government failed in implementing the 1984 deadline (Aghalino 2009; Sonibare and Akeredolu, 2006).
- **1985 - Associated Gas Re-injection Act Amendment Decree 7:** As a result of the failure of the 1979 AGRA, the 1985 AGRA amendment decree was promulgated which provided for exemption to the 1979 AGRA and permits a company engaged in the production of oil or gas to continue to flare gas in a particular field or fields on the payment of a fee set by the Minister of petroleum. The fine was 2 kobo (0.0009US$ equivalence) per 1000 standard cubic feet (scf) of gas flared. This rose to 50 kobo (0.03US$ equivalence) in 1992 and further to N10.00 (0.46US$ equivalence) in 1998. This policy was also unsuccessful as fine were very inconsequential and did not provide any incentive to encourage the multi-national oil companies to reduce flaring of AG (Aghalino 2009; Malumfashi, 2007; Sonibare and Akeredolu, 2006).
- **1992 - Associated Gas Framework Agreement (AGFA):** This is a form of fiscal incentives for companies involved in gas utilization (Aghalino 2009; ICF, 2006).
- **1988/92 - The Federal Environmental Protection Agency (FEPA) Act:** This act is mainly for environmental management (Malumfashi, 2007).
- **1998 - Finance (Miscellaneous Taxation Provision) Decree:** This is also a form of fiscal incentives for companies involved in downstream and upstream gas utilization, by reducing their tax burden (Sonibare and Akeredolu, 2006).
- **2004 - Associated Gas Re-Injection Act and the Associated Gas Re-Injection (Amendment) Act:** This also prohibited flaring of associated gas without the permission from the Minister of Petroleum. It obligated all oil producing companies in the country to submit detailed plans for gas utilisation (Malumfashi, 2007).
- **Petroleum Industry Bill (PIB):** This bill is yet to be passed by the Nigeria

government. The initial PIB draft (2008), had provisions to enforce multi-national oil companies to comply with international standards on integrated health, safety and environmental quality management systems by specifying quality, effluent and emission targets (Legall, 2009). However, this draft according to a joint position paper by three Civil Society Organizations in Nigeria (Social Action, Environmental Right Action (Friends of the Earth Nigeria) and Civil Society Legislative Advocacy Centre, 2011), have been adjusted, deleting the clauses that has to do with the prohibition of gas flaring and the imposition of penalties for gas flaring. This new PIB draft (2010), unfortunately have given absolute legality to the flaring of gas. Nigeria has not been an exception in paying lip-service to issue of gas flaring as demonstrated by successive extension of gas flaring deadline many times namely; 2004, 2007, 2008, 2010 and lately December 31st, 2012 as the terminal date for gas flaring by the legislative, hence, the need for a reporting framework.

Table 2.2: Component of gas flared and their percentage composition

Component gas flared	Percent composition (%)
CH_4	90.35
C_2H_6	5.85
C_3H_8	2.70
C_4H_{10}	1.10
C_5H_{10}	0.00
CO_2	0.00
N_2	0.00

Source: Rahmouni et al., 2003.

2.3.3 Natural Gas Composition

Natural gas is a subcategory of petroleum that is a naturally occurring complex mixture of hydrocarbon with a minor amount of non-hydrocarbon gases (Ubani and Onyejekwe, 2013). Natural gases contain more than three components (generally five constituents). Natural gas is a mixture of hydrocarbons (mainly methane, ethane, propane and butane, as well as some stable derivatives such as ethylene, butylene, etc.), occurring in a gaseous state at room temperature and pressure, and also containing other trace gaseous impurities and non-combustibles. A typical composition of natural gas from a Nigerian oil well is given in Table 2.2. According to Sonibare et al. (2004), 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 and 1.4-2.4% heavier hydrocarbons. The trace element in Nigeria's natural gas is mainly sulphur.

2.4 Pollution due to Gas Flaring

The Niger Delta region of Nigeria has suffered all forms of pollutions and degradation arising from oil and natural gas exploitation. Ofuoku et al., 2014 reported some forms of pollution witnessed in oil-producing communities of the agriculture zone of Delta State, Nigeria due to gas flaring. This includes; noise, soil, water and air pollutions.

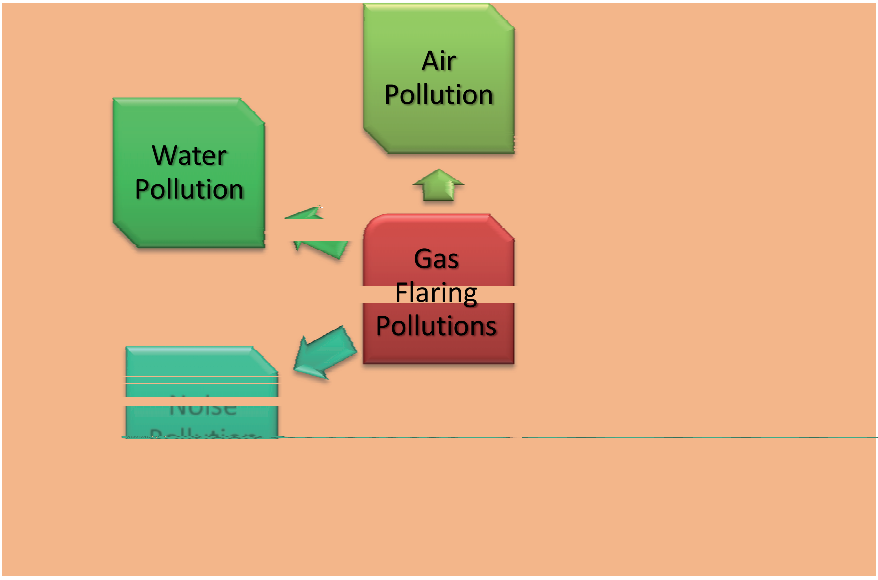

Figure 2.4: Pollutions associated with gas flaring

2.4.1 Air Pollution

An air pollutant includes any physical, chemical, biological, radioactive substance or matter which is emitted into or otherwise enters the ambient air (DeAngelis, 2013). Air pollution is one of the major environmental problems confronting the Niger Delta area. Gas flaring is generally discouraged as it releases carbon dioxide, methane, nitrous oxide and a variety of poisonous chemicals including nitrogen dioxides, sulphur dioxide, volatile organic compounds like benzene, toluene, xylene and hydrogen sulphide, as well as carcinogens like benzapyrene and dioxin into the atmosphere. Because of these gases flaring is potentially harmful on the health and livelihood of communities in the vicinity where flaring operation takes place. The primary causes of acid rain are emissions of SO_2 and NO_x which combine with atmospheric moisture to form sulfuric acid and nitric acid, respectively. In addition, gas flaring has been said to be a major contributor to air pollution and acid rain with many of the communities claiming that nearby flares cause acid rain which corrodes their homes and other local structures, many of which have zinc-based roofing (Tamari et al., 2012). The acid rain results in environmental degradation including soil and water contamination, and roof corrosion.

2.4.2 Water Pollution

The gaseous emission components from gas flaring activities have left hazardous materials to equally pollute the water, which the rural populace depend on for drinking. Acid rain formed as a result of the release of SO_2 and NO_x into the atmosphere through flaring of gas gets into rivers and lakes and therefore polluting the water bodies. The onetime area known for its fish now barely has enough, and now tends to depend on imported frozen fish as polluted water has either killed or poisoned the aquatic life of the area (Orimoogunje et al., 2010). In a recent study by Nwankwo and Ogagarue (2011), surface and ground water from gas flared region in Warri, Delta State was found to have high concentration level of heavy metals beyond the World Health Organization (WHO) maximum permissible limits.

2.4.3 Noise Pollution

Noise pollution has been suggested as a form of environmental pollution outside soil and water pollution (Ubani and Onyejekwe, 2013). A study conducted in oil-producing communities of the agriculture zone of Delta State, Nigeria, showed that noise pollution is ranked highest amongst the major environmental problems (soil erosion, bush burning, land degradation, water and air pollution) experienced in the area (Ofuoku et al., 2014). In addition to atmospheric pollution, gas flaring produces thermal and noise pollution near the flare. One major problem which the people had to contend with, is noise pollution. The noise of flow stations vibrate on their buildings and created cracks on the walls. For example, the Utorogun gas plant creates much noise and vibrations on the land and houses at about 6 km radius from it (Aghalino, 2009). Visitors to the Niger Delta have always complained of how the people in the region talk at high pitch tone. This may not be unconnected with long exposure to intense noise and vibration from gas flare stacks (Aghalino, 2009).

2.4.4 Soil Pollution

The flares also contribute to acid rain, which apart from corroding corrugated aluminum roofs, acidify the soil, thereby causing soil fertility loss and damaging crops. For instance, studies have shown that in cassava, there is a decrease in length, weight, starch, protein, and ascorbic acid content while okra plants and palm trees around the flares do not flower, and therefore, do not fruit (Orimoogunje et al., 2010). Crop yield has reduced to the barest minimum as the land can no longer sustain cultivation after several years of environmental degradation from the flares, and as fumes released from the flaring operation affect crops, leading to low agricultural yield (Orimoogunje et al., 2010). The findings of Abdulkareem (2006) showed that gas flaring has undeniably brought about degradation in the soil quality of the area. The once lush forest is almost completely gone due to acid rain; corrugated sheets used for roofing have given way (Orimoogunje et al., 2010). In addition, study has shown that the soils of the study area are fast losing their fertility and capacity for sustainable agriculture due to the acidification of the soils by the various pollutants associated with gas flaring in the area (Orimoogunje et al., 2010).

2.4.5 Light Pollution

In addition to air pollution, gas flaring produces light pollution near the flare. Heat from flares can damage soil and vegetation within 10 to 150 m around the flare site, while light pollution from actual flares is also creating places where the sun seems to never set. There is the problem of light pollution in gas flaring communities. Once the sun is set behind the mangrove, its light is replaced by the glow from roaring natural gas flare close to village edge. In a way, the oil industry has expelled darkness from the oil-bearing enclave of the Niger Delta region. The social implication of this is that, the joy of playing in the night under the eye-catching presence of the moon is now a thing of the past due to the ever-present flare sites (Aghalino, 2009). Figure 2.5

apparently illustrates this scenario of light pollution in the region.

Figure 2.5: Light pollution of Niger Delta region via gas flaring activities

2.4.6 Thermal Pollution

Another form of pollution resulting from gas flaring in the Niger Delta region is thermal pollution, since there is a limit to which the human body can tolerate the fluxes released during gas flaring. Besides, both habitat and structural buildings nearby also have heat threshold. Apart from the release of greenhouse gases into the atmosphere, gas flares are reported to dissipate roughly 45.8 billion kilowatts of heat from 1.8 bcm of gas into the atmosphere of the Niger Delta from gas flared on daily basis (Tawari et al., 2012). As a result of this incineration of the environment, gas flaring has raised temperatures rendering large areas uninhabitable coupled with negative effects on vegetation, animal life and ecological equilibrium (Tawari et al., 2012; Bassey, 2008). It is common to see women drying kpokpo, garri and fish at flare sites, bearing the intense heat and reaping a benefit of snacks dried by the infernal flames as presented in Figure 2.6. The oil corporations may count this as an economic benefit to the people but the truth is that the products of these processes, the kpokpo, garri and the dried fish are all poisoned and harmful to human health. In addition, study showed that with rise in air and soil temperatures of the flare site, relative humidity, soil moisture and all the soil chemical parameters decrease toward the flare (Odjugo and Osemwenkhae, 2009).

2.5 Effects of Gas Flaring

The impacts of gas flaring in the region in view are immense and far-reaching. These effects are felt locally and globally. Local communities around the flare bear most of the multifaceted adverse effects of gas flaring in their localities. Communities in the Niger Delta region have been under the negative effect of gas flaring for over 40 years and the situation is worsening from time to time with no solution in sight. Gas flaring has impacted negatively the Niger Delta region causing a decrease in agricultural yield, deformities in children, liver damage and skin problems, increasing concentrations of airborne pollutants, acidification of soils and rainwater, corrosion of corrugated roofs and substantial increase in concentrations of sulphates, nitrates and dissolved solids coupled with associated socio-economic problems.

Figure 2.6: Drying of farm produce using heat from gas flaring

2.5.1 Socio-economical Effect

Unfortunately, the Niger Delta people‘s main occupation is farming and fishing. Thus, gas flares not only have a devastating effect on the environment but also on their means of livelihood. Gas flaring has been reported to be a major cause of low agricultural (Odjugo and Osemwenkhae, 2009). Other studies associated gas flaring with increasing poverty among rural women, climate change, and increase in political activism in the Niger Delta region (Nwaocha and Pat-Ebano, 2010).

2.5.2 Ecological and Environmental Degradation Effect

Continued degradation in the form of spills and gas flares render the Niger Delta extremely vulnerable to the impacts of climate change with a projected loss of 50% ability to produce cereals by the year 2020 that would rise to 80% loss by 2050 (Bassey, 2008). The flared gas has a lot of environmental implications. For instance, gas flaring is observed to reduce atmospheric quality through the release of pollutants like carbon monoxide, NO_2, SO_2 and lead among others into the atmosphere. Gas flaring is also reported to cause acid rain within the flare's microenvironment (Nwaocha and Pat-Ebano, 2010). Studies show that gas flaring significantly affects not only the microclimate but also the physico-chemical properties of the soil near the flare sites (Ofuoku et al., 2013; Orimoogunje et al., 2010). Another impact of gas flaring reported is the destruction of vegetation, wild life and ecological destabilization (Tawari et al., 2012).

The effects of gas flaring were so much on the farmlands, crops, and water such that the people no longer engage in productive farming, fishing and hunting as they used to (Orimoogunje et al., 2010). It is obvious that the people of this area are dependent on the environment for their source of livelihood. In the times past, the people depended so much on resources from their natural environment, and made their living through exploiting the resources of their land, such as water and forests, as fishermen and farmers or hunters. These economic activities were distorted by the discovery of oil in the area, and subsequently, gas flaring, that has caused immense environmental degradation in the area (Orimoogunje et al., 2010).

2.5.3 Corrosion Effect

Exhaust gases released from gas flaring stacks contribute to corroding corrugated aluminum roofs apart from causing acidic rain which acidify the soil, thereby causing soil fertility loss and damaging crops. A study examined the effect of gas flaring on the built environment using buildings at Obrikom and Omoku communities as the main observed objects (Nwaocha and Pat-Ebano, 2010). Results revealed a strong association between emissions from the flare point and some impacts observed on the buildings in the area. The results showed that the most probable air pollutants that caused these observed impacts (corrosion of roof tops, coloration of walls, leakage of roof tops etc) were SO_2, NO_2 and PM_{10} as they matched the criteria for causative agents in this case (Nwaocha and Pat-Ebano, 2010). In addition, monuments, economic structures, arts work and several building structures are glaring evidences of the impacts of corrosion due to acid rain as a result of gas flaring in the region (Tawari et al., 2012). Figure 2.7 shows the corrosion of corrugated roofing sheets in Niger Delta Community as a result of gas flaring activities.

Figure 2.7: Corroded roofing sheets of Niger Delta community due to gas flaring

2.5.4 Public Health Effect

In addition to having an impact on climate, particles are also known to have a negative impact on human health. For example, a study in Bayelsa State of Nigeria in 2005 found that gas flaring caused 49 pre-mature deaths, 120,000 asthma attacks and 8 additional cases of cancer (Nwaocha and Pat-Ebano, 2010). Gas flaring in the Niger Delta region has also contributed to numerous diseases among the residents, such as asthma, bronchitis, cancer, blood disorders, and skin diseases; these diseases are directly correlated to gas flaring. As a result of these diseases life expectancy in the Niger Delta region is markedly lower than what obtains elsewhere in Nigeria. It stands at about 40 years on the average. This is not surprising because of the toxic elements (including benzene) being released regularly into the atmosphere. Diseases related to gas flaring include asthma, bronchitis, cancers, blood disorders and skin diseases (Bassey, 2008; Ukala, 2011).

2.6 Cost Implication of Gas Flaring

Continual gas flaring activities in the Niger Delta region of Nigeria for close to 50 years leaves a devastating landmark on the environment of the area. The environmental degradation and ecological destruction experienced in this region in all its ramifications cannot be evaluated in monetary terms. The cost of gas flaring in this region can be measured in terms of greenhouse gas emissions (and other forms of emissions), and the value of avoiding those emissions in evolving carbon markets. There is also a significant and measurable economic cost in terms of lost revenue that otherwise could be generated if flared natural gas was captured and sold into whatever end-use outlets that exist in region. Calculating costs in terms of health impact on local populations or lost output from degraded agricultural output and fisheries are somewhat more difficult (Farina 2011).

2.7 Emissions from Gas Flaring

Gas flaring is simply the combustion of natural gas which is a fossil fuel comprising of hydrocarbons. The combustion of natural gas leads to the emission of gases (NO_x, CO_2, CO, SO_2 and H_2O etc.), particles (PM, BC, brown carbon etc.) and heat. Complete combustion which is not practically feasible would turn all carbon in the fuel into CO_2. In practice, combustion is never complete, and CO_2, CO, VOCs, organic carbon (OC) and BC are all formed which are released into the atmosphere. Figure 2.8 presents the main emission constituents of the combustion of natural gas due to flaring. The emissions from the flaring of gas in this region have caused irreversible and unquantifiable damage to the environment, economy, ecosystem and health of the inhabitants of the region.

2.7.1 Greenhouse Gases

Global warming is mainly caused by the emission of greenhouse gases (GHGs) from combustion processes. Specifically, the GHGs (carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbon, perfluorinated compounds and sulfur hexafluoride) have relatively long atmospheric lifetimes that have a propensity to be evenly distributed throughout the atmosphere, and thus have global average concentrations. The amounts of GHG emissions from natural gas flaring depend on gas production, it composition, and the flare efficiency. The efficiency determines how much gas will be burnt as CO_2, while the rest will be vented as methane, which has higher greenhouse intensity.

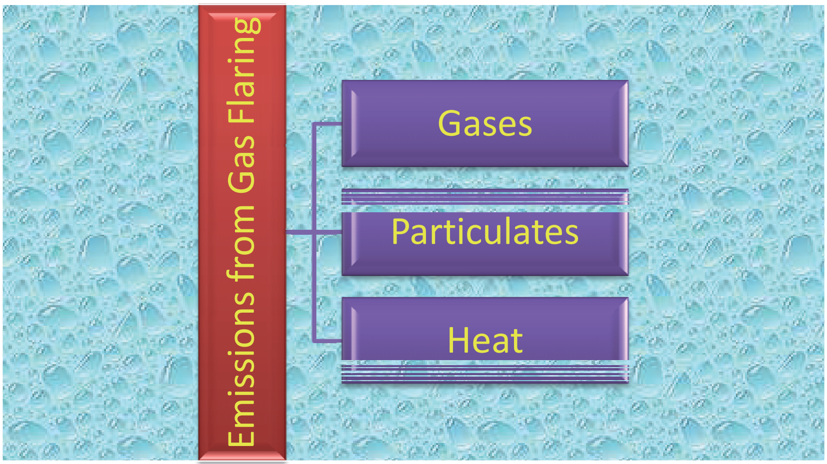

Figure 2.8: Basic emission products from gas flaring activity

Gas flaring is one of the most demanding and important energy and environmental problems confronting the world today. Approximately 150 bcm of gas are flared in the world per year, representing a US$15 to US$20 billion waste of resources and a 260 to 400 million tonnes per year of CO_2 contributed to global GHG emissions (Farina, 2011). The impact of gas flaring on the global community in terms of GHG emissions is substantial. Gas flaring emissions contribute significantly to global warming and climate change (Ukala, 2011). They are produced when extra gases are burned off during the oil-drilling process. Gas flares are composed of toxic gases such as sulphur dioxide, nitrogen dioxides, benzapryene, toluene, xylene and hydrogen sulfide. These gases including CO_2, N_2O and CH_4 are released into the atmosphere in large quantities and have an adverse effect on the environment. In fact, the World Bank estimated that about 10 percent of global CO_2 emission comes from flaring. Nigerian gas flaring alone releases 35 million tons of CO_2 and 12 million tons of CH_4, which is known to have a higher warming potential than CO_2 (Dung et al., 2008). The global warming potential values of some key greenhouse gases are provided in Table 2.3.

2.7.2 Precursor Gases

Flaring natural gas emits other injurious gases beside greenhouse gases, these gases are NO_x, CO, SO_2, H_2S and a number of other harmful gases. Assessments show larger concentrations of nitrogen oxide (NO_2) are found within one to three km of flaring sites. SO_2, CO and various unburned hydrocarbon gases can be present within five to 15 km from flare sites. Also, SO_2 and NO_x emissions are known to form acid rain in gas flaring areas that can pollute and poison water bodies, soil and vegetation, and corrode buildings.

Table 2.3: Some major greenhouse gases global warming potential values

Greenhouse gas	**Lifetime (Years)**	**Estimated Global Warming Potential**		
		20 years	**100 years**	**500 years**
Carbon dioxide (CO_2)	Variable	1	1	1
Methane (CH_4)	12.0	62	23	7
Nitrous Oxide (N_2O)	114	275	296	156
Chlorofluorocarbons (CFCs)	_ _	_ _	_ _	_ _
$CFCl_3$ (CFC-11)	45	6300	4600	1600
CF_2Cl_2 (CFC-12)	100	10200	10600	5200
$CClF_3$ (CFC-13)	640	10000	14000	16300
$C_2F_3Cl_3$ (CFC-113)	85	6100	6000	2700
$C_2F_4Cl_2$ (CFC-114)	300	7500	9800	8700
C_2F_5Cl (CFC-115)	1700	4900	7200	9900

Source: Based on Intergovernmental Panel on Climate Change Third Assessment Report, 2001.

2.7.3 Heat

In addition to the emission of gaseous products from gas flaring activities, enormous heat is also being continual released around the flare site. Heat from flares can damage soil and vegetation within 10 to 150 m around the flare site with the forming of a place where the sun never sets. The huge amount of heat release increases the atmospheric air around the communities making the environment uncomfortable for day to day activities, especially, sleeping. Skin irritation and other dermal problems due to the excessive heat is a common health issue in these communities as a result of gas flaring operations. Noise associated with the heat oozing from gas flaring stacks close to communities cause ear deafening of the habitants of these areas.

2.7.4 Particulate Matter

Particle is an integral part of the emission products of gas flaring which is reflected in the release of PM, BC, OC, brown carbon and inorganic compounds into the atmosphere during gas flaring activities. PM is a complex mixture of extremely small particles and liquid droplets suspended in the atmosphere. Sources of PM can be human activities, such as the burning of fossil fuels in vehicles and power plants, gas flaring and various industrial processes generate significant amounts of particulates. In addition, PM occurs naturally from volcanoes, forest and grassland fires, living vegetation, and sea spray. It is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. For purposes of air quality and health studies, PM is typically measured in two size ranges: PM_{10} and $PM_{2.5}$. In terms of the size, PM_{10} has an aerodynamic diameter less than or equal to a nominal 10 μm while $PM_{2.5}$ is a fine PM with an aerodynamic diameter less than or equal to 2.5 μm.

In addition to having an impact on climate, particles are also known to have a negative impact on human health. Health effects linked with PM emission in the gas flaring region of Niger Delta includes respiratory and cardiovascular problems, premature death, heart attacks, strokes, as well as acute bronchitis and serious asthma among children. The fine particles (<3μm) are the worst causes of lung damage due to their ability to infiltrate into the deep air passage. Larger particles (>3 μm) are stuck in the nose and the throat from which they are easily removed, but finer particles can stay intact for years in the innermost regions of the lungs, which have no effective mechanism for particle removal. The stuck particles in the lungs can cause severe breathing difficulty by physical blockage and irritation of the lung capillaries (Rao and Krishna, 2012).

2.7.5 Black Carbon, Organic Carbon and Other Particles

PM, a complex mixture of mostly BC and OC, is the primary light-absorbing pollutant emitted by the incomplete combustion of fossil fuels, biofuels, and biomass. BC is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. OC generally refers to the mix of compounds containing carbon bound with other elements like hydrogen or oxygen. Other carbon-based PM may also be light-absorbing, particularly brown carbon (BrC), which is a class of OC compounds that absorb light within the visible and ultraviolet range of solar radiation and that can exist within the same particles as BC. The net contribution of BrC to climate is presently unknown. BrC can be directly emitted as a product of incomplete combustion, or it can be formed in the atmosphere as pollutants age. BC, BrC and OC have relatively short residence times in the atmosphere, days to weeks, and hence, they are considered as short-lived climate forcers (SLCF).

The ratio of OC to BC emitted per mass of PM is a function of combustion conditions that depend on several factors (e.g., combustion device and the way it is operated as well as the fuel that is burned). There is a close relationship between emissions of BC and OC. They are always co-emitted, but in different proportions for different sources. A high BC-to-OC ratio means a predominantly absorbing aerosol that will contribute to warming. A low BC-to-OC ratio means a predominantly reflecting (or scattering) aerosol that will contribute to cooling. The ratio depends on the emission source. Diesel engines and gas flaring emit more BC than OC and, as a result, their emissions have high BC to OC ratios. Open biomass burning typically emits more OC than BC such that biomass burning emissions have relatively low BC to OC ratios. While combustion is the primary source of BC, OC can also be produced from gaseous precursors which undergo processing in the atmosphere to form secondary organic aerosol (Bond et al., 2013).

2.8 Black Carbon

Recently, BC has received a great deal of attention among climate scientists and policymakers for its warming effects on global and regional climate. It is reported as the second most important contributor to global warming after carbon dioxide (Bond et al., 2013). BC is emitted directly into the atmosphere in the form of fine particles. The United States contributes about 8% of the global emissions of BC. Within the United States, BC is estimated to account for approximately 12% of all direct $PM_{2.5}$

emissions in 2005 (US EPA, 2012). Numerous international and intergovernmental bodies, including the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), the Convention on Long Range Transboundary Air Pollution (CLRTAP), and the Arctic Council, have identified BC as a potentially important piece of the climate puzzle (Aasestad, 2013).

2.8.1 What is Black Carbon?

BC is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. BC is a type of aerosol and the most effective form of PM emitted into the atmosphere through the incomplete combustion of fossil fuels and biomass. BC emissions come from industry, transportation, residential cook stoves, gas flaring and open burning. Uncertainties regarding the exact effects of BC have slowed global action in mitigating its impacts even though it is a leading contributor to climate change and has deleterious effects on public health (US EPA, 2012). BC is emitted with other particles and gases and depending on their composition, these emissions mixtures can generate mixed effects on the climate.

It is a particle rather than a greenhouse gas, it is the second largest climate warmer of the atmosphere after CO_2 and together with other pollutants that have a similarly powerful but short-lived warming influence, is known as a SLCP. One gram of BC dispersed in the atmosphere absorbs about as much light as 10 black umbrellas (Jacobson et al., 2013). Although black carbon remains in the atmosphere for only a few days, one gram of black carbon warms the atmosphere several hundred times more during its short lifetime than one gram of carbon dioxide does during 100 years (Jacobson et al., 2013). BC has global warming properties, due to its ability to absorb heat in the atmosphere and by reducing albedo, i.e. reducing the ability to reflect sunlight, when deposited on snow and ice. Given the climate properties of BC in particular, seen from a global warming perspective, the short-term climate benefits of reducing these emissions are promising.

2.8.2 Properties of Black Carbon

Black carbon is a distinct type of carbonaceous material, formed only in flames during combustion of carbon-based fuels. It is distinguishable from other forms of carbon and carbon compounds contained in atmospheric aerosol because it has a unique combination of the following physical properties:

1. It strongly absorbs visible light with a mass absorption cross-section of at least 5 m^2g^{-1} at a wavelength of 550 nm.

2. It is refractory; that is, it retains its basic form at very high temperatures, with a vaporization temperature near 4000 K.

3. It is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol.

4. It exists as an aggregate of small carbon spherules (Bond et al., 2013).

2.8.3 Sources of Black Carbon

BC comes from incomplete combustion. The largest sources are open burning of forests and savannas, diesel engines, household burning of solid fuels, gas flaring and some kinds of industrial processes The type of combustion greatly affects BC emission rates, and poor combustion emits more BC than good combustion for the same type of fuel (Bond et al., 2013). 75% of global BC emissions come from Asia, Africa and Latin America. U.S. currently accounts for approximately 8% of the global total, and this fraction is declining. Emissions patterns and trends across regions, countries and sources vary significantly. Developing countries (e.g., China and India) have shown a very sharp rise in BC emissions over the past 50 years. Total global BC emissions are likely to decrease in the future, but developing countries may experience emission growth in key sectors (transportation and residential). Majority of BC emissions come from the developing world with China and India accounting for about 25–35 percent of its emissions. Figure 2.10 presents BC particles embedded in cloud droplets.

2.8.4 Impacts of Black Carbon on Climate Change and Environment

The global warming potential (GWP) for BC has been estimated at 680 over a 100-year period, and 2,200 for a 20- year period (Bond et al., 2013). BC influences climate in three ways: direct effect, snow albedo effect, and cloud interactions. First, BC contributes to warming of the atmosphere by absorbing radiation at all wavelengths (direct effect). Second, BC deposited on snow and ice darkens the surface, reduces reflectivity and consequently increases absorption and melting (snow albedo effect).

Third, BC also interacts with clouds, which affects cloud stability, precipitation, and reflectivity (cloud interaction effects). These influence - particularly the snow albedo effect - also make the Arctic mostly vulnerable to BC emissions. A recent study concluded that BC had a net climate forcing of +1.1 Wm^{-2}, making it the second most important contributor to climate change after CO_2 (Bond et al., 2013; Aasestad, 2013). In addition, the climate effect may increase the likelihood of extreme weather, such as the prolonged and extreme summer heat in Moscow in 2010, which appears to correlate with high mortality during that period (DeAngelis, 2013). Scientists have documented similar warming effects in the Himalayas because of its proximity to India and China, which are large producers of BC emissions. BC contributes to the melting of the Himalayan glaciers, which threatens the water supply of more than ten percent of the world‘s population (DeAngelis, 2013).

Figure 2.10: Artist rendition of black carbon cloud droplets (Source: US EPA, 2012)

BC also contributes to the formation of Atmospheric Brown Clouds (ABCs) and the resultant changes in the pattern and intensity of precipitation. In cases of gas flaring, especially, in the Niger Delta region of Nigeria where BC is being continually released for over four decades, utilizing the gas is of course a natural option to reduce BC emissions. But in some cases, gas utilization infrastructure may be costly or take considerable time to commission. Though the knowledge on BC emissions from gas flaring is very limited, it seems that opportunities exist to reduce particulate (BC) emissions drastically by improving flaring systems and optimizing combustion's conditions. There still is, however, insufficient knowledge on how various parameters influence the quantities of BC.

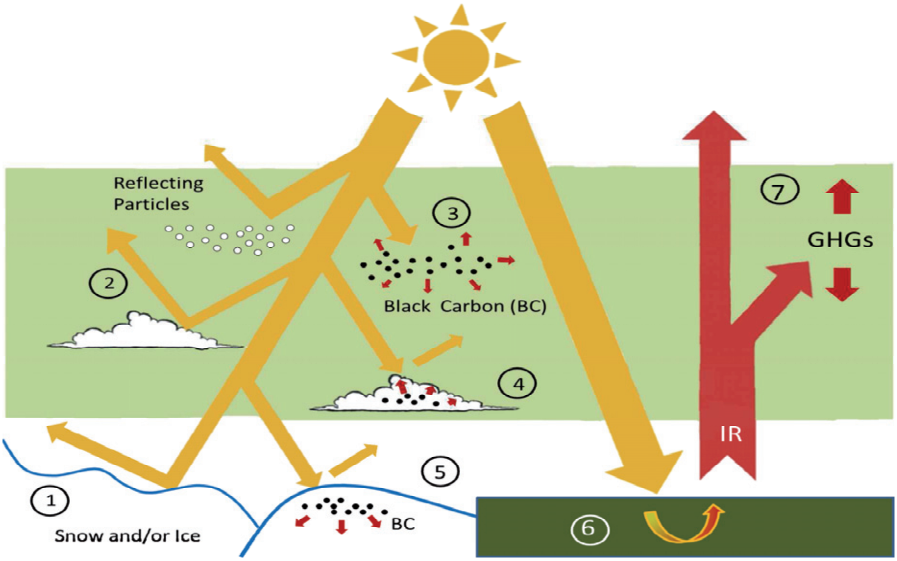

Figure 2.11: Effects of BC on climate, as compared to greenhouse gases (Source: US EPA)

2.8.5 Health Implication of Black Carbon

BC emissions have significant impacts on public health, the environment, and the Earth's climate. BC is an important component of particle pollution, which has been associated with adverse health and environmental impacts through decades of scientific research. BC has been linked to a range of climate impacts including increased temperatures, accelerated ice and snow melt, and disruptions to precipitation patterns (US EPA, 2012). BC, as part of $PM_{2.5}$, has serious effects on human health, ecosystems, and visibility. BC causes grave health problems and even death in humans. These health negative effect include pneumonia, acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), and lung cancer (DeAngelis, 2013). These effects fall disproportionately on the developing world because BC emissions originate primarily in developing nations. BC sources from household use of solid fuels alone cause about 1.8 million deaths each year (US EPA, 2012).

BC particles can penetrate into the human body through the lungs with inhalation, through the gastrointestinal tract with water and food contact, and through skin and mucosa. Short-term and long-term exposures to $PM_{2.5}$ are associated with respiratory and cardiovascular diseases, as well as premature death (US EPA, 2012; Janssen et al., 2012). $PM_{2.5}$, including BC, is also linked to reduced crop yields and damage to materials and buildings. Short-term epidemiological studies provide sufficient evidence of an association of daily variations in BC concentrations with short-term adverse health effects e.g. cardiopulmonary hospital admissions. Also, a long-term average BC exposure has been directly linked to cardiopulmonary and all-cause mortality (Janssen et al., 2012). BC may not be a major directly toxic component of $PM_{2.5}$, but it may operate as a universal carrier of a wide variety of chemicals of varying toxicity to the lungs, the body's major defence cells and possibly the systemic blood circulation. Therefore, a reduction in exposure to $PM_{2.5}$ containing BC and other combustion related particulate materials should lead to a reduction in the associated health effects (Rao and Krishna, 2012).

The aforementioned health problems clearly reflect the true picture of what have been reported in literature (Ukala, 2011; Nwaocha and Pat-Ebano, 2010; Bassey, 2008; Odjugo and Osemwenkhae, 2009) and what is practically obtainable in the Niger Delta region of Nigeria concerning the health implications of gas flaring activities in this region of the country. In agreement with the fact that particulates, especially, BC that is emitted into the atmosphere of this region due to gas flaring activities is largely responsible for the widely reported respiratory and pulmonary problems of the inhabitants of communities around gas flaring sites. The health issues of the people of this region have culminated into premature death as a result of the reduction in their life expectancy rate, which is reported to be around 40 years (Nwaocha and Pat-Ebano, 2010; Bassey, 2008). Estimation of the quantity of BC released into the atmosphere in this region due to over four decades of gas flaring in the country is the primary aim of this study.

2.9 Gas Utilization Projects in Nigeria

The Nigerian gas sector is presently undergoing a major expansion, growing from less than 500 million cubic feet per day (MMCFPD) a few years ago to an expected capacity of over 5000 MMCFPD by 2018 (Nigeria National Petroleum Corporation, 2013). This expansion has brought about a major revamp of the existing system and growth of gas infrastructure. Nigerian federal government's dream of increasing gas utilization in order to reduce gas flaring and its associated problems both locally and globally has led to numerous projects in the gas sector of the economy. These projects are either on-going or completed or have been conceived to harness the enormous wastage of the country's huge gas resources due to gas flaring and to monetize this natural endowment as means of earning foreign exchange.

2.9.1 Nigeria LNG Project

The Nigeria Liquefied Natural Gas Company (NLNG) was incorporated as a limited liability company in 1989 to harness Nigeria's vast natural gas resources and to produce LNG and natural gas liquids for export. The Liquefied Natural Gas Project is Nigeria's most ambitious natural gas project. The $3.8 billion LNG liquefaction plant in Bonny Island was completed in 1999 and processes about 400 MMCFPD of LNG. NLNG is a joint venture project comprising of NNPC (49%), Shell Gas BV (25.6%), Totalfinaelf LNG Nigeria Limited (15%) and Agip International BV (10.4%). With the completion of a sixth production train in December 2007, the NLNG Plant at Bonny Island has an overall capacity of around 22 million tonnes a year of LNG and 4 million tonnes per annum (MTPA) of LPG. It accounts for about 11% of the world's total LNG capacity and making it the fourth largest LNG exporting country in 2013 (Nwaoha and Wood, 2014). This project is well positioned to serve the European and North American markets. Presently, Nigeria is embarking on the construction of an LNG plant through NLNG Limited. This plant is located at Finima in the Eastern region of Nigeria and will supply up to 1 billion scf of natural gas as feedstock to the plant from their Obite, Obiafu and Soku fields. It is expected that flaring will be substantially reduced by the time this project comes on stream couple with the expected huge revenue (Anthony and Anyadiegwu, 2013). Furthermore, the NLNG's 8.4 MTPA Train 7 project originally proposed more than 5 years ago, which will raise the liquefaction capacity to 30.4 MTPA continues to wait for a positive final investment decision (FID) (NLNG, 2013; Nwaoha and Wood, 2014).

2.9.2 Escravos Gas – Gathering Project

This is also a joint venture project composed of Chevron Texaco (75%), NNPC (25%) and Sasol (10%) recover associated gas from offshore fields in Escravos, Nigeria. The Escravos Gas-to-Liquid (EGTL) plant is expected to use part of the gas currently being flared with a production capacity of 34,000 barrel per day (BPD) of GTL diesel, GTL naphtha and a small amount of liquefied petroleum gas (LPG). The country's ambition to further monetize and diversify the use of its huge natural gas resources has led to the construction of a GTL plant. The aim of the GTL plant is to put to use associated natural gas the rather than to flare it; an initiative which is in agreement with the pursuit of the Federal Government of Nigeria to reduce and ultimately stop gas flaring in the country. The EGTL plant is engineered to use Sasol's Fischer-Tropsch process technology and Chevron's iso-cracking technology. When finally on-stream, EGTL is expected to convert more than 325 MMCFPD of natural gas to 33,000 BPD of ultra-clean diesel and naphtha for use as a petrochemical feedstock. When the project was initially sanctioned there was the intention to expand the EGTL to 120,000 BPD capacity within 10 years (Nwaoha and Wood, 2014).

2.9.3 Oso Natural Gas Liquid Project

This is an NNPC (49%) and ExxonMobil (51%) joint venture project that converts associated wet gas into natural gas liquid (NGLs). This project produces about 50,000 BPD of NGL.

2.9.4 West Africa Gas Pipeline Project

The West African Gas Pipeline (WAGP) project is a regional initiative intended to transmit natural gas from Nigeria to consumers in republic of Benin, Togo and Ghana. The project is a joint venture comprising of Chevron, Texaco, Shell, NNPC, Nigeria Gas Company (NGC), Societe Beninoise de Gas, Societe Togolaise de Gas, and Ghana's National Petroleum Corporation for the extension of the existing Escravos-to-Lagos pipeline to Takoradi, Ghana. A $1 billion basically submarine pipeline project is designed with an initial capacity of 200 MMCFPD and an ultimate capacity of 450 MMCFPD. It is the intention of WAGP to supply Ghana in principle and in the process, Benin and Togo with secure and predicable gas supply. It is projected that about 85% of the gas will be utilized for power generation and 15% by local industries (Odumugbo, 2010). The total length of the pipeline is 1.033 km. The final capacity is estimated to be 580 MMCFPD with additional compression at Lagos and Lome.

to the International Glass Industry Limited PZ, Aba Textile Mills and Aba Equitable Industry; the Obigbo North -Afam system caters for PHCN Power Station at Afam; the Alakiri to Onne Gas pipeline system supplies gas to the Notore Chemicals for fertilizer production; the Alakiri - Obigbo North - Ikot Abasi system for gas supply to the Rusal Industries in Ikot Abasi; the Escravos-Lagos Pipeline (ELP), which supplies gas to Egbin Power Plant near Lagos. Subsequent spur lines from the ELP supply the West African Portland Cement Plants at Shagamu and Ewekoro, PZ Industries at Ikorodu, City Gate in lkeja, Lagos, PHCN Delta IV at Ughelli, and Warri Refining and Petrochemical Company at Warri; Ibafo – Ikeja Gas Supply Pipeline System supplies gas to Ikeja City Gate from where Gaslink distributes to the Lagos Industrial Area. Ikeja – Ilupeju – Apapa Gas Pipeline System currently operated by Gaslink for Gas Supplies to Greater Lagos Industrial Area.

All these facilities comprise of over 1,250 km of pipelines ranging from 4 to 36 in diameter with an overall design capacity of more than 2.5 billion cubic feet per day (BCFPD), 16 compressor stations and 18 metering stations. The facilities represent a current asset base of more than N21 billion (Nwaoha and Woods, 2014).

2.9.8 Industrial Gas Project

Gaslink, a Nigerian gas company through its distribution schemes plans to provide natural gas for domestic consumption. These include the Ajaokuta-Abuja-Kaduna pipeline that will supply Northern and Central Nigeria and Aba-Enugu-Gboko that will supply Eastern Nigeria.

2.9.9 Brass LNG Project

In the year 2006, four shareholders signed an agreement for the Brass LNG Project, involving an estimated cost of US$8.5 billion. The shareholders were NNPC (49%), ENI (17%), ConocoPhillips (17%), and Total (17%) (Nwaoha and Woods, 2014), but ConocoPhillips announced its intention to withdraw in 2013, and NNPC also expressed its intention to divest a 17% interest following the final investment decision (FID) for the project. The Brass LNG facility is planned to be built on Brass Island in Bayelsa State, Nigeria and will initially consist of two trains with a combined capacity of 10 MTPA. The plant will also produce 2.5 MTPA of LPG with additional facilities for liquefied butane and propane extraction and treatment, and some condensates.

2.9.10 Olokola LNG Project

Olokola LNG (OK-LNG) was at first part of the Nigerian government commitment to ensuring sustainable economic growth in the country. In 2005, a Memorandum of Understanding (MOU) was signed by the then equity holders for the OK-LNG project to be sited in Olokola free trade Zone, with NNPC (40%), Chevron (19.50%), Shell (19.50%), and BG Group (14.25%), and the remaining 6.75% held open for strategic investors (Nwaoha and Woods, 2014). OK-LNG was planned to have four liquefaction trains, each with 5.5 MTPA capacity and expected to cost around $10 billion in 2006. Gas supply to OK-LNG was expected to originally come from Shell and Chevron operated JVs with about 1 BCFPD of gas required for each train (Nwaoha and Woods, 2014). The site selected for OK-LNG was some distance from the Niger Delta and a feed gas supply, and securing that supply and the transit routes for that supply to the site has always been problematic for the project. Chevron and Shell withdrew from OK-LNG in 2013, following the earlier exit of BG in 2012, leaving just NNPC in that project (Nwaoha and Woods, 2014). It seems doubtful that this project will now go ahead unless it receives considerable fiscal incentives following the final passing of the PIB.

2.9.11 West Niger Delta LNG Plant

The plant is the second LNG facility jointly floated by NNPC, Chevron Texaco, Conoco and ExxonMobil and operated by ExxonMobil. The MOU to conduct feasibility studies for this project was signed in February, 2001 and the plant came on stream by 2005 (Anthony and Anyadiegwu, 2013).

2.9.12 Bonny Non-Associated Gas Plant

Shell Petroleum Development Company (SPDC) in 2004 began a $48 million expansion of the BNAG plant from 300 MMCFPD to 450 MMCFPD with a view to increasing supply to the NLNG Plant’s fourth train. Non-associated gas reserves will include the Shell-operated Shoku field of 4.4 TCF capacity and Bomu field of 1.1 TCF, and the Agip-operated Oshi and Idu fields of 2.5 TCF. However, according to plan, the associated gas supply was to be about 65% by the year 2010 (Anthony and Anyadiegwu, 2013).

2.9.13 Gas to Methanol (GTM)

Global demand for methanol is projected to increase from 60.2 million metric tons in 2012 to 92.3 million metric tons in 2016, which stood at more than 100,000 tons of methanol being used daily either as a chemical feedstock or for transportation purposes (Nwaoha and Woods, 2014). Methanol is a synthetic fuel produced typically from synthesis gas and is able to utilize existing liquid (oil) storage and transport infrastructures relatively easy (Odumugbo, 2010). In Nigeria, the Gulf of Guinea Oil Exploration Limited (GGOEX) revealed plans in 2012 to construct the largest West African methanol plant in Nigeria by 2015, at a project cost of about $700 million. The proposed plant would produce 850,000 metric tonnes of methanol per annum (about 2500 metric tons per day of grade AA methanol). The cost of the project will be debt and equity financed by International Financial Corporation (IFC) and fund syndication from local banks. The project would utilize the Mitsubishi Methanol Process (MMP) and would be located at the Ogidigbe gas Industrial Park in Delta State. If successful the project has plans to double the capacity (Nwaoha and Woods, 2014). Methanol has potential in Nigeria to be used as a blend stock in liquid transportation fuels as well as in the petrochemical sector.

2.9.14 Gas to Fertilizer (GTF)

Demand for fertilizer is expected to increase in Nigeria. The global demand for urea for all uses is projected at 176 metric tonne in 2016, growing 2.4% per annum compared with 2011 (Nwaoha and Woods, 2014), signifying potential export opportunities. Increases in demand are projected for all three major nutrients, showing average annual growth rates of 1.3% for nitrogen, 2.1% for phosphorus, and 2.8% for potassium. From the Nigerian point of view, fertilizer demand is likely to increase as domestic agriculture expands in attempts to reduce the present enormous reliance on imported foods. Two developments projects (Ammonia and Urea synthesis) are underway in Nigeria and will contribute to expanded fertilizer production.

An Indonesia-based Indorama Eleme Fertilizer and Chemicals Limited (IEFCL) commenced construction of a gas-to-urea fertilizer plant project, which is projected to be completed in last quarter of 2015 and cost about $1.2 billion (Nwaoha and Woods, 2014). Indorama's new facility at the complex will produce urea from natural gas as feedstock using KBR's purifier technology and is amongst the world's largest of such plants. The IEFCL project consists of 2300 MTPD ammonia plant, a 4000 MTPD urea plant, a urea granulation plant, and associated infrastructure and utilities (Nwaoha and Woods, 2014). Feedstock will be supplied by Agip (ENI) through an 84 km pipeline. About 60-70% of the fertilizers produced at the plant will be transported to the jetty for export markets, while the remaining 30-40% of the urea will be filled in 50 kg bags and sold within the domestic market. Production from the new plant should enable the country to reduce its dependence on urea imports and help Nigeria become self-sufficient.

Notore Chemical Industries Limited (Notore), which is the owner of the only operating urea fertilizer plant in the sub-Saharan Africa, signed a Joint Venture Agreement with Mitsubishi in 2012 to increase ammonia production, and other petrochemical plants at its plant located at Onne, Rivers State, Nigeria (Nwaoha and Woods, 2014). This integrated plant complex will be constructed for the production of ammonia (1700 MTPD), urea (3000 MTPD) and other petrochemical plants (1500 MTPD). Natural gas will be utilized as the feed gas for the plant. The plant will be built on a brown-field site and will have access to existing gas facilities and other relevant infrastructure, and it's expected to come on-stream by 2016.

2.9.15 Ogidigbe Industrial Gas City

Nigeria's gas development is being driven by the government's Gas Master Plan (GMP) which is promoting the development of gas infrastructure across the country in order to abate gas flaring. According to the GMP, gas for power generation will support at least a threefold short term increase in generation capacity to 12,000 MW by 2015 (OPEC, 2012). Furthermore, Nigeria is to become the regional destination for gas-based industries, such as fertilizer, petrochemicals and methanol by 2014. As a result of this, the Federal Government of Nigeria has proposed an 'Industrial Gas Park'. They are inviting private investors to participate in the gas-based industrial city it is building in Ogidigbe, Delta State, which will cost around 1.11 trillion Nigerian naira ($7 billion), and construction is expected to be finished by 2017 (OPEC, 2012). The Ogidigbe Industrial City is expected to include a fertilizer plant, a petrochemical plant, a central processing facility and a power plant of 350 MW capacity (OPEC, 2012). The city would also include large commercial and residential areas and provide substantial direct and indirect employment. This project will seriously offer many opportunities for investments existing in the sectors of financial services;

upstream gas development, LNG and gas processing facilities, pipe milling and fabrication yards, and above all gas based manufacturing industries.

2.9.16 Compressed Natural Gas (CNG)

Transportation represents an enormous and visible opportunity for gas market development in Nigeria. However, before this it is possible to exploit this opportunity, it is necessary to develop a market for CNG vehicles and the associated infrastructure to store, transport and distribute natural gas to those vehicles throughout Nigeria. Development of CNG transportation-fuel infrastructure requires large capital expenditure, as is currently evident in the U.S.A. (Onwukwe, 2009). The main problem is commercial and public acceptance of natural gas vehicles (NGVs) rather than CNG vehicle technology. CNG has become the matter of interest today, as the combustion of gasoline and diesel fuels result in the emission more noxious pollutants (Semin et al., 2009) and cost more due to high oil prices and high levels of taxation on conventional liquid vehicle fuels. CNG growth as a transportation fuel in certain parts of the world (Asia and South America) remains strong due to the current investments in natural gas vehicles (NGVs) and fuel-station infrastructure (Leather et al., 2013).

However, in Nigeria an additional difficulty is the subsidies that are applied to gasoline and diesel fuels which have subsequently increase the price of the fuels. Although these subsidies have been gradually reduced over the past decade, they still pose an obstacle to acceptance of alternatives. In addition, distribution and availability of gasoline and diesel as transportation fuel has been problematic down the years, leading to long queues at filling stations and at higher prices. Pursuing a target of 65 million NGVs on the road globally by 2020, International Association for Natural Gas Vehicles (IANGVs) is devoted to support the NGV's industry in every aspect and issue requiring action necessary to reach this target (IANGV, 2010). At the end of 2011, Nigeria could only boast of 345 NGV's and about 6 refueling stations (NGV Global, 2012) despite the huge potential with Nigeria having over 11 million vehicular population. This goes to show that there is great possibility to expand CNG use as a transportation fuel as Nigeria's gas pipeline distribution network expands, providing fiscal incentives to encourage road users to switch from liquid fuels to natural gas and the refueling infrastructure necessary is funded and built.

2.9.17 Domestic Gas Demand

The Nigerian government has commenced a revolution in the power sector, which has stimulated several new gas-to-power projects to progress under the National Integrated Power Project (NIPP) and Independent Power Plants (IPP) initiatives. Nigeria finalized a major part of the privatization process of Power Holding Company of Nigeria (PHCN) in September 2013, dividing the incumbent, and now defunct, monopoly into six generation and 11 distribution companies, all sold separately, for around $2.5 billion which they took control of in November 2013. The power sector is the single principal consumer of natural gas in the domestic market. It is estimated that about 80% of natural gas utilized in Nigeria is consumed annually by PHCN and Independent Power Producers. The remaining 20% is used as fuel in the cement, fertilizer, rubber, manufacturing, aluminum and steel industries. It is projected that domestic gas demand will increase from less than 500 MMCFPD 1800 MMCFPD by 2010 and almost 4800 MMCFPD by the year 2020. The current domestic gas demand is estimated at around 1800 MMCFPD. This demand estimates includes almost 1400 MMCFPD for power generation while the remainder is concentrated in a small number of other sectors by a few consumers. The limited natural gas utilization in Nigeria is due to her low level of industrialization coupled with the current importation of liquid distillate fuel to sustain the high demand for liquid fuels.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

This present work was carried out to investigate the serious and current global sensitive issue of BC emission in the light of gas flaring in the Niger Delta region of Nigeria. This region consists of nine states out of 51 states that make up the country and it is in the bottom south of the country as shown in Figure 2.2. It remains the singular area for oil and gas production in Nigeria, which has contributes over 95% revenue to Nigeria's Gross Domestic Product (GDP), 95% of external reserve and 90% of the country's National Annual Budgets (Effiong and Etowa 2012). This region is the largest wetland in the country and the third largest wetland in the world, and it is known for its unique bio-diversity (Tamari et al., 2012).

3.2 Data Collection and Data Processing

The data utilized in this study were sourced from published articles and bulletins released on the website of NNPC for information on gas produced and flared in Nigeria. The data covered a period of 49 years (1965 - 2013). Although NNPC gave the volumes of the gas produced and flared for this period in thousand cubic feet but we have converted them to million cubic metres, so that it can be in international standard unit. These data were divided into five decades (1965-1974, 1975-1984, 1985-1994, 1995-2004, and 2005-2013) for detailed and in-depth understanding of the subject. Microsoft Excel (Window 8.1) was employed as the statistical tool to calculate and analyze the data. Also, the correlation between the volumes of gas produced and the volumes of gas flared for the entire 49 years, and each decade were calculated.

3.3 Black Carbon Estimation

The BC emitted through gas flaring undertakings in the Niger Delta area of Nigeria was estimated for the period under consideration using Equation (1). Emission factors of 0.51 kg of BC/10^3 m^3 and 2.5632 kg of BC/10^3 m^3 for gas flaring processes as reported in literature were utilized (McEwen and Johnson, 2012). In this present study, 0.51 kg of BC/10^3 m^3 was used as the baseline emission factor while

2.5632 kg of BC/10^3 m^3 was used as the upper bound emission factor.

$$\text{Black carbon (kg)} = \text{Emission factor (kg of BC}/10^3\,\text{m}^3) \times \text{Vol. of gas flared (m}^3) \quad (1)$$

$$1\ m^3 = 35.3147\ ft^3 \quad (2)$$

$$CO_2\ equivalent\ (tons) = BC\ emitted\ (tons) \times GWP\ of\ BC\ (900) \quad (3)$$

Conversions employed in this work are expressed in Equations 2 and 3. Total amounts of BC released into this region of the country for 49 years were estimated along the average yearly emissions. Also, the yearly and decade by decade BC emissions in the region for the entire period under study and the monthly emissions for year 2013 were reported. Furthermore, the cost implications comprising of the cost of gas flared at $4 per 1000 cubic feet and BC emissions in terms of carbon credit tax at $15 per metric tonne of CO_2 were estimated and reported for each of the decade and for the entire period in focus.

CHAPTER FOUR

4.0 INVENTORY OF BLACK CARBON EMISSIONS

Recently, BC has been reported as the second-ranked pollutant of the atmosphere behind CO_2, leading to serious global warming. It has remained a silent and relatively unknown climate forcer in recent time. With a global warming potential of 2200 for 20-year period and 900 for 100-year period (Bond et al., 2013). BC remains a significant contributor to global warming despite its shorter life span in the atmosphere compared to other contributors such as CO_2, methane and nitrous oxide. The size particle of BC which enables it penetrate easily into the respiratory system and its atmospheric air warming capabilities make it a threat to both the human being and the environment, respectively.

4.1 Estimation of Total Black Carbon Emissions

The volume of gas produced and flared in the Niger Delta region of Nigeria from 1965 to 2013 is presented in Tables 4.1 and 4.2. The data for the first 25 years are shown in Table 4.1 while the data for the remaining (24 years) are provided in Table 4.2. Generally, a gradual increase in the volume of gas produced was observed from 1965 to 2007, where maximum production of 84.71 BCM was recorded and a relative decrease in volume from 2007 to 2013 was also observed (Tables 4.1 and 4.2). A volume of 61.64 BCM was reported for the year 2013. The result of data analysis shows that the correlation coefficient between the volumes of gas produced and the volumes of gas flared for the 49-year period as presented in Table 4.1 and 2 is 0.56. This implies that there is a moderate disparity between the gas produced and that flared. In this present study, the BC emissions obtained using an emission factor of 0.51 kg of BC/10^3 m^3 were reported and discussed as the baseline emissions while the upper bound emissions were only reported. In all the Tables and Figures provided in this work, "BC1" and "BC2" represent the baseline and upper bound emissions of BC, respectively.

The total estimated amount of BC (baseline emissions) emitted into the atmosphere due to continuous gas flaring activities in the Niger Delta region of Nigeria for a period of 49 years was 4.56×10^5 tons (4.11×10^8 tons of CO_2 equivalent) (Table 4.1 and 4.2). This result corresponds to a yearly emission of 9315.46 tons (8.38×10^6 tons of CO_2 equivalent) for the region. From Tables 4.1 and

4.2, the total amount of BC2 (upper bound emissions) emitted into the environment for the duration of 49 years was estimated to be 2.29×10^6 tons. For the period of 49 years, the total volume of gas produced was 1.63 TCM (33.21 BCM yearly) and the total volume of gas flared accounting for the amount of BC (4.56×10^5 tons) released into this region was 895.01 BCM (18.27 BCM yearly) (Table 4.1 and 4.2). This value of gas flared represents 55.0% of the total volume of gas produced for the 49-year period.

Table 4.1: Estimation of black carbon emissions from gas flared (1965 – 1989)

Year	Gas Produced (million cubic metre)[a]	Gas Flared (million cubic metre)[a]	BC1 (tonnes)	BC2 (tonnes)
1965	2849.00	2733.00	1393.83	7002.766
1966	2908.00	2692.00	1372.92	6897.712
1967	2634.00	2532.00	1291.32	6487.744
1968	1462.00	1311.00	668.61	3359.175
1969	4126.00	4062.00	2071.62	10408.06
1970	8068.00	7957.00	4058.07	20388.22
1971	12996.00	12790.00	6522.90	32771.82
1972	17122.00	16848.00	8592.48	43169.63
1973	21882.00	21487.00	10958.37	55056.14
1974	27170.00	26776.00	13655.76	68608.14
1975	18656.00	18333.00	9349.83	46974.65
1976	21274.00	20617.00	10514.67	52826.94
1977	21815.00	20952.00	10685.52	53685.31
1978	20468.00	19440.00	9914.40	49811.11
1979	27450.00	26073.00	13297.23	66806.85
1980	24551.00	22214.00	11329.14	56918.93
1981	17113.00	13470.00	6869.70	34514.18
1982	15382.00	11940.00	6089.40	30593.86
1983	15192.00	11948.00	6093.48	30614.36
1984	16251.00	12813.00	6534.63	32830.75
1985	18569.00	13922.00	7100.22	35672.34
1986	18738.00	13917.00	7097.67	35659.53
1987	17170.00	12194.00	6218.94	31244.69
1988	20250.00	14740.00	7517.40	37768.30
1989	25129.00	18784.00	9579.84	48130.24

[a] NNPC (1997). Note: BC1 = Baseline emission and BC2 = Upper bound emission

Table 4.2: Estimation of black carbon emissions from gas flared (1990 – 2013)

Year	Gas Produced (million cubic metre)[a]	Gas Flared (million cubic metre)[a]	BC1 (tonnes)	BC2 (tonnes)
1990	28430.00	22410.00	11429.10	57421.14
1991	31460.00	24660.00	12576.60	63186.32
1992	32084.00	24575.00	12533.25	62968.52
1993	33680.00	25770.00	13142.70	66030.47
1994	33680.00	26910.00	13724.10	68951.49
1995	35100.00	26986.00	13762.86	69146.23
1996	35450.00	26590.00	13560.90	68131.56
1997	37150.00	24234.00	12359.34	62094.78
1998	37039.00	23632.00	12052.32	60552.27
1999	43636.00	22362.00	11404.62	57298.15
2000	42732.00	24255.00	12370.05	62148.59
2001	52453.00	26759.00	13647.09	68564.59
2002	48192.45	24835.58	12666.15	63636.21
2003	51766.03	23943.03	12210.95	61349.23
2004	58963.61	25090.91	12796.36	64290.44
2005	59284.97	23002.71	11731.38	58939.84
2006	82036.86	28584.39	14578.04	73241.78
2007	84707.34	27307.13	13926.64	69969.06
2008	80603.61	21811.00	11123.61	55886.33
2009	64882.86	17987.59	9173.67	46089.60
2010	67757.65	16468.18	8398.77	42196.42
2011	60720.35	12317.46	6281.90	31561.02
2012	64694.68	11278.23	5751.89	28898.21
2013	61642.07	12700.78	6477.39	32543.20

[a]NNPC (1997; 2009; 2010-2013). Note: BC1 and BC2 = Baseline and upper bound emissions

The value of 895.01 BCM (volumes of gas flared) represents colossal waste of resources in terms of money, foreign exchange, environmental pollution and degradation as currently witnessed in the Niger Delta region of Nigeria (Madueme, 2010). Resource wastage in financial terms for the gas flaring operations in this region for the period in view amounted to $132.57 billion. This cost includes $126.46 billion for the gas flared at $4/1000 cf ($0.141/cm) and $6.17 billion for the carbon credit tax of the BC emitted into the environment at $15 per ton of CO_2. This value translates to an average annual loss of $2.71 billion ($2.58 billion for gas flared and $125.7 million as carbon credit cost) to the country due to gas flaring in the region for 49 years. These costs are beside the irreparable and unquantifiable damage already done to the environment. Apart from the emission of BC to this region via gas flaring, CO_2 released through this same activity in the same region accounted for 13% of world CO_2 emission (Bassey, 2008).

4.2 Analysis of Black Carbon Emission

4.2.1 First Decade (1965-1974) of BC Emission

For this decade, the data obtained for the volume of gas produced and the volume of gas flared gave a correlation coefficient (r) of 0.99, which shows the strong positive linear relationship between the parameters as given in Table 4.1. The first decade of gas flaring in the Niger Delta of Nigeria involved the release of 5.06×10^4 tons (4.55×10^7 tons of CO_2 equivalent) of BC from the flaring of a total volume of 99.19 BCM of gas. This represents a yearly average of 5058.59 tons of BC and 9.92 BCM of gas flared, respectively. For this decade, a total of 2.54×10^5 tons of BC2 was released into the atmosphere (Table 4.1). Economic loss of releasing 4.55×10^7 tons of CO_2 equivalent of BC into the atmosphere in this region due to gas flaring was estimated to be \$14.70 billion, in which gas flared accounted for \$14.02 billion (at 0.141\$/cm) and BC emission amounting to \$682.5 million (at \$15 per ton of CO_2) as carbon credit tax.

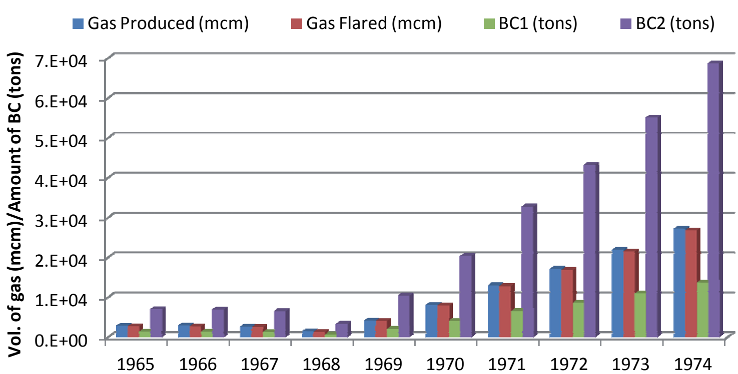

Figure 4.1. Black carbon emissions for the first decade of gas flaring

It can be seen in Figure 4.1 that the highest quantity of BC released into the atmosphere for the decade was in 1974. This amounts to 1.37×10^4 tons of BC from 26.78 BCM of gas flared. It was observed that an increase in the volume of gas flared corresponds to an increase in the amount of BC released into the environment (Figure 4.1). Also, the year 1968 recorded the least amount of BC emission for this decade which represents 668.61 tons of BC from 1311 MCM of gas flared. Only two years (1973 and 1974) in this decade exceeded 1.00×10^4 tons of BC (Figure 4.1). From Figure 4.1, little or no difference was observed between the volume of gas produced and the volume of gas flared for each year in this decade. This may be connected to the non-utilization of the gas during this time due to lack of technological know-how.

4.2.2 Second Decade (1975-1984) of BC Emission

The correlation coefficient (r) between the volume of gas produced and that flared for this decade (Table 4.1) was 0.98. This value indicates a strong relationship between the data garnered for this work. For the second decade of gas flaring activities in the Niger Delta region, 9.07×10^4 tons (8.16×10^7 tons of CO_2 equivalent) of BC was emitted from the flaring of 177.8 BCM of gas, which corresponds to an annual average of 9067.8 tons of BC and 17.78 BCM of gas flared. The financial implication of gas flared in the region for this decade was $26.34 billion. This value comprises of $25.12 billion of gas flared and $1.22 billion of BC emission associated with the flaring activities.

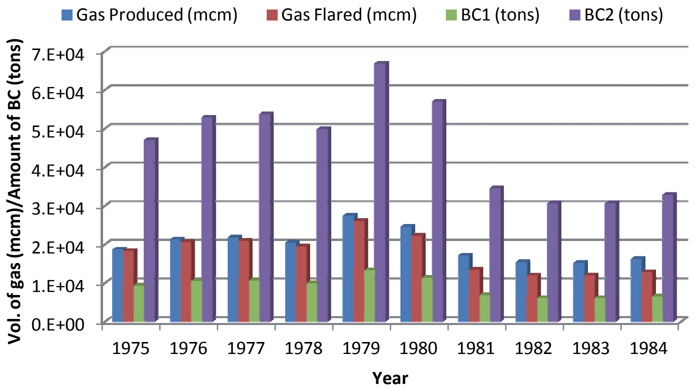

Figure 4.2. Black carbon emissions for the second decade of gas flaring

This decade accounted for an increase in the volume of gas flared by 78.61 BCM (44.21%) and an increase in the quantity of BC emitted by 4.01×10^4 tons (44.21%).

The maximum and minimum amount of BC released into the region during this period was 1.33×10^4 tons in 1979 and 6089.40 tons in 1982, from 26.07 BCM and 11.94 BCM of gas flared, respectively. Figure 4.2 reveals that four years (1976, 1.05×10^4 tons; 1977, 1.07×10^4 tons; 1979, 1.33×10^4 tons; 1980, 1.13×10^4 tons) in this decade emitted over 1.00×10^4 tons of BC. Also, the total quantity of BC2 emitted into the environment for this decade was 4.56×10^5 tons (Table 4.1). In addition, a slight difference was observed in the volume of gas produced and the volume of gas flared in this decade, which increases as the year runs (Figure 4.2). This may be due to slight increase in the use of the gas produced leading to slight reduction in the volume of gas flared.

4.2.3 Third Decade (1985-1994) of BC Emission

A correlation coefficient of 0.99 obtained from the data for the volume of gas produced and the volume of gas flared in this decade demonstrates a strong positive linear correlation between these two volumes as provided in Tables 4.1 and 4.2. The third decade of gas flaring activities in the Niger Delta region of Nigeria witnessed the burning of a total volume of 197.88 BCM of gas, which led to the release of 1.01×10^5 tons (9.08×10^7 tons of CO_2 equivalent) of BC into the atmosphere (Table 4.1 and 4.2). It was observed that the quantity of BC emitted into this region increased by 1.02×10^4 tons (10.15%) from the second decade to the third decade, representing an increase in the volume of gas flared from 177.8 BCM to 197.88 BCM. This value of BC corresponds to a yearly average of 1.01×10^4 tons from 19.79 BCM of gas flared.

In economic terms, flaring during this decade accounted for $29.32 billion which is the sum of the costs of gas flared put at $27.96 billion and carbon credit of BC released standing at $1.36 billion. For this decade, the highest quantity of BC (1.37×10^4 tons) was emitted in the year 1994 while the lowest amount of BC (6218.94 tons) was released in the year 1987 (Figure 4.3). The last five years (1990-1994) of this decade showed that over 1.00×10^4 tons of BC was released yearly into the atmosphere of this region (Figure 4.3). Total amount of BC2 emitted into the environment was estimated to be 5.07×10^5 (Tables 4.1 and 4.2). As seen in Figure 4.3, a moderate difference was observed in the volume of gas produced and the volume of gas flared in this decade of gas flaring. This is probably due to the increased utilization of the gas for oil exploration (reinjection into oil wells) and manufacture of fertilizer, cement, steel etc.

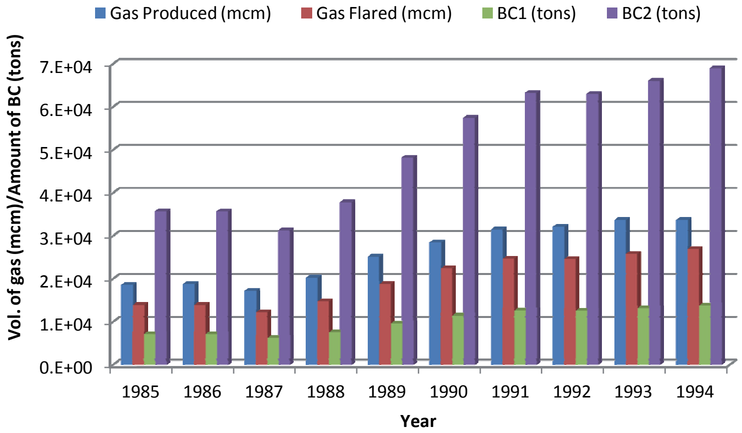

Figure 4.3. Black carbon emissions for the third decade of gas flaring

4.2.4 Fourth Decade (1995-2004) of BC Emission

For this decade, the data for the volume of gas produced and that flared has a correlation coefficient of -0.06, which indicates a weak relationship (nonlinear) between these parameters as can be observed in Table 4.2. Total quantity of BC released into the atmosphere in the region within this decade was 1.27×10^5 tons (1.14×10^8 tons of CO_2 equivalent) and this was emitted during the flaring of a total volume of 248.69 BCM of gas (Table 4.2). A yearly average of 1.27×10^4 tons of BC (from 24.87 BCM of gas flared) was released during this decade of gas flaring in the Niger Delta region.

Financial cost of both the gas flared and the BC emitted during this decade amounted to \$35.14 billion and \$1.71 billion, respectively, which sums up to \$36.85 billion. BC emissions into this region increased by 2.59×10^4 tons (20.43%) from a total of 1.01×10^5 tons (third decade) to 1.27×10^5 tons as a result of an increase in the volume of gas flared by 50.81 BCM. During this decade, 1.38×10^4 and 1.14×10^4 tons of BC were emitted as the maximum and minimum quantities of BC in the year 1995 and 1999, respectively (Figure 4.4). For this decade, the total amount of BC2 released into the immediate environment was 6.37×10^5 tons (Table 4.2). Due to an all time increase in the volume of gas flared in this decade resulting from a record high volume of gas produced, each year recorded the release of BC exceeding 1.00×10^4 tons (see Figure 4.4). A significant difference between the volume of gas produced and the volume of gas flared was observed in Figure 4.4, indicating that a handful of the gas produced was utilized. The utilization of gas in this decade involved the exportation of Nigeria Liquefied National Gas (NLNG) to Europe and United States of America, and the transportation of natural gas to West African countries through the West Africa Gas pipeline project amongst others.

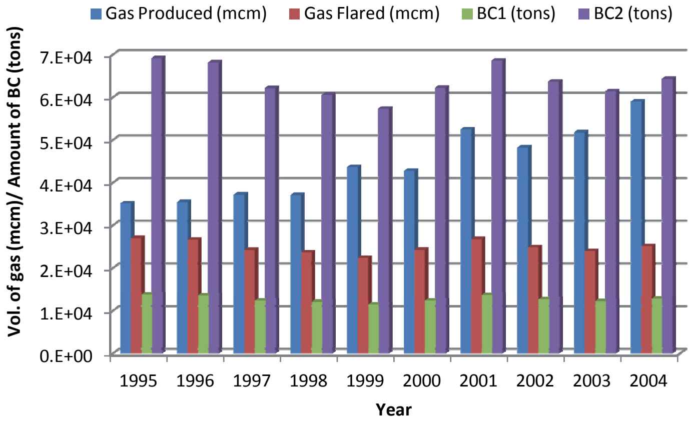

Figure 4.4: Black carbon emissions for the fourth decade of gas flaring

4.2.5 Fifth Decade (2005-2013) of BC Emission

For the volume of gas produced and the volume of gas flared collected for this decade, a correlation coefficient of 0.75 was obtained. This value shows a slight weakness in the relationship between the volumes as provided in Table 4.2. Although the data collected for this fifth and last decade were for nine years, the quantity of BC emitted into this region under this decade was also estimated. From the flaring of 171.58 BCM of gas, the total amount of BC released into the atmosphere for this decade was 8.74×10^4 tons (7.87×10^7 tons of CO_2 equivalent) (Table 4.2). These values translate to the flaring of 17.15 BCM of gas per year with the emission of a yearly average of 8744.33 tons of BC. In monetary terms, this decade recorded resource loss of $24.24 billion as a result of gas flared and $1.18 billion loss due to the quantity of BC released into the atmosphere of this region. Year 2006 recorded the release of the highest quantity of BC (146×10^4 tons) from 28.58 BCM of gas flared into the environment while the lowest amount of BC (5751.90 tons) from 11.28 BCM of gas flared was emitted in the year 2012 (Figure 4.5). From Table 4.2, the total estimated quantity of BC2 emitted through the flaring gas during this decade was 5.04×10^5. It is worth noting that this decade recorded a reduction of 3.94×10^4 tons (31.06%) in the quantity of BC released into the Niger Delta region when compared with the fourth decade. This is apparently due to increased utilization of the gas produced which is evident in the highly significant difference in the volume of gas produced and the volume of gas flared as observed in Figure 4.5. This decade experienced the foundation laying and commissioning of many gas-powered turbines for the generation of electricity in the country, hence, the increased use of gas.

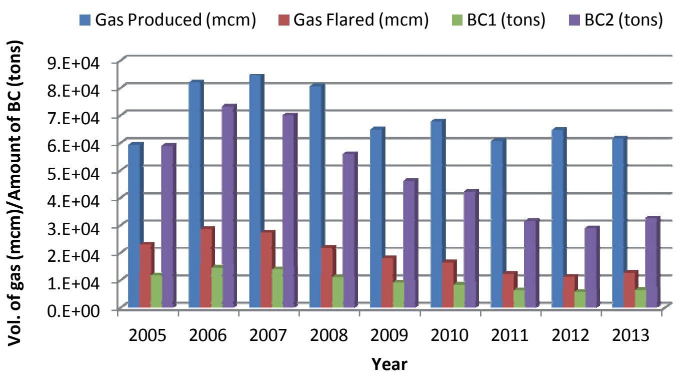

Figure 4.5. Black carbon emissions for the fifth decade of gas flaring

4.3 Gas Utilization Trend

The level of utilization of the gas produced in the Niger Delta region of Nigeria over the 49-year period was observed to determine to a reasonable extent the volume of gas flared. The highest volume of gas flared (28.58 BCM) was in the year 2006 while the lowest percent of gas flared was 17.43, which corresponds to 11.28 BCM in the year 2012. Down the years (from 1965 to 2013) and subject to the available data provided in Tables 4.1 and 4.2, 2008 recorded the year with the most gas utilization which stood at 58.79 BCM.

For 32 years (1965 to 1996), the percent of gas flared remained above 75 and in 12 years after (1997 to 2008), the value was below 30% (Tables 4.1 and 4.2). Increased utilization of the gas produced (Diugwu et al., 2013 and Odumugbo, 2010) has led to significant reduction in the volume of gas flared to 20.60% in 2013 (Table

4.2). As can be observed in Figure 4.6, it is obvious that there is no clear distinction between the lines representing the volume of gas produced and gas flared from 1965 to 1980 as also provided in Table 4.1. This illustrates that very high or almost all the gas produced was flared during this period. The gap between the volumes of gas produced and flared increased progressively and widened increasingly from 1999 to 2013 with the widest in the year 2008. This demonstrates the increased utilization of the gas produced in order to reduce the volume of gas flared in the country, which subsequently reduce BC emission in this region of the country. It is worth mentioning that the last seven years (2006 – 2013) witnessed significant reduction in the amount of gas flared in relation to considerable decrease in the volume of gas produced (Figure 4.6) which by extension results in momentous reduction in the amounts of BC emitted into the environment for this short period in view.

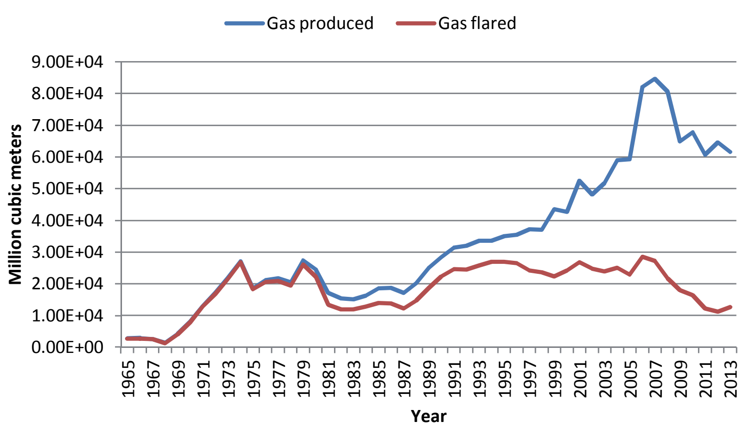

Figure 4.6: Gas utilization trend from 1965 to 2013

4.4 Health Effect of BC Emission

The breakdown of the monthly emission of BC from the gas flared in the Niger Delta region of Nigeria for the year 2013 is provided in Figure 4.7. For the year 2013, a total of 12.7 BCM ($1.35 billion) of gas flared led to the release of 6477.40 tons (5.83×10^6 tons equivalent CO_2) of BC into the atmosphere in the region with a monthly average of 539.78 tons (4.86×10^5 tons equivalent CO_2) of BC from the flaring of 1.06 BCM ($112.15 million) of gas. Consequently, a daily BC emission of

17.993 tons (1.62× 10^4 tons equivalent CO_2) was experienced from 35.28 mcm (\$3.74 Million) of gas flared. The month of April recorded the highest emission of BC with 808.21 tons (from 1.58 BCM of gas) released into the environment (Figure 4.7). With the Niger Delta region covering an area of 75000 km^2; yearly, monthly and daily discharge of BC to this region through gas flaring in the year 2013 was 86.37 kg/m^2, 7.09 kg/m^2 and 0.24 kg/m^2, respectively.

As this present work is bringing to the fore the quantity of BC particles released into the environment (Niger Delta area of Nigeria) via gas flaring as recently reported that BC is the second global warming agent behind CO_2, its health impact on the inhabitants of this area is imperative. The size (0.12 to 0.16 μm; mass median diameter) of the BC particle (Bond et al., 2013) which enables its penetration down into the lungs of human when exposed to air containing BC particles place a high risk on the well-being of inhabitants of gas flaring areas. As gas flaring stacks or gas flaring sites are mostly located close to already existing residential areas (villages and towns), the residents are exposed to the daily release of BC from gas flaring activities. Subject to the above, the inhabitants of the Niger Delta area, especially those close to gas flaring sites (where there is high concentration of BC particles) would have been suffering from an unknown cause as evidence supporting the link between particles and adverse respiratory and cardiovascular health continues to mount (Pope et al., 2009).

Gas flaring is found to have considerably affected the health of the residents of Otujeremu, Igbide, Olomoro and Ubeji, causing ailments like respiratory, eye, skin and intestinal diseases (Odjugo and Osemwenkhae, 2009). Recent study has suggested that individuals exposed to chronic-low level of oil and gas flared associated-environments had increased levels of renal dysfunction biomarkers and hence, are more predisposed to developing kidney diseases (Egwurugwu et al., 2013). In addition, it has been reported that soot particles (eg. BC) in the air are a contributing factor in respiratory diseases (Janssen et al., 2012). As fine particles (<3 μm) penetrate into the deep air passage and are the worst causes of lung damage, the larger particles (>3 μm) are trapped in the nose and the throat from which they are easily eliminated. However, the fine particles can stay intact for years in the inner most regions of the lungs and can cause severe breathing trouble by physical blockage and irritation of the lung capillaries. The deep penetration of these fine particles into the lungs have been linked to a wide range of serious health effects, including premature death, heart attacks, and strokes, as well as acute bronchitis and aggravated asthma among children (Janssen et al., 2012). In addition, short-term and long-term exposures to $PM_{2.5}$ (majorly containing BC) are associated with respiratory and cardiovascular diseases, as well as premature death (Janssen et al., 2012).

From the aforementioned, a nexus can be established between the reports of studies conducted on the impacts of gas flaring activities on human health and environment in the Niger Delta region of Nigeria and the outcome of studies carried out on the short and long-term exposure to PM2.5 containing BC. The common ground here in terms of human health is basically respiratory problem associated with the inhalation of BC particles contained in the emissions resulting from gas flaring in this region. Others have to do with the impacts of BC on soil fertility (leading to reduced drop yields), materials and buildings in this region, though investigations have been scarce in this regard.

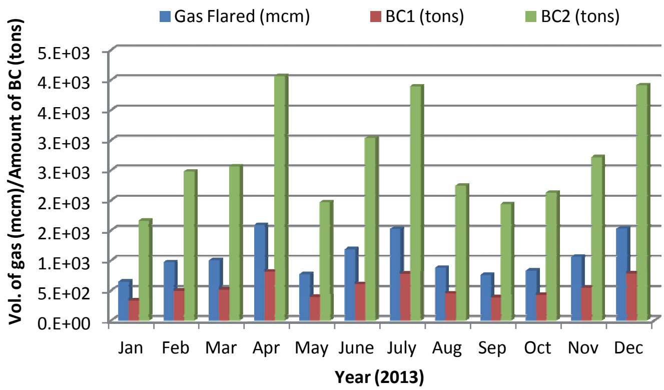

Figure 4.7. Black carbon emissions for the year 2013

4.5 Solutions to BC Emission

The concentrations of BC in the atmosphere disappear almost as soon as emissions cease, therefore, accelerated actions are needful for BC mitigation in order to slow regional warming which in turn slow global warming, and improve the health and air quality of the Niger Delta region. The desperate need for Nigeria to either completely stop gas flaring or reduce it to the bearest minimum is of both of global and domestic concern. Locally, the consequences of gas flaring are devastating and far-reaching while the global community's share of it is significant in its contribution to global warming and climate change. The following radical and pragmatic solutions are hereby suggested to be taken to considerably reduce flared gas and the release of hazardous gases, and particles associated with it into the atmosphere in this region of the country:

1. Financial fine seems lenient considering the extent of damage done to human health, socio-economic lives, and environment through the emissions released into the region, especially, BC particles from gas flaring. Stringent and implementable legal framework coupled with strong political will against gas flaring in the Niger Delta region should be put in place to curb this social menace pending a lasting solution.

2. Combustion efficiency of 98% is generally the norm in gas flaring activities but with the use of improved flare system, over 99% efficiency of combustion is attainable. This technology should be employed by the oil companies involved in gas flaring activities operating in this region.

3. The creation of international treaties to reduce BC emission would slow regional warming and would improve public health, especially in this region.

4. Gas flaring sites should be carefully located at a reasonable distance from already existing communities to avoid high degree of exposure of the people to BC particles and to reduce the concentration of BC inhaled by the residents of these communities.

5. Increased utilization of gas is a natural alternative to solve the problem of gas flaring and its associated environmental, and public health impacts in the region. A possible way beside the increasing use of the gas for power generation is its utilization as transportation fuel in the form of CNG and LNG in vehicles. The increasing population of the country (over 170 million) has triggered increased vehicular population (over 11 million) in which a substantial number of vehicles can be fuelled using CNG and LNG to reduce or eliminate to the barest minimum both the amounts of BC emitted via gas flaring and the volume of gas flared in the country. Consequently, the negative impacts of these gas flaring activities can be a thing of the past.

6. Increased awareness on the part of the Government on the health implications of inhaling emitted gases and particles from gas flaring in the region is very important. The residents of communities close to the flaring sites make use of the enormous heat from the gas burning process to dry cloths and farm produce, and to roast fish and corns. This act is not hygienic as these materials are poisoned by

carcinogenic substances such pyrene, toluene, dioxin, benzene, BC emitted from the gas flared.

7. Domestic market development for increased utilization of natural gas to naturally reduce gas flaring in the country.

8. Development of gas infrastructure to encourage gas utilization in all forms in the country.

9. Expansion of natural gas utilization as industrial material, industrial and domestic fuel, and increased electricity generation using gas turbines.

10. The utilization and monetization of natural gas to diversify the economy to increase foreign earnings.

11. Encouragement of indigenous entrepreneurs to be involved in the end-use devices for natural gas utilization.

12. Establishment of adequate fiscal/gas pricing policies as a means of encouraging investments opportunities in the gas market.

13. Strengthening existing legal framework to be at par with international standards.

14. The final drafting and passing into law of the PIB in Nigeria will significantly assist in the development of the gas sector of the economy.

CHAPTER FIVE

5.1 CONCLUSION

Gas flaring activities involved the release of harmful gases (CO_2, CO, SO_2 etc) and particulates (BC and $PM_{2.5}$) into the atmosphere leading to negative impacts on the environment and public health. This study has estimated the total amount of BC released into the Niger Delta area to be 4.56×10^5 tons via the flaring of a total volume of 895.01 BCM of gas worth $94.87 billion. It was observed that the quantity of BC emitted increased with an increase in the volume of gas flared. The amount of BC released into the environment increased progressively (5.06×10^4 to 1.27×10^5 tons) from the first decade of gas flaring to the fourth decade with a significant reduction (8.74×10^4 tons) in the amount of BC emitted in the fifth decade. Also, a strong link between the previous reports on the impact of gas flaring on public health and that reported by studies on $PM_{2.5}$ exposure of which BC is a major component has been established. In addition, possible solutions to reduce or totally eliminate BC emissions through gas flaring in this region have been proffered and these will consequently lower health cases associated with BC exposure.

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