



Air pollution in the Niger Delta region of Nigeria: Sources, health effects, and strategies for mitigation

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Abstract: Air pollution regularly releases unpleasant odors, particles, and harmful gases into the environment. Depending on the type of pollutant and its concentration, the effect could be deleterious to humans who live or work near the polluted area over time. This study examines the air quality status, sources of pollutants, health hazards, and possible mitigation strategies in the Niger Delta region of Nigeria. The study findings show that waste dumps, gas flaring, and food processing units are sources of ammonia, hydrogen sulfide, carbon monoxide, sulfur dioxide, nitrogen dioxide, volatile organic compounds, and particulates released into the atmosphere. The identified pollutant sometimes exceeds the allowable level recommended by the Federal Environmental Protection Agency of Nigeria and the World Health Organization, an indication of a possible adverse health effect. Some of the associated health concerns associated with air pollution include irritation of the nose, eyes, skin, and throat; coughing; shortness of breath; dizziness; and weakness. The pollutants can predispose the body to specific organ dysfunctions, particularly in those with compromised immune systems. The health effects depend on the type of pollutant gas, concentration, and duration of exposure. As a result, adequate mitigation measures, including installation of filters in exhausts of vehicles, emissions stacks in emissions chambers from industrial processes, efficient burners as cooking stoves, use of adequate personal protective equipment when in industrial areas, use of electricity, use of alternative energy sources, particularly biofuel and solar to reduce emissions. It will reduce the risks to public health from human activities polluting the air.

Keywords: Human activities, Impacts, Noxious gases, Particulates, Public and Environmental Health.

Introduction

The oil and natural gas output in the Niger Delta region of Nigeria is well known. Most of the resources that comprise Nigeria's primary source of foreign revenue are in the Niger Delta. Moreover, profits from petroleum and natural gas exploitation in Nigeria serve to support substantial projects throughout time. According to [Izah \(2016\)](#) and [Ohimain \(2015\)](#), petroleum accounts for around 90 percent of Nigeria's exports and 85 percent of its earnings. According to [Donwa et al. \(2015\)](#), oil and gas exports accounted for about 98% of total export income and 83% of federal government revenue in 2000. [Ede & Edokpa \(2015\)](#) report that the Niger Delta generates over 80 percent of the national budget.

Thus, petroleum exploitation considerably adds to Nigeria's gross domestic product (GDP). In addition,

the area has fertile ground suitable for plant growth and water bodies home to various fish and other aquatic species. Moreover, it has led to industrialization, fast population growth, urbanization, and other economic activities. These are possible sources of air pollutants having seasonal concentration changes.

The exploration of oil and gas, food production, and even the utilization of refined products, as well as improper management of wastes from manufacturing and consumer sectors, have several environmental impacts. For instance, during the combustion of fossil fuels used as transportation fuel, emissions into released the atmosphere lead to environmental degradation. Improper management of municipal waste from industrial and domestic sources could lead to odor pollution and the release of other noxious

gases, primarily from anaerobic degradation. Furthermore, the usual practice in the Niger Delta is open-air combustion of the wastes during the dry season, which releases noxious gases into the atmosphere. Odor pollution also occurs in cassava and oil palm processing mills in Nigeria. Specifically, an offensive odor often oozes from processing/de-watering in cassava processing mills (Izah et al., 2018a). Market activities giving rise to waste are another potential source of air pollution. Ben-Eledo *et al.* (2017a, b) and Seiyaboh & Izah (2017_a) reported the effects of market wastes on water quality. Many markets in the Niger Delta, especially in Bayelsa, Rivers, and Delta states, are close to the major expressways. During the dry season, while some garbage is removed by burning, others, especially food waste, are left to decay, emitting an offensive odor into the atmosphere.

Individuals residing with or close to these sources face negative environmental and health consequences. Incidentally, there is a dearth of empirical investigations into the public health implications of the seasonality of air pollutants in the core Niger Delta. Researching environmental factors that negatively affect health is required to support the selection of system actions about recognized direct and indirect ecological exposure sources. For example, suppose the Federal Ministry of Environment's response system will work in the future to protect the environment and public health. In that case, finding the links between sources, emissions, and exposure is essential. Studies in this area are common in the United States, Europe, and other Western nations. However, in Africa, particularly Nigeria, there is a dearth of information on the correlation between exposure to air pollutants and the development of related health conditions. This study is significant because there are more and more cases of respiratory problems, and people are worried about the possible role of environmental pollutants (especially during the dry season) in disease patterns in the Niger Delta area.

The setting of waste ablaze during the dry season results in the emission of noxious gases. Food processing, such as cassava and oil palm, is commonly done with biomass, especially in the rural areas of the Niger Delta. Over a prolonged period, there may be a health impact, especially on women. It is noticeable that surfaces around the area often get contaminated by dust. Waste dumps often occur on busy highways close to residential areas. Odor pollution is a common feature of dumpsites. All these activities release pollutants into the atmosphere, which may have

deleterious effects on the health of people in the region. So, this study aims to find out what kinds of air pollution there are in the Niger Delta, what types of health risks they might pose, and suggest possible mitigation measures.

This review will help identify, predict, and evaluate critical variables associated with air pollutants. The findings will form a springboard for awareness and sensitize people to the necessity for further research in this area of health. The results will also enable those in the health sector to propose preventive and adequate safety measures and sound waste management policies and implementation that will minimize the effects of pollutants on those residing nearby. Finally, the study will be a source of information that interested parties, like the government, can use as a guide when making policies or taking actions that would be good for public health.

An Overview of air quality in the Niger Delta

An air pollutant is any chemical, physical, or biological substance that alters the inherent properties of the atmosphere. Indoor and outdoor air pollution occur as well. Common causes of air pollution include motor vehicles, factories, building sites, homes with combustion appliances, and forest fires. One of the most significant contributors to air pollution and greenhouse gas emissions is fossil fuel combustion (WHO, 2022). Fossil fuel accounts for about 50% of global energy resources. Pollutants that are very dangerous to people's health include particulate matter, carbon monoxide, ozone, nitrogen dioxide, sulfur dioxide, hydrogen sulfide, ammonia, volatile organic compounds, and potentially toxic metals. Indoor and outdoor air pollution are known to cause respiratory and other ailments, significantly contributing to morbidity and mortality. The health effects associated with these pollutants depend on the type of pollutants, concentration, exposure duration, and immune condition of the person.

Air pollution is a global concern. According to WHO (2022), 99.9% of the world's population breathes air high in pollutants and exceeds WHO guidelines, a feature common in low- and middle-income countries. As a result, air quality has a direct impact on the planet's ecosystems and climate. In addition, about one-third of the world's population uses inefficient stoves that run on kerosene, biomass, or coal to cook, which results in dangerous indoor air pollution. A 2020 estimate shows that 3.2 million deaths per year are due to home air pollution, including over 237 000 deaths of children under the age of five (WHO, 2022).

Daily biomass usage for cooking and food production, such as cassava and oil palm, is prevalent in Nigeria's Niger Delta rural communities (Ohimain & Izah, 2013; Ohimain *et al.*, 2013_a; Richard, 2019, 2021). In addition, according to Olukoya (2015) and Omotosho *et al.* (2015), gas flaring and other industrial pollutants are common in the region. The frequent pollutants reported are particulate matter, carbon monoxide, ozone, nitrogen dioxide, sulfur dioxide, hydrogen sulfide, ammonia, volatile organic compounds, polycyclic aromatic hydrocarbons, and potentially hazardous metals from these activities. In certain areas of the region, it is also typical to encounter particles from building sites and unpaved roads. These air pollutants generally deteriorate visibility and harm the public health (Dowan *et al.*, 2015).

Particulates

Particulate refers to solid and colloidal microparticles produced during direct and open combustion. Particulates are one of the pollutants of most concern since they are hazardous. Particulates consist of both organic and inorganic substances. Fine particulate (PM_{2.5}) and coarse particulate (PM₁₀) are the two most prevalent kinds of particulate matter, with aerodynamic dimensions of 2.5 μm and 10 μm , respectively (Uzoekwe *et al.*, 2021; Izah *et al.*, 2021; Ngele & Onwu, 2015). In addition, there are PM₁, PM₄, PM₇, and PM₁₀ particles (Richard *et al.*, 2019_a). PM_{2.5} consists primarily of organic matter, elemental carbon, and trace elements and originates from natural and human-made sources. According to Tian *et al.* (2014), the origins of PM₁₀ include natural dust, industrial pollutants, and traffic fumes. Multiple reports of particles in the vicinity of the Niger Delta (Table 1). The concentrations of PM_{2.5}, PM₁₀, and total suspended particulate (TSP) depend on the prevalent activities. Frequently, the concentration of particles surpasses regulatory limitations. For example, Ibe *et al.* (2020) in Imo State; Ohimain *et al.* (2013_a) in Rivers State; Richard *et al.* (2019_a, 2021_a), and Richard (2021) in Rivers, Bayelsa, Delta, and Abia states report the presence of particulate matter. In Rivers State, Okoye *et al.* (2022), Opara *et al.* (2016), and Nwakire (2014) reported similarly. Ibe *et al.* (2020) and Okoye *et al.* (2022), Opara *et al.* (2016), Simbi-Wellington & Ideriah (2020) expressed unit as mg/m^3 . Nwakire (2014) expressed unit as ppm. * Federal Environmental Protection Agency Nigeria (1991).

Note: $1 \text{ mg}/\text{m}^3$ or $1 \text{ ppm} = 1000 \text{ }\mu\text{g}/\text{m}^3$

Noxious gases

Sulfur Dioxide and hydrogen sulfide

Sulfur dioxide and hydrogen sulfide are typical examples of sulfide oxides. Numerous human-made

activities, including some industrial processes and, to a lesser extent, the burning of hydrocarbons, generate hydrogen sulfide and sulfur dioxide. Additionally, the nature and physical state of the burned materials affect the concentration. As a hygroscopic substance, sulfur dioxide combines with moisture to produce sulphuric and sulfurous aerosol acids, eventually contributing to so-called acid rain. Meteorological indications and the number of resulting compounds discovered in the air determine the level of aerosol generation and their persistence in the atmosphere. Hydrogen sulfide and sulfur dioxide gas cause a broad spectrum of health problems. Different concentrations of hydrogen sulfide and sulfur dioxide occur in other regions in the Niger Delta (Table 2). Though FEPA has no limits for hydrogen sulfide, the concentrations reported in different studies (Table 2) are higher than the permissible level.

Adoki (2012) expressed units as $\mu\text{g}/\text{m}^3$. Ede *et al.* (2011) expressed units as g/sec (emission rate), Ibe *et al.* (2020) expressed units of VOC as mg/m^3 , and (NO₂ and SO₂); Onakpohor *et al.* (2020), Weli & Adekunle (2014) expressed the units as mg/m^3 , Akpan (2016) presented the values as carbonate (as CO₂), sulphate (SO_x), nitrate (NO₃), and CO; * and ** in the rows are dry and wet seasons respectively.

SO_x, NO_x, and CO: the limits were expressed as a daily average of 1 hourly value. Also, the data in the bracket are expressed as $\mu\text{g}/\text{m}^3$.

Carbon oxides

Carbon oxides are a significant pollutant group that causes widespread global harm. Carbon monoxide is a colorless and odorless poisonous gas released in the incomplete combustion of fossil fuels. Its emission during normal discharge is the primary cause of the greenhouse effect. In the Niger Delta, several industrial activities, particularly gas flaring from petrochemical activities, industries, and bush burning for agricultural processes, are typical. Many rely heavily on fuel wood as a primary energy source, with a concomitant release of carbon monoxide. Carbon monoxide monitoring is routine in the Niger Delta compared to carbon dioxide. Different concentrations of carbon monoxide exceeding the FEPA permissible limits occur in other regions in the Niger Delta, especially in artisanal crude oil refining areas (Onakpohor *et al.*, 2020), natural gas liquefying plants (Ede *et al.*, 2011), gas flaring (Akpan, 2016), built areas and forest swamps (Obisesan, 2019) (Table 2). Furthermore, a few studies have reported a high concentration of carbon dioxide in the Niger Delta region of Nigeria.

Ammonia

Ammonia is one of the nasty gases and the most abundant alkaline gases in the atmosphere. It

Table 1: Concentration of particulates in the Niger Delta region of Nigeria

Seasons	PM _{2.5}	PM ₁₀	TSP	Activities	Locations	References
	µg/m ³					
-	0.002-0.006	0.009 – 0.021	0.011 – 0.024	Gas Flaring	Awoba Flow Station, Rivers State	Simbi-Wellington & Ideriah, 2020
-	-	-	-	Natural gas liquefying plants	Bonny Island, River State	Ede <i>et al.</i> , 2011
Wet season	-	3.75-10.10	-	Rock mining/ quarrying and other commercial and industrial activities	Owerri, Orlu, Okigwe and Egbema, Imo State	Ibe <i>et al.</i> , 2020
Dry season	-	4.80-12.38	-			
-	-	-	24 – 71	Semi-mechanized oil palm processing	Elebele, Bayelsa State	Ohimain & Izah, 2013
-	-	-	17 – 7853	Small scale palm oil processing	Elele, Rivers State	Ohimain <i>et al.</i> , 2013a
-	19.85 – 27.95	55.66-80.59	74.29-140.44	Outdoor biomass combustion	Rivers, Bayelsa, Delta and Abia state	Richard <i>et al</i> 2019b
-	18.70 – 22.34	46.91-72.49	57.94 – 99.49	Small scale gari processing	Rivers , Bayelsa, Delta and Abia state	Richard 2021
-	26.44 – 40.10	81.63 – 41.51	110.20-270.91	Waste dump site	Rivers , Bayelsa, Delta and Abia state	Richard <i>et al</i> 2019a
Dry season	0.074 -0.0095	0.401-0.620	-	Oil communities	Ogba/Egbema/Ndoni Local Government Area in Rivers state	Okoye <i>et al.</i> , 2022
Wet season	0.020-0.071	0.007-0.039	-	Some locations with industrial activities	Owerri Okigwe Orlu Egbema in Imo State	Opara <i>et al.</i> , 2016
-	-	-	7.11	Gas flaring	Izombe, Imo State	Nwakire, 2014
-	25 (10)	50 (20)	*250	For PM _{2.5} and PM ₁₀ , is expressed as 24-hourly average (annual average)	WHO Limits	Richard <i>et al.</i> , 2021a

contributes significantly to total reactive nitrogen. Agriculture, which includes animal husbandry and ammonia-based fertilizers, is the largest source of its emissions. It can also be released via the decomposition of waste materials and produced by industrial processes and vehicular emissions (Behera *et al.*, 2013). Different ammonia concentrations occur in the Niger Delta region of Nigeria (Table 2). However, from a few studies (Ohimain *et al.*, 2013a) that reported the concentration in both leeward and windward directions, it is clear that human activities in the area contribute to ammonia gas in the atmosphere.

Volatil organic compounds

Most volatile organic compounds are organic chemicals with an elevated vapor pressure at room temperature. Many substances tend to sublime—a process when a solid material transforms into a gas—and enter the atmosphere at high vapor pressures. There are many volatile organic molecules, some of

which result from human activity. Some volatile organic molecules are advantageous to ecosystem biodiversity. Some microorganisms may also produce volatile organic chemicals, which are then helpful in reducing the number of diseases that affect plants (Richard *et al.*, 2019c). While some of the flammable organic substances produced by plants damage the environment and its biota, others are known to provide chemosensory and signaling aids for animals in the forest (Richard *et al.*, 2019c). VOCs include gasoline combustion, solvents, and industrial compounds like tetrachloroethene, benzene, methylene chloride, and perchloroethylene (Richard *et al.*, 2019c). A previous study by Ohimain *et al.* (2013a) showed that human activities contribute to volatile organic compounds in the atmosphere.

Sources of air pollutants in the Niger Delta

One of the main issues influencing the sustainability of the global ecosystem is environmental degradation.

Table 2: Concentration of pollutant gases from the atmosphere in the Niger Delta region of Nigeria

O ₃ , ppm	CO ₂ , ppm	CO, ppm	SO _x , ppm	NO _x , ppm	H ₂ S, ppm	NH ₃ , ppm	VOC	Activities	Location	References
-	-	0.00–0.708	0.002–0.072	0.008–0.078	-	0.00–6.204	1.169–27.74	Gas Flaring	Awoba Flow Station, Rivers State	Simbi-Wellington & Ideriah, 2020
-	-	10145.50–9843.25	99.50–438.75	138.00–475.25	98.75–374.75	-	-	Oven Heating/Crude Oil Boiling, Vapour Condensation, Refined Product, Collection	Rivers and Bayelsa States	Onakpohor et al., 2020
-	-	-	0.22–0.23	0–0.5 (for NO ₂) & 0.2–5.2 (for NO)	0.06–0.08	0.30–3.00	-	Landfill site	Eliozo/Eligbolo and Obigbo In Port Harcourt, River state	Ezekwe & Arokoyu, 2017
-	-	-	0.03–1.68	0.10–0.39	0.08–0.40	0.00–0.30	-	Landfill site	Rumuolumeni, Port Harcourt, River state	Weli & Adekunle, 2014
-	-	1.61	1.91	0.83	0.95	-	2.96	Gas flaring	Izombe, Imo State	Nwakire, 2014
-	-	-	32.9–910	29.2–347	-	-	-	industrial, human and natural activities	Oyigbo (Obigbo) and environs in Rivers State	Adoki, 2012
-	-	070	0.00	0.00–0.20	0.30–0.40	0.00–0.20	-	Semi-mechanized oil palm processing	Elebele, Bayelsa State	Ohimain & Izah, 2013
-	-	0.00–27.17	0.00–2.03	0.00–0.27	0.00–2.40	0.00–0.67	-	Small scale palm oil processing	Elele, Rivers State	Ohimain et al., 2013a
-	-	0.03–1.22	0.14–0.30	0.02–0.30	1.86–4.92	2.16–4.11	-	Waste dump site	Rivers, Bayelsa, Delta and Abia state	Richard et al., 2019b
-	37.91–12,978	00–40.7	0.00–0.5	0.3–11.49	-	-	-	Natural gas liquefying plants	Bonny Island, River State	Ede et al., 2011
*	-	(wet season) 18,75–46.25	0.32–0.81	0.33–0.76	0.00–0.02	-	014–1.23	Rock mining/quarrying and other commercial and industrial activities	Owerri, Orlu, Okigwe and Egbema, Imo State	Ibe et al., 2020
**_	-	(dry season) 31.00–52.00	0.19–0.92	0.33–0.76	0.00–0.20	-	0.30–2.76			
*	1762–11.05	41.06–90.86	6.00–9.00	39.76–53.03	-	-	6.77–11.05	Access the air pollutant due to flaring	Mkpanak Ibeno, in coastal area of Akwa-Ibom State	Akpan, 2016
**_	652.84–4006.19	28.65–43.68	2.59–8.75	13.17–23.30	-	-	5.773–8.54			
0.00–0.03	-	-	0.00–0.04	0.00–0.46	0.00–0.18	0.00–0.04	-	Some activities in the study cities include timber, rubber, palm oil, furniture, tamarind balm, footwear, flour mill and petroleum industries	Warri, Ughelli and Sapele in Delta State	Ifezue et al., 2021
-	-	-	-	-	-	-	1.62–12.07	Garri processing facility	Rivers, Bayelsa, Delta and Abia state	Richard, 2019
-	-	-	-	-	-	-	11.88–15.11	Waste dump site	Rivers, Bayelsa, Delta and Abia state	Richard et al., 2019c
-	-	0.00–1.58	0.00–0.06	0.00–0.08	-	-	-	Outdoor biomass combustion	Rivers, Bayelsa, Delta and Abia state	Richard et al. 2021b
118.5–125	-	635–856.9	26–27	-	3.56–4	-	-	Thick vegetation, built up area, fresh water swamp, farmland/sparse vegetation	Port Harcourt Metropolis, Rivers State	Obisesan, 2019
-	-	10 (11.4) – 20 (22.8)	0.01 (26)–0.1 (260)	0.04–0.00 (75.0–113.0)	-	-	-	-	FEPA limit	FEPA, 1991; Fagbeja et al., 2008; Ohimain et al., 2013a

Several anthropogenic and natural activities have exacerbated ecological problems. However, a sizable portion of the environmental worries seems to be caused by human-made activities.

Additionally, unnatural disasters emanate from natural disasters. Wealthy nations focus on the environment, just like the energy industry. However, despite numerous environmental authorities, the attention paid to ecological deterioration caused by anthropogenic activity is less in nations like Nigeria. The world has recently seen several natural calamities, such as earthquakes, desertification, flooding, patterns of land use changing, and climate change. Unsustainable farming practices, mining, dredging, the use of fossil fuels, and—most significantly—the search for crude oil and natural gas all contribute to the climate change currently witnessed in many parts of the world. This section focuses on the sources of air pollution in the Niger Delta region of Nigeria.

Oil and Gas Activities

Combustion of Fossil Fuel

Crude oil, a flammable liquid defined by its physical and chemical characteristics, such as heating value, color, density, and viscosity, is a complex mixture of hydrocarbons with various molecular weights (Demirel, 2012). Depending on the carbon concentration, the composition and structure of hydrocarbons vary from light to heavier products (Demirel, 2012). The numerous frequently utilized products from crude oil include gasoline (premium motor spirit), home kerosene, and automotive gas oil, among others. Like other petroleum products such as premium motor spirit and automotive gas oil, kerosene is immiscible in water but miscible in petroleum solvents (Opara *et al.*, 2013). The combustion of these petroleum-based products in the quest for energy releases pollutant gases such as particulate matter, volatile organic compounds, oxides of carbon, nitrogen, sulfur, hydrogen sulfide, and ammonia into the environment. In the Niger Delta, combustion is mainly via vehicular emissions and the use of generators and power plants.

Gas flaring

Nigeria is a large country that flares gas. Nigeria now opens the most natural gas. Removing natural gas paired with crude oil is known as gas flaring. By burning, the elimination is accomplished. Natural gas is primarily used to generate power and warmth in homes. However, due to weak governmental regulation and under-investment, natural gas is underutilized and released into the environment

through burning. Gas flaring is burning off gases produced by chemical plants, oil refineries, oil wells, rigs, landfills, gaseous waste, and other production sources at the tip of an elevated vertical chimney, according to Donwa *et al.* (2015). The authors blamed difficulties with storage and transportation for the gas wasted by these operations in Nigeria. In general, gas flaring is done chiefly on oil rigs and wells, and this industry dramatically contributes to the atmosphere's greenhouse gas emissions (Donwa *et al.*, 2015). Seiyaboh & Izah (2017,) reported that gas flaring affects air, water, and soil quality and food production from plants in the area. Several studies carried out in the Niger Delta about flare gases and varying concentrations of air pollutants are reported (Table 2). Instances of pollutant gases exceeding recommended limits abound in the literature (Simi-Wellington & Ideriah, 2020; Nwakire, 2014).

Activities of Artisanal Crude Oil Refining

Artisanal refineries exist in creeks and mangrove forests in the Niger Delta. During artisanal processes, hydrocarbons are discharged directly into the environment, causing pollution in the biophysical components of the environment, including the air environment (Figure 1) (Odubo & Onyige, 2019). In addition to the environmental impacts, artisanal crude oil refining has economic and social consequences. The artisanal petroleum refining technology in the Niger Delta contributes to air pollution by releasing pollutants at the various processing units (Oven Heating/Crude Oil Boiling, Vapour Condensation, Refined Product, Collection) exceeding the World Health Organization's recommended limits (Onakpohor *et al.*, 2020).

Non-oil and gas-related human activities

Activities in the industrial and production sector, including the manufacturing of cement, iron and steel, fertilizer, and food items like flour, sugar, maize, and rice, as well as those at cassava mills, breweries, wineries, and distilleries, may have an impact on air quality. Unlike oil and gas activities, agricultural processes, such as oil palm and cassava processing, produce uncontrolled emissions. Despite air pollution threatening human life, Nigeria's non-oil and gas businesses get little attention. Thus, it promotes multiple illnesses. Its severity depends on the concentration of the pollutant, the duration of exposure, and its chemical composition. Nearly all Nigerians are vulnerable to air pollution due to human activity.

The food processing industry



Artisanal crude oil refining activities along Escravos River

Mangrove Destruction in Artisanal refining camp

Burning of artisanal refineries bound crude oil loaded vessel

Figure 2: Environmental degradation caused by artisanal crude oil refineries in the Niger Delta region of Nigeria. Permission to reproduce the figures from the Publisher: Odubo TR, Onyige CD (2019). Environmental Degradation and Livelihood Vulnerabilities in the Niger Delta: Examining the Role of Artisanal Crude Oil Refining. *International Journal of Innovative Social Sciences & Humanities Research* 7(4):45-52.

Food processing discharges emissions into the environment. The emissions can exist as pollutant gases or particulates. For instance, during oil palm processing in the Niger Delta region of Nigeria, biomass is commonly used for boiling the palm fruits while motorized systems powered by fossil fuels enable digestion processes (Ohimain *et al.*, 2012a-c; Izah & Ohimain, 2013, 2015; Izah *et al.*, 2016; Ohimain *et al.*, 2013a, b; Ohimain *et al.*, 2013, 2014a-c, 2015). Ohimain *et al.* (2013a) and Ohimain & Izah (2013) report on the increase in oil palm processing by smallholder and semi-mechanized processors in the Niger Delta.

There are many places on the globe where cassava is grown, but Africa produces most of the world's cassava. Nigeria is the world's leading cassava producer, accounting for approximately 20% of total output (Izah & Ohimain, 2015; Izah *et al.*, 2017a-h, 2018a, b; Izah, 2018a, b). During gari production, emissions and pollutant gases are generated and released into the atmosphere (Richard, 2019, 2021). Some gaseous emissions, especially the offensive odor, make habitation in the processing area difficult. Emissions from cassava processing areas have been found in the

literature (Table 2). As cassava decomposes, isobutylene, an example of a volatile organic molecule, ammonia, and hydrogen sulfide are the main odor-producing substances. During the frying of gari, additional gases such as carbon monoxide, ammonia, hydrogen sulfide, and particulates are produced. Environmentalists and professionals in public health are concerned about these air quality indicators. Furthermore, there are many other food processing units in the Niger Delta, but the emission sources and the potential health risk have not been investigated.

Combustion of biomass during cooking

Cooking biomass is sometimes referred to as fuel wood. They are known as cookstoves in some places. In many developing nations, particularly in rural areas, these cook stoves are typically used for heating and preparing food. For example, most Nigerians living in rural areas rely primarily on wood fuel for cooking, likely due to the country's inadequate electrical supply. Nigeria is one of the countries that use the most fuel wood for cooking. Low-income levels and, to a lesser extent, low levels of education may be to blame for this because some people who use cookstoves spend a

sizable portion of their income on fuelwood or its equivalent.

Additionally, people working in the food industry, particularly those who roast fish, yams, and plantains, use charcoal (produced from fuelwood) for cooking. Many people, especially women and children, are now in the health risk group due to the widespread acceptance of wood biomass. Particulates, volatile organic compounds, carbon monoxide, and sulfur dioxide are some pollutants released during cooking with biomass. (Ohimain *et al.*, 2013_a; Ohimain & Izah, 2013). The moisture content of the biomass determines the kind and concentration of the emissions. Also, the biomass's heating or calorific energy content significantly affects how it is heated and the extent of pollution.

Waste dumpsite

Poor waste management is a significant source of worry, not only for the environment but also for public health. Wastes are managed poorly in many developing countries, including Nigeria. Typically, trash sorting is not done before it is burned outdoors or allowed to go through a biological process. In addition, it frequently produces an offensive odor that degrades the surrounding air quality. Population expansion, urbanization, and industrialization have increased the volume of waste generated in many households.

In the Niger Delta's expanding urban areas, where waste management systems are often weak, overflowing trash cans that cause traffic delays before removal are a common sight. Some people prefer to dispose off their garbage in water bodies (creeks) (Ben-Eledo *et al.*, 2017_{a, b}; Seiyaboh & Izah, 2017_{a, c}; Ogamba *et al.*, 2021, 2015_{a-c}), unapproved locations, such as unfinished buildings or constructions, undeveloped land, among others. It harms aesthetics, causes ecological concerns, and has a significant odor problem.

Home waste and municipal waste often end up in the exact location, resulting in a waste dump site. In the dry season, open-air combustion of dump sites is carried out (a primitive management technique), leading to a leak of emissions into the atmosphere. This procedure emits harmful gases that could have an impact on both the environment and human health. Previous studies have recorded the concentration of different pollutant gases from waste dumps in the Niger Delta region of Nigeria (Table 2).

Effect of season and factors that promote the dispersal of pollutant gases

Climate and weather elements, particularly precipitation, temperature, wind, and humidity, change dramatically with the seasons, which could bring about variations in the concentration and availability of pollutants in the atmosphere and, by extension, the occurrence and distribution of diseases related to the pollutants (Izah *et al.*, 2022). For example, Nigeria has two predominant seasons, viz., wet and dry. The wet season lasts 7/8 months, covering April to October/November. Similarly, the dry season begins in October or November and ends in about March of the following year.

Seasons impact significantly on the dispersion of noxious gases and other related parameters. For example, Anomohanran (2012) reported that thermal pollution occurred between 2.15 km for the wet and 2.06 km for the dry seasons. In addition, various meteorological indicators, including wind speed, wind direction, elevation (altitude), and closeness to the ocean, influence the dispersion of noxious gases. For example, the toxic gas disperses farther at high wind speeds than when the wind speed is low.

The concentration of the toxic gases depends on the distance between the gas flare and the wind direction. For example, a study on oil palm processing plants by Ohimain *et al.* (2013_a) and Ohimain & Izah (2013) revealed that concentration decreases as the distance from the source of emission increases. According to Ojeh (2012), as one gets farther away from a gas flaring station, the concentration of harmful gases decreases. At a gas flare site, the most hazardous area of a gas flaring location is typically located 50 to 350 meters away from the flare station (Ojeh, 2012). Following Ojeh (2012), the impacts of gas flares are felt up to 450 meters away from the source, depending on the volume of gas flared, wind speed, ambient temperature, discharge velocity, and stack height. Ozabor & Obisesan (2015) reported that gas pollution from gas flaring makes it harder for farmers to grow crops.

The health risk of air pollutants in the Niger Delta

Air pollution occurs as a result of industrial and home activities. Many forms of home air pollution (HAP) are not regulated, while industrial pollution is in many developing countries. HAP results from improperly burning solid fuels and kerosene for cooking and causes 3.2 million preventable deaths per year (Figure 2) (WHO, 2022). Particulate matter and other pollutants in indoor air pollution can irritate the lungs and airways, impair immunity, and reduce the blood's capacity to carry oxygen (WHO, 2022).

The effects of particulates are significant in children

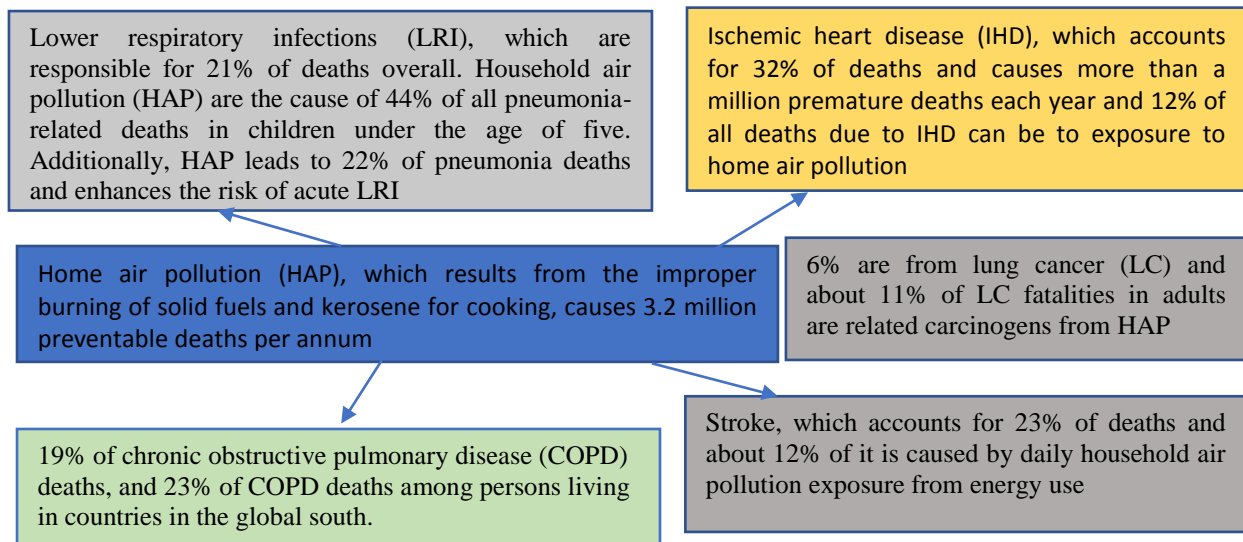


Figure 2: Distribution of Home air pollution prevalence in the World (Adapted from WHO, 2022).

Table 3: Effect of hydrocarbon exposure of gas flaring on human health

Compounds	Parameter/Diseases	Pathology/ health effects	References
Hydrocarbon	Hematological	Causes adverse effects on blood and blood-forming	Donwa et al. (2015); Ajugwo (2013)
Hydrocarbon combustion associated with gas flaring	Renal problem	Alteration in calcium, potassium, urea, creatinine, uric acid and inorganic phosphate content of blood	Egwurugwu et al. (2013b)
Hydrocarbon combustion associated with gas flaring	Cardiovascular (Hypertension)	Alteration in Systolic blood pressure, diastolic blood pressure and Mean arterial pressure	Egwurugwu & Nwafor (2013)
Hydrocarbon combustion associated with gas flaring	Cardiovascular (atherosclerosis, hypertension and ischaemic heart disease)	Alteration in high-density lipoprotein, triglycerides, and serum total cholesterol. Lipoproteins with low and very low densities	Egwurugwu et al. (2013a)

under five. As a result of HAP, 86 million healthy life years were lost in 2019, with women in developing countries bearing the brunt of this loss. According to WHO (2022), indoor air pollution causes low birth weight, cataracts, laryngeal and nasopharyngeal carcinoma, and tuberculosis.

Pollutant gases

Nitrogen dioxide

Combusting fossil fuels in automotive engines, industrial plants, power plants, and biomass combustion produce nitrogen oxide. Common gases that contribute to smog and the greenhouse impact include nitric oxide and nitrogen dioxide. The measurement of nitrogen dioxide levels in the Niger Delta area of Nigeria's atmosphere is a routine occurrence. The quantity of nitrogen dioxide released during combustion depends on the burnt substance's composition. Studies describe atmospheric nitrogen as nitrogen oxide (NO_x), nitrogen dioxide, and nitrous oxide simultaneously. In all these, nitrogen dioxide is the most popular method for assessing atmospheric nitrogen. Nitrogen dioxide is a significant indicator of air pollution since it correlates strongly with other air

and WHO (2006) occur in the scientific literature (Table 2).

In the Niger Delta area of Nigeria, burning hydrocarbon products releases pollutant gases that trimester of pregnancy (Gobo et al., 2009). Odor is a significant source of air pollution in the industrial sector and crowded public locations such as pollutants. Nitrogen dioxide occurs in numerous places in the Niger Delta region of Nigeria (Table 2). In addition, several occurrences of nitrogen oxide surpassing the legal limits defined by FEPA (1991) marketplaces, cassava and oil palm processing mills, and rubbish dumps (receptacles close to residential areas and along busy highways). In addition, skin and eye irritation, respiratory issues, and other ailments occur due to exposure to fumes from burning of hydrocarbon in these places.

Polluted air may have varying health impacts depending on its source and composition. For example, the literature is replete with information on the air pollution caused by burning hydrocarbon-rich compounds, such as gas flaring. However, there is a paucity of data on the physical and psychological

consequences of oil and gas pollution on the health of the Niger Delta's indigenous communities (Nriagu *et al.*, 2016). In addition to gastrointestinal problems, skin cancer, neurological, reproductive, and developmental problems, as well as respiratory and hematological disorders, are associated with hydrocarbon combustion (Donwa *et al.*, 2015). Multiple factors generally forms these symptoms, making it difficult to differentiate between illnesses caused by flaring and other associated kinds of pollution and those caused by different causes or sources of pollution. Studies have shown the effects of gas flaring and other polluting gases resulting from hydrocarbon burning in the region. For example, Egwurugwu *et al.* (2013a) examined the effects of chronic oil/gas flaring exposure on human lipids. They concluded that such exposure might increase the prevalence of cardiovascular diseases such as atherosclerosis, hypertension, and ischemic heart disease (Table 3).

In the scientific literature, sulfur dioxide, nitrogen oxide, carbon monoxide, ozone, and particles present the most significant health concerns. Carbon monoxide poisoning, for instance, restricts oxygen transport to tissues, resulting in symptoms such as decreased concentration, trouble performing tasks, and delayed reflexes. These symptoms include headaches, fatigue, weakness, muscle pain, cramps, nausea, vomiting, stomach upset, incoordination, chest discomfort, rapid pulse, difficulties or shallow breathing, and modifications in hearing, vision, and smell sensitivity (Shoshat, 2009). In addition, patients with chronic obstructive pulmonary disease (COPD), asthma, and chronic bronchitis are also more susceptible to carbon monoxide poisoning symptoms.

High nitrogen dioxide affects people. Common symptoms of elevated nitrogen dioxide exposure in people include flu, colds, and respiratory issues (Kippelen *et al.*, 2012; Griffiths, 2014). Sulfur dioxide significantly impacts health, causing breathing problems, eye irritation, lung problems, and circulatory system problems (Pollutant Release, Transfer Register and Undated Rizvi, 2015). Furthermore, high amounts of hydrogen sulfide can lead to death. Low doses irritate the eyes, nose, throat, and respiratory system, according to the Oshea Fact Sheet (2005), and extended exposures can result in aggravated eye irritation, headaches, exhaustion, irritability, sleeplessness, digestive problems, and weight loss. The authors say that even moderate doses can cause more severe irritation of the eyes and lungs,

headaches, nausea, vomiting, stumbling, and irritability.

Carbon dioxide is a major environmental pollutant that can cause many human health problems due to greenhouse gases. Carbon monoxide is released into the atmosphere by several human activities. For example, Ohimain *et al.* (2013_a) revealed that breathing in much carbon monoxide inhibits the blood's ability to deliver oxygen to vital organs like the heart and brain. Furthermore, the body's high quantities of carbon monoxide may produce carboxyhemoglobin (Abelsohn *et al.*, 2002; Ohimain *et al.*, 2013_a).

A high concentration of ammonia may irritate the skin, eyes, nose, throat, and lungs (Seiyaboh & Izah, 2019_b). It irritates the respiratory tract and, if not properly controlled, may lead to blockage of the respiratory system. Ammonia is absorbed mostly via the skin, ingestion, and inhalation (Seiyaboh & Izah, 2019). A high concentration of volatile organic molecules can irritate the eyes, nose, and throat (Ohimain *et al.*, 2013_a). Long-term exposure may also increase the chance of developing liver and kidney issues. Ozone may make breathing difficult and is associated with coughing and a painful or scratchy throat. It may worsen asthma, emphysema, and chronic bronchitis (USEPA, 2022).

PM2.5 particulate matter contains components like airborne asbestos particles (Efe, 2008). According to Miller (1994) and Botkin & Keller (1998), most industrial processes emit particulate matter into the atmosphere, including burning fossil fuels. However, particles smaller than 2.5 microns may enter the alveoli, the deepest section of the lung, resulting in higher death rates from various causes, such as lung cancer, heart disease, and respiratory sickness (Pope & Dockery, 1996). According to Ossai *et al.* (1999) and Efe (2005), greater exposure to particulate matter causes respiratory illnesses such as emphysema, pneumonia, bronchitis, asthma, and respiratory tuberculosis. According to related research, it may injure the eyes, teeth, and bones, increase people's susceptibility to illness and other stress-related environmental threats, and reduce the reproductive capacity of some animals (McAughy, 1997; Injuk *et al.*, 1995; Blake & Rowland, 1995).

Additionally, particulate particles may cause cardiorespiratory disorders and pulmonary edema.

The release of gases, such as carbon monoxide, sulfur dioxide, and nitrogen dioxide, has severe effects on people's health depending on the length of time and concentration, which can change depending on the season and the nature of the substance.

Conclusion and the way forward

Human activities are the major source of air pollution in the Niger Delta region of Nigeria. Pollution is a significant risk factor for respiratory, pulmonary, and cardiovascular diseases and birth abnormalities. In the Niger Delta, some of the common health concerns associated with air pollution include dizziness, irritation, shortness of breath, and neurobehavioral issues, an indication that over a prolonged period the pollutant may have an impact on the nervous system of the exposed individuals. In recent times, sustainable environmental management has become a front-burner issue in Nigeria. Depending on the consequences, various approaches exist that minimize pollutants and prevent the release of airborne particulates into the environment. The process requires waste segregation and treatment using an improved cooking and food processing system. Sensitization of the masses on the effects of man's activities on the physical environment and human health via awareness campaigns and even extensive classroom education will be useful in reducing air pollution. In addition, adequate mitigation measures include the use of filters in vehicle exhausts, stacks in industrial process emissions chambers, efficient burners as cooking stoves, the use of personal protective equipment when in industrial areas, the use of electricity, and the use of alternative energy sources, particularly biofuel and solar, among others. It will lower the risks to public health from the air pollutants resulting from human activities in the region.

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