RIVERS STATE UNIVERSITY
PORT HARCOURT

DECOUPLING SPATIAL DECISION SUPPORT MECHANISM IN ATMOSPHERIC CRISIS

AN INAUGURAL LECTURE

BY

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DEDICATION

To Lambert, Oma, Huoma, Emily, Mich and Nkanuye, my children

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PROTOCOL

Chairman of the Governing Council
The Vice-Chancellor and Chairman of this occasion
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Deans of Faculties and Directors of Institutes and Centres
Heads of Departments and Units
Distinguished Professors and Members of Senate
Academic, Administrative and Technical Staff
Graduate and Undergraduate Students
Ministers of God
Your Royal Majesties and Highnesses
All Invited Dignitaries,
Distinguished Ladies and Gentlemen.

1.0 ACADEMIC FOCUS AND INFLUENCES

My sojourn into academics that led to this inaugural lecture began in 1990 when I enrolled to study climatology at graduate level in the University of Port Harcourt, Choba, Port Harcourt. After registration the sole expert in the field in the programme, as at then, Dr. (Mrs) O. Salau requested us, the new intakes, to begin our dissertation by suggesting topics. Intuitively, I decided on "air pollution". Two years earlier, and after 1990 proved to be pivotal in nurturing the direction of development in environmental policies and practice in Nigeria for many reasons. The nexus of which was the dumping of toxic waste by an Italian ship in Koko Port, Bendel State (now, Delta State). Unknown to me my choice of project topic will have a resounding ramification, and shape my academic and personal life profoundly. The irony of it all was that this lady lecturer had a style to students' supervision. She pointed her students to the direction of the problem and left them to figure out the solution. Getting to the solution was a common preoccupation of the class I belonged. That approach was initially cumbersome, but it had a lasting reward, and those benefits are part of what I intend to showcase today. Those days I was underemployed, restless and willing to delve into uncharted territories. I saw opportunities in

her approach, for instance, the application of climatology to air pollution to the extent I was going to pursue it was not a regular field of specialisation but my supervisor let me get involved with it without reservation. She also supported my endeavour with instruments and fieldwork opportunities. I sensed a future and nudged on with her tacit encouragement. I cannot thank Dr (Mrs) O. Salau enough for the tutelage. She perceived hope where others saw academic deadlock; now see how far it all took me. The best way to validate yourself is how many international stage you have mounted. Prof (Mrs) O. B. Owei gave me a big boost in that wise. Thank you Madam because you see the good in everything, including me.

The area of knowledge I was engaged in those early days belong to pollution climatology. On the surface it strikes owe because lengthy calculations and theoretical appreciation were embedded in understanding atmospheric dynamics. The beauty of the rigorous process emerges from the numerical solutions that simplifies our understanding of the problem.

I embraced geography early. I am one of those who was introduced to the subject at all levels of my pre-university education. The subject evoked owe in me as I am able to imagine distant places, the people, landforms, weather and environment,

in one breathe. The love for geography easily made it a subject I could withstand, even in times of adversity. It is remarkable that being an undergraduate was a harsh experience for me and that being in a discipline I had a passion for made the process endurable. Throughout those times, my father, the sole breadwinner of the family was incapacitated with stroke. He was unconscious for 40 days and when he came to, he was permanently paralysed on the right side of his body. When I announced to him that I have been offered university admission, he advised that his physical state cannot support me through school, rather I should use his Peugeot 504 salon car as taxi. I however opted not to, and my earning a university degree may have inspired all my other siblings, eight in number, to pursue higher education.

I am not here today to mystify professorship, rather I will simplify the persona. I will break it down, because I believe profound things spring from the careful and systematic interpretation of the mundane. My presentation will be in three parts: I will anchor geography as a spatial science, introduce air pollution and my exploits as a climatologist in it, appraise the things I have achieved, and the modest contributions by me, then conclude with mapping future challenges.

1.1 Geography as a Decision Support Mechanism

Decision Support System (DSS) is defined by Stefan and Filip (2011) as a computerized information system that assists decision making activities in various domains such as business, finance, management, manufacturing or medicine. DSS gives its users access to a variety of data sources, modelling techniques, and stored domain knowledge via an easy to use graphical user interface (GUI). In the spatial sciences, that is, those discipline that investigate how things are structured on the earth surface, led by geography, DSS adds "space", especially terrestrial space as a variable. DSS would not be viable without computers and the internet and as a consequence it is now AI driven. Figure 1 by Stefan and Filip (2011) illustrates the main components of DSS.

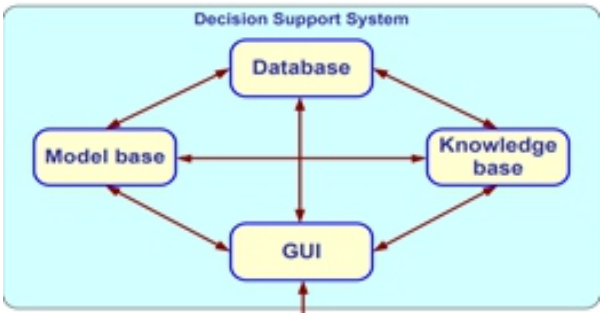


Figure 1: Main Components of Decision Support System (Source: Stefan & Filip, 2011)

Spatial Decision Support Systems (SDSS) combine spatial and non-spatial data, the analysis and visualization functions of Geographic Information Systems (GIS), and decision models in specific domains, to compute the characteristics of problem solutions, facilitate the evaluation of solution alternatives. By using two or more known points in history the models can be calibrated and then projections into the future can be made to analyse different spatial policy options. Using these techniques spatial planners can investigate the effects of different scenarios, and provide information to make informed decisions.

There are practical spatial problems that confront humanity. There are problems of places and location of things whose fortunes, favours and perils are because of where they are, what they are and how they are, of their survivability, of their productivity, of their soil, vegetation, water and air. It is the purpose of geography to fathom the dynamics of man and nature in a connected form that make sense of the earth as a home for mankind. Thus, geography strives to understand, or more correctly, explain the complex link between social and natural variables and man's role in the environment. It raises questions on where and how we live and what we do for survival (livelihoods), to the understanding of all. Geography finds meaning in how things on the earth surface are evolving. That is how there are a lot of geography in almost all other disciplines

and a lot other disciplines in geography. There are movements: one intellectual and the other academic that influenced my orientation:

* The scientific (or quantitative) revolution in geography.
* The ascendance of climate change as a focal environmental challenge of mankind

There are many ways life can be snuffed off the earth, such as a pandemic, large scale eruption of volcanoes, asteroid encounter, magnetic oscillation of the earth, anthropogenic climate change, nuclear war or the robots taking over the earth. The earth must not die from human induced effects! Ironically, the most immediate of these catastrophes according to the United Nations is climate change (DevelopmentAid, 2022; Hilton, 2022). In a document by African Heads of State and Government in the presence of global leaders and high-level representatives on 6 September 2023 in Nairobi, Kenya, the Africa Union (2023) declared that they: "Acknowledge that climate change is the single greatest challenge facing humanity and the single biggest threat to all life on Earth. It demands urgent and concerted action from all nations to lower emissions and reduce the concentration of greenhouse gases in the atmosphere".

An urban geographer does not design the city, but interprets the designs of planners and architects as to critique their

functionality, scrutinises it vertically and horizontally, provides a framework for doing so because the earth is the home of man for phenomena, such as pollution, rainfall or heatwave. This is in the mould of science, like geography, it does not create or recreate the world, but to explain it in formal terms. The purpose of geography is not to change the order of things on earth, but to bring insight that provide room to appreciate how human beings intervene on things that are on the earth surface, such as the air, water and crust. Also, on human activities, such as farming systems, tourism, settlements and population distribution. There will always be a place for geography to decipher natural and manmade systems on the earth, hypothesize and theorise with.

To achieve the complex task of how the earth surface is ordered, the geographer has to think in spatial terms, such as dimension (length, breadth, depth and distance), relationships (social, man and nature interactions), time (lags and magnitudes) that constitutes the milieu in which all activities including change and variations unfold. Time is the non-physical medium in which change takes place. Geography integrates these multi-dimensional view of processes on the earth surface.

Let us take the geographical view of a popular stream in Port Harcourt called Ntamogba, variously called: Diobu Creak or Onueza. The stream begins somewhere in Orazi, a completely

urbanised locale. Flows across Abacha Road, Ikoku and then Port Harcourt Aba Expressway. In all of its catchment, it picks up materials and pollutants, most times carelessly dumped or washed into it. The foul effluents at Ikoku, portions with bridges and reclamations along the river banks narrows the channel. There is intense silting immediately after the Expressway Bridge from where the stream is tidal. This process has led to a shallow draft, which limits flow velocity, at high tides and rainfall intensities around Federal Road Safety Commission. This situation was not so a few years ago. Here is how natural and manmade activities comingle and the resultant effect diminishes the quality of human environment. We can cite several places in Port Harcourt where flash floods, ponding of storm water, and effluent contaminations are issues of concern in Port Harcourt.

Ntamogba is dead due to depleted fisheries. Ntamogba is dead due to the massive silting. Ntamogbo is dead because its flood water is not tamed. It is dead because it is highly polluted. When we develop in physical and engineering terms, it does not yield desired results because it excludes environmental concerns as represented in geography. This unique perspective is how geography views the earth as the home of man. A similar effort by Ede and Asuebeogun (1995) was conducted in the study of the hydrogeomorphic considerations for siting an engineered

landfill in Etche, Rivers State.

1.2 Decoupling Geographers View of the Earth

To decouple means to deconstruct, disentangle and separate things into their components. Geographical issues are usually not apparent and could be amorphous to the uninitiated, therefore can only be understood through decoupling. Like many disciplines, geography traces its source from antiquities. Erastothenes (276-194) and Claudius Ptolemy (AD 100-70) of Alexandra already established geography as a discipline. Eratosthenes, fondly described as the father of geography defined geography as "writing about the world". In addition, he accurately established the circumference of the earth, a fact lost 1000 years later in the Middle Ages when the world was thought to be flat.

Greater impetus was given to Geography as an organised discipline starting with European voyages of discovery in the 14th to 17th century. The National Geographic Society was founded in January 13, 1888 by a group of elite scholars, explorers and scientists to further their interest in geography. They continue in their mission today ostensibly to "increase and diffuse geographic knowledge, while conserving the world's social and natural resources". (National Geographic, 2023)

Contemporary, scientific and modern geography pioneered in the 1950s and 60s is meant to understand that bankable solutions

to geographic problems depends on how applications to real world situations responsive to research questions are met. As a corollary, if you chase after easy questions, you end with trite and mediocre solutions, and if your questions are deep and penetrating you reap a bountiful harvest and insight to the problem. Taking advantage of relevant guiding geographical tools I lend myself to questions that tackle cogent and penetrating questions that bear rich benefits. For the rest of the lecture I will unfold how I applied this in my career.

I am a consummate geographer and I am nurtured in it. There are challenges of the earth, and of mankind which only geography can solve. I richly and repeatedly tapped into that thought process and I think the wonderful people who groomed me, most especially my teachers in University of Port Harcourt did a wonderful job.

What differentiates science from other fields of knowledge is methodology and how geography secures its place is through the application of scientific methodology. I am inclined towards positivism and I seek explanation for scientific questions as they pertain to geography (Ede, 2012). The unique approach to investigation yields numerical solution to every research I had interest in.

Today, many trends bordering on technological advancements is affecting orthodox geographical perceptions of space and

time. Revolutions in the organisation of human activities on air, water and land in the 20th century affected the way man organised space. For instance, it evolved the suburbia and the morphology of cities in its entirety. In the early 21st century there are emerging trends (mostly in their infancy) that are poised to change the geographer's conception of space and time. Chief among these trends are:

* Mobile telephony, and its applications, especially in social media
* Autonomous vehicles, robotics and automation in general
* Virtual and augmented reality

These technologically driven changes impact on space in the following ways:

* Whether we work, become mere consumers of things
* Where we work, from home, office or on the move.
* How we work; physically, mentally or virtually
* And, by extension how we learn; spend leisure time and travel.

The big questions for the geographer are:

* How will space be organised optimally to accommodate these new trends?
* How will space evolve in view of these new trends to benefit man and his environment?

* What will be the role of the geographer in the emerging space-time realities?

2.0 ATMOSPHERE IN CRISIS

In terms of human perception, there is a hierarchy of things with God at the top, followed by human, animals, and then nature. This false hierarchy subsists only among people and systems influenced by the Judeo-Christian monotheistic world outlook. In African religion, the forest, hill, the land (soil), water, sky, all of nature and animals can acquire sacred status. Kami are the divine spirits of Japan's native religion, Shinto. According to Japanese folktales, there are 8 Million kami, a number considered synonymous with eternity in Japanese traditions and culture (Superprof, 2021). It is this lack of reverence for nature that is at the root of environmental and atmospheric crises. In the order that places man in the middles between God and nature, who needs the other more? Man is distinctively unique in causing crisis with nature, sometimes, with God also. If there is conflict between man and God, or man and nature, watch carefully, man is the instigator. The crises in the atmosphere and the environment as a whole is clearly caused by man. As Shakespeare succinctly wrote in the Sonnet, "*Measure for Measure*:" Man, dressed in very brief authority, most ignorant of what he is most assured make the Angels weep. This is a

metaphor for the assault on the environment by man because Angels live in Heaven, therefore, depending on vocabulary and meaning, the heaven here could mean the sky or the atmosphere, which man has despoiled.

Why are human beings who must breathe every minute or die not holding the air sacred? How much desecration will nature endure before we realise ourselves and do what is right. We say increase carbon dioxide is causing greenhouse-effect and climate change, but nobody is saying anything about the real issues, have we ever considered for a moment why the petroleum ministerial position in Nigeria is held by the President? Without petroleum resources can Nigeria exist? Is it not petroleum, a thing from nature that holds Nigeria together as a nation? Crises becomes a vocabulary of note when human beings disagree with themselves, among themselves and disagree with their environment based on how nature is attributed. The crises in the atmosphere is manmade.

Precedent on the declarations of the United Nations and the Africa Union that climate change is the greatest threat to humanity (see DevelopmentAid, 2022; Africa Union, 2023), it is necessary to explain what crisis it is that is plaguing the atmosphere. The National Geographic (2019) says air pollution consists of chemicals or particles in the air that can harm the health of humans, animals, and plants. Pollutants in the air take

many forms: they can be gases, solid particles, or liquid droplets. Air pollution is most common in large cities where emissions from many different sources are concentrated. Air pollution causes damage to crops, animals, forests, and bodies of water; and Ede, Ubong and Osuagwu (2018) analysed it absorption by plants. Measurements of the impact on animals in Port Harcourt was conducted by Ede *et al.* (2007), Amakri *et al.* (2008), Amakiri, Monsi and Ede (2008), and Amakiri *et al.* (2009). The spatial impact of air pollution in the Niger Delta was documented in Ede and Edokpa (2015) and Ede (2020). Air pollution also contributes to the depletion of the ozone layer, which protects the Earth from the sun's ultra-violet rays. Another negative effect of air pollution is the formation of acid rain, which harm trees, soils, rivers, and wildlife (Ede, 1995). Some of the other environmental effects of air pollution are haze, eutrophication, and global climate change (Newair, 2019). Forouz (2016) and Przss-Ustżn (2016) estimates that in 2015, polluted air was responsible for 6.4 million deaths worldwide: 2.8 million from household air pollution and 4.2 million from ambient (outdoor) air pollution. The total disease burden, including morbidity, is estimated at 36 million (WHO, 2007). Data from 2016 shows that air pollution worldwide according to Wang (2016) caused:

* 19% of all cardiovascular deaths

* 24% of ischaemic heart disease deaths
* 21% of stroke deaths
* 23% of lung cancer deaths

Many human activities cause air pollution: large industrial complexes cause air pollution (Ede *et al.,* 2011; Edokpa & Ede, 2018); cottage industries like palm oil mills are potent air polluters (Ede *et al*., 2010); poultry farms can cause air pollution (Nwagwu *et al.,* 2010; Nwagwu *et al*., 2011) and even oil lanterns used in evening markets cause air pollution (Ujile & Ede, 2012). Ede and Oriji (2013) also identified private power generating sets, very common in Nigerian homes as important source of air pollutants. The main pollutants according to (WHO, 2019) are:

a) Particulate matter, a mix of solid and liquid droplets arising mainly from fuel combustion and road traffic;

b) Nitrogen dioxide from road traffic or indoor gas cookers;

c) Sulphur dioxide from burning fossil fuels; and

d) Ozone at ground level, caused by the reaction of sunlight with pollutants from vehicle emissions.

The pollutant that affects people the most is particulate matter

(often abbreviated to PM and used as a measure for air pollution). While particles with a diameter of 10 microns or less, (d PM_{10}) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 microns or less, (d $PM_{2.5}$). These particles are so small that 60 of them make up the width of a human hair. $PM_{2.5}$ can penetrate the lung barrier and enter the blood system. They can increase the risk of heart and respiratory diseases, as well as lung cancer. Ozone is a major factor in causing asthma (or making it worse), and nitrogen dioxide and sulphur dioxide can also cause asthma, bronchial symptoms, lung inflammation and reduced lung function. For $PM_{2.5}$, WHO guidelines say the maximum safe level is an annual average concentration of 10 $\underline{d}g/m^3$ or less. To encourage cities to reduce air pollution, even if they are unable to meet the ideal safe levels, WHO has set three interim targets for cities: these are:

a) 15 $\mu g/m^3$ (interim target 3);

b) 25 $\mu g/m^3$ (interim target 2);

c) 35 $\mu g/m^3$ (interim target 1).

Many cities are now exceeding the very upper level of interim target 1.

Particulate matter (PM) is the urban air pollutant that has most

consistently been shown to have the largest health effects in studies around the world. It is especially finer particulates, usually measured as PM_{10} and $PM_{2,5}$ that have the largest health effects. PM air pollution originating in the outdoor environment is estimated to contribute as much as 0.6 to 1.4 percent of the burden of disease in developing regions (WHO, 2002). This excludes air pollution caused by major forest fires (e.g. Indonesia in 1997), and serious accidents causing release of organic chemical substances (such as Bhopal, India in 1984), or radioactive pollution (such as Chernobyl in 1986). Fifteen countries account for 77 percent of global deaths. China and India alone account for 45 percent of global deaths

Air pollution has a disastrous effect on children. Worldwide, up to 14% of children aged 5 – 18 years have asthma relating to factors including air pollution. Every year, 543,000 younger than 5 years die from respiratory disease linked to air pollution. Air pollution is also linked to childhood cancers. Pregnant women are exposed to air pollution, it can affect foetal brain growth. Air pollution is also linked to cognitive impairment in both children and adults. Ede (1998) has shown that there is a link between pollution in general and poverty.

2.1 Indoor and Outdoor Air Quality Crises

Air pollution may be indoors or outdoors. Rates of exposure to

these two types of air pollution therefore vary greatly between rural and urban areas, and between developing regions, given variations in vehicles ownership and use, extent and location of industrial areas and power generation facilities, fuel availability, purchasing power, climate and topology, among others. Pollution outdoor is prevalent all over the world. Some outdoor work environments can be deleterious as seen in Ede and Pere (2013) where policemen who work as traffic wardens in Port Harcourt exhibited diminished lung functions than their counterparts who work inside buildings, such as the police stations.

Indoor Air Quality

The air pollution levels around and within buildings and structures is known as indoor air quality. Indoor air quality has a direct effect on the comfort and health of occupants, whether it is the home, office or other buildings. Some of the common pollutants of indoor air include radon, moulds, carbon monoxide, volatile organic compounds, asbestos fibres, carbon dioxide, ozone, and the burning of biomass. Proper ventilation, filtration, and the control of pollutant sources are some of the primary ways to improve indoor air quality (Newair, 2019). While there are many air pollutants, current assessment methods identify fine particulates ($PM_{2.5}$) as the pollutant with the largest health effects globally (Larsen *et al*., 2008)

About 1.2 million or 80 percent of global deaths from household solid fuel use (SFU) occur in 13 countries. Eight of these countries are in Sub-Saharan Africa and five are in Asia. India and China alone account for over 50 percent of global deaths from SFU. Average prevalence of household SFU is over 90 percent in these 13 countries, ranging from 67 percent in Nigeria, 70 percent in Pakistan, about 80-82 percent in China and India (Larsen *et al*., 2008). Epidemiologically, household SFU and urban air pollution differ in important respects. SFU is disproportionately affecting young children and adult females, while urban air pollution, according to current evidence and assessment methods, is predominantly affecting adults and especially the older population groups. In most countries, a majority of deaths from SFU is mortality from acute lower respiratory infections (ALRI) in children under-5 and chronic obstructive pulmonary disease (COPD) in adults, and to a lesser extent lung cancer. Indoor air pollution is also related to environmental tobacco smoke ('passive smoking') and exposure to chemicals and gases in indoor workplace. Particulates are caused directly by combustion of fossil fuels and biomass, industrial processes, forest fires, burning of agricultural residues and waste, construction activities, and dust from roads, but also arise naturally from marine and land based sources (e.g. dust from deserts). Particulates, or so called secondary

particulates, are also formed from gaseous emissions such as nitrogen oxides and sulphur dioxide (Larsen *et al*., 2008).

Indoor Microbial air pollution

The effect of building design and structure on the microclimate of indoor atmosphere in Port Harcourt metropolis was investigated in two seasons: wet and dry, and in the day and in the night by Ede *et al*. (2008). The study revealed that sites whose structure were poorly designed had elevated ambient microclimatic conditions, depending on whether the site is located on dry or flood prone area. Building location influenced temperature and relative humidity, which affect airborne microbes. In a follow up study, different microbiological media were used to determine the level of microbial populations and physiological types in sampling sites of indoor environment. Generally, more bacteria genera were isolated during the dry season than during the wet season, whereas the reverse was the case for fungi (Wemedo, Ede & Chuku, 2012). Earlier, a bioclimatic approach to building design was advocated in Ede *et al*. (2009). From Nwagwu *et al*. (2012) we now know that all structural dimensions for a building impact on indoor air quality irrespective of the activities involved.

Why Air Pollution Matter

Air pollution and global warming will ascend to the top causes of death in the next three decades, leading to a rise in premature

deaths dues to lung disease, heart attacks, and strokes (Harman, 2017). Air pollution is now the fourth-highest cause of death worldwide, trailing smoking, high blood pressure and diet. Almost every Nigerian is exposed to air pollution levels exceeding WHO guidelines and inflicting significant damage and cost (Ogundipe, 2018). It is the leading cause of non-communicable diseases such as respiratory, cardiovascular, cancer and even mental health. Air pollution is very important because UNEP (2019) estimates that:

* 92 per cent of people worldwide do not breathe clean air
* Air pollution costs the global economy $5 trillion every year in welfare costs
* Ground-level ozone pollution is expected to reduce staple crop yields by 26 per cent by 2030

2.2 Air Pollution Crises in Nigeria: A Tale of Two Cities

According to a 2016 WHO report, Onitsha, Kaduna, Aba, and Umuahia were among four of the 20 African cities with the worst air quality in the world (WHO, 2016). Air pollution is hardly listed among causes of death on death certificates in Nigeria, although the health conditions linked to air pollution exposure, such as lung cancer and emphysema, are often fatal. Nigeria has the highest maternal mortality in the world. It's the country with highest number of extremely poor people in the

world and now, it has the highest burden of fatalities from air pollution in Africa and 4th with 150 death per 100,000 people attributable to air pollution in 2016 (Ogundipe, 2019). Only Afghanistan with 406, Pakistan, 207, and India, 195 deaths per 100,000 people per country, exceed the Nigeria figure.

Onitsha, Nigeria

The city of Onitsha sets fire on its scattered heaps of refuse containing rotten organic wastes, mounded rubbish, castoff computers, and slaughterhouse scraps fuelled with old tires sliced into ribbons. This is how the city incinerate its waste and send out noxious plumes of smoke laden with dangerously high levels of particulates. The smallest and most dangerous form of particulate matter, that is, $PM_{2.5}$ records 1000 åg/m^3 or 40 times the World Health Organization's guideline for an average 24-hour level of exposure near the dump. In some places 283 åg/m^3 is registered only 50m away; yet nobody wears nose mask around in the city. This paints a picture of why WHO (2016) branded Onitsha, Nigeria, the dirtiest city in the world from the perspective of air quality in 2016. WHO measured air quality by examining the annual mean concentration of particulate matter in nearly 3,000 cities across the world with populations of at least 100,000. Onitsha averaged annual PM of 594 åg/m^3 – nearly 30 times greater than the WHO recommended annual level of 20 åg/m^3.

Port Harcourt, Nigeria

Port Harcourt metropolis with a population projection of about 2.6 million (Rivers State Government, 2008) is the largest city in the Niger Delta and South-South Nigeria. The city has been experiencing soot deposits (black carbon) in large quantities since 2016 and it still persists. Prior to 2016, assessment of air pollution in the city has been conducted by Ede (1999). The structural implications of the assessment on the proposed city expansion was also analysed in Ede (2008). Figure 2 is a schematic illustration of pollution transfer directions over the city of Port Harcourt. This implies that the heavy industrial zones of Eleme has little impact on the air quality of Port Harcourt.

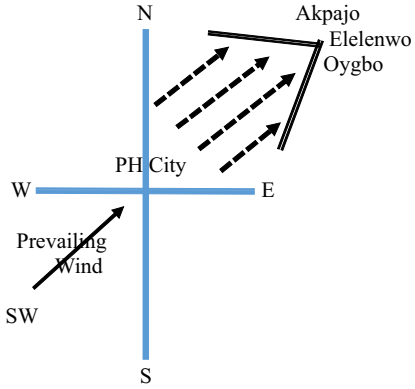


Figure 2: Dominant Pollutant Trajectory over Port Harcourt (Sources: Ede, 1998; 2008)

The advent of the soot on Port Harcourt was so severe that it led to mass hysteria. This is because the soot is visible as it accumulates on surfaces such as floors, household items like tables, apparels and artefacts. A swipe on objects placed in the open or poke of the nose stains the finger. People were emphatic that their daily dose of the soot is deleterious, hence the panic. Several studies on the soot have been undertaken by Ede and Edokpa (2017); the Rivers State Ministry of Environment (2017; 2019), SPDC (2017); Edokpa and Ede (2019). These studies are unanimous on the source of the soot being a consequence of crude oil combustion. The conclusion was based on the examination of spatial source of the soot, its physico-chemistry and informants account. Detailed laboratory analysis of its composition showed that the carbon chain values in the soot are predominantly in the longer segment (C>20) as those associated with crude oil and high pour fuel oil combustion. According to the Rivers State Ministry of Environment (2019), the soot in Port Harcourt and its environs is laden with abnormally high levels of air pollutants, such as particulates, heavy metals, polycyclic aromatic hydrocarbons, volatile organic compounds and criteria air pollutants. Some of the pollutants found in the soot, such as benzo(a)pyrene are known cancer makers. The report predicted an increase in cancer incidents in the region as a result of the indiscriminate utilization of crude oil in artisanal refining processes which has

become common throughout the Niger Delta.

According to McCollum *et al*. (nd) climate change mitigation can be an important entry point for achieving society's pollution- and health-related goal through an integrated, holistic approach to our energy challenges is needed. Nigerians erroneously argue that it is a petroleum rich country, yet billions are expended on energy import. If policies are put in place to also invest in alternative energy in the short, medium and long terms there will be an energy mix that decarbonises the economy. Extend carbon credit system to other known atmospheric pollutants such as sulphur oxide, nitrogen oxide, carbon monoxide, methane, and aerosols and annually reduce the total amount of pollutants permitted (Mission, 2015).

Economic growth lessens air pollution in many ways, importantly in fuel substitution and greater capacity to invest in cleaner energy. Lersen *et al.* (2008) has presented a linear regression analysis which shows that an increase of US $1,000 in GNI per capita is associated with a 20 percentage point decline in SFU prevalence. An important question is if countries will grow themselves out of the SFU and associated health effects in the next few decades without a need for large scale interventions. The argument is that prevalence of household SFU is strongly correlated with country income level, so economic growth will solve the problem. A counter-argument is however that COPD mortality could possibly increase with

aging populations even with a gradual decline in SFU.

2.3 Air Pollution and the Future of the Planet

Urban air pollution is set to become the biggest environmental cause of premature death in the coming decades, overtaking even such mass killers as poor sanitation and a lack of clean drinking water. Four interlinked areas will be impacted, namely: climate change, loss of biodiversity, water and the health impacts of pollution. For instance, species extinction arise from biodiversity loss, which in turn is caused by climate change and land use, while water is linked to health problems. A combined model of population statistics and health data to estimate premature deaths caused by pollutants such as ozone and fine particulate matter of less than 2.5μm estimates that in a business as usual scenario death from outdoor air pollution could rise from 3.3 million annually to 6.6 million by 2050 (Hadlington, 2015).

With the economic, ecologic and human toll air pollution takes, forecasting technology is an increasingly important endeavour. Similar to forecasting weather, there are models to predict levels of air pollution and air quality. There are many forecast models that require more complexity than weather forecast models. These models are mathematical simulations of how airborne pollutants disperse in the air (Air Quality Life, 2019). Air pollution forecasting is a worthwhile investment on multiple levels - individual, community, national and global. Accurate

forecasting helps people plan ahead, decreasing the effects on health and the costs associated.

If people are aware of variations in the quality of the air they breathe, the effect of pollutants on health as well as concentrations likely to cause adverse effects and actions to curtail pollution. Furthermore, there is a greater likelihood of motivating changes in both individual behaviour and public policy, as people want air quality information. Such awareness has the potential to create a cleaner environment and a healthier population. Governments also make use of early forecasting to establish procedures to reduce the severity of local pollution levels (Kelly, 2015; Dawes, 2013).

Warmer temperatures also increase natural emissions of volatile organic compounds (VOC). But climate change will not be all bad for air pollution. Higher temperatures also reduce particulate levels by preventing the condensation of "semi-volatile" compounds, like ammonium nitrate and some organics. More frequent summer rains in some areas would also tend to reduce ozone levels (Schwartz, 2007). Air pollution is closely linked to climate change - the main driver of climate change is fossil fuel combustion which is also a major contributor to air pollution - and efforts to mitigate one can improve the other. Intergovernmental Panel on Climate Change warned that coal-fired electricity must end by 2050 if we are to limit global warming rises to 1.5 ^{O}C. If not, we may see a major

climate crisis in just 20 years (WHO, 2019).

2.4 Geographic and Climatic Aspects of Air Pollution

Traditionally, the best means by which you measure atmospheric pollution concentrations is by exposing a probe to where you wish to determine the air quality. This method of evaluating air pollution is flawed because the person deploying the probe is constrained by many factors, a few of which are:

a) The atmosphere is fluid and in constant flux, so nothing is usually left for the researcher measuring after a pollution episode.

b) If the researcher realises that air is fluid and always in motion he may try to adjust his data gathering position in the downwind side; but wind trajectory can change in any instant,

c) There is no way to repeat a measurement because the air and the contaminants in it will be dispersed by wind, thus data so obtained cannot be validated through repeat measurement.

d) Measurement of air pollutants does not allow the researcher to isolate the present state of the air quality with future conditions or post-tests, because instrumental measurements are not endowed with such capabilities.

It is point (d) above which more than any other frustrates researchers into exploring alternative methods of assessing emissions. The application of models of atmospheric dispersion, interfaced pollution climatology use quantitative data to arrive at numerical solutions to air quality status of a

place or facility. By the early 1990s when I was trying to master what this was all about my examiners confessed that I was into a novel area. I pioneered emissions modelling among Nigeria's geographers. When I first conceived it over 30 years ago estimating air quality by whatsoever means was not even the concern of Nigerian geographers. I not only determined air quality in the traditional way using a myriad of probes (SPDC, 1999), I also did predictive assessment of the atmosphere for critical events and projects. Although the core of this lecture is on my works in air pollution modelling, I had profound knowledge of how energy is propagated from a determinate source as evidence of thermal radiation (see Ede & Johnson, 2001). Similarly, I modelled noise emission, such that patrons got advised on how emissions from existing and proposed facilities are propagated and attenuated (see Ede and Sonebare, 2009). These kind of applications were indispensable in the design, situation and location of an integrated oil and gas processing plant in Gbaran, Bayelsa and a helipad in Onne, Rivers State. In the case of the helipad, we modelled noise from an array of helicopter types and advised on which will have the least noise and vibration impact, preserve and protect the immediate vicinity.

Thermodynamic Properties of the Earth`s Atmosphere

Here, it is assumed that the substance of the atmosphere is a thermodynamic system. Arising from the equation of state, the

atmosphere has a definite mass, molecular composition and structural distribution. Within this context can be considered the transfers or transport of heat, momentum and mass. In general air volumes expand when temperature is rising and contract when temperature is falling. Air parcels also expand and cool during ascent due to fall in atmospheric pressure; conversely, it contracts and heats when descending. The stability of the atmosphere is a concept used to evaluate the temperature relationships in the atmosphere. The three basic possible stability states of the atmosphere are illustrated in Figure 3:

a) The stable,
b) The unstable and
c) The neutral or conditional states.

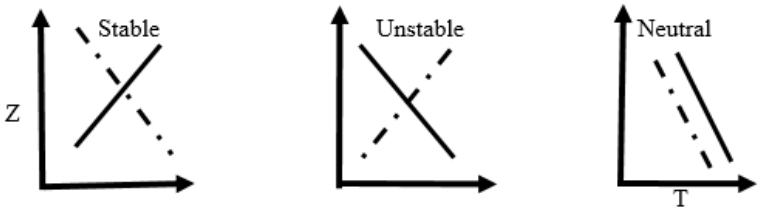


Figure 3: Atmospheric Stability Conditions

A stable atmosphere is when temperature lapse rate for a free atmosphere is lower than that of a parcel of air introduced into it. The unstable state is when the parcel's temperature lapse rate is lower than that of the atmosphere and neutral stability is when the temperature of a parcel is equal to that of the atmosphere (or

the environment)

The lapse rate of the atmosphere is defined by the equation:

$$\Gamma = -dT/dz \qquad (1)$$

Where is the lapse rate, T is the temperature and z is height. Temperature in the atmosphere is therefore a function of height except in the case of an inversion, hence the negative sign.

Lapse Rate

Air parcels expand with height because of falling pressure. The rate of decrease of pressure p with height z is given by:

$$dp = -ge dz \qquad (2)$$

Where g is the acceleration due to gravity, assuming that the perfect gas law applies to dry air, pressure p, can be expressed

$$p = eRT \qquad (3)$$

Where R is the gas constant for dry air and T is the temperature in Kelvin.

Combining the last two equations

$$dp/p = -g/RT.\ dz, \qquad (4)$$

Where T is the temperature of the surrounding air.

If T is the temperature of the ascending parcel of air and it is assumed that the ascent takes place without an exchange of heat between the parcel and its environment (an adiabatic process), then the first law of thermodynamics gives:

$$-dt/dz = Ag/Cp.\ T/\mp \qquad (5)$$

Under normal circumstances T is the very nearly equal to $\mp$ and Ag/Cp can approximate the rate of decrease of temperature with

height for any ascending parcel of dry air. This has a value of about 9.8 °C/km and is known as dry adiabatic lapse rate. If the air parcel is saturated or becomes saturated during ascent, the dry adiabatic lapse rate no longer applies since the parcel through the latent heat released as water vapour condenses into droplets will gain heat. Because the amount of water vapour condensed depends on the temperature and pressure of the air, the saturated adiabatic lapse rate will not be constant. At low temperature and pressure, the saturated adiabatic lapse is almost equal to the dry adiabatic lapse rate, but at high temperature and pressure it is considerably less. A typical value of the saturated adiabatic lapse rate (SALR) is for 20 °C and 1000mb about 4.4 °C/km. Dry adiabatic lapse rate (DALR) is 10 °C/km, normal adiabatic lapse rate (ELR) 6.4°C/km, and for super adiabatic and sub-adiabatic there are no fixed values.

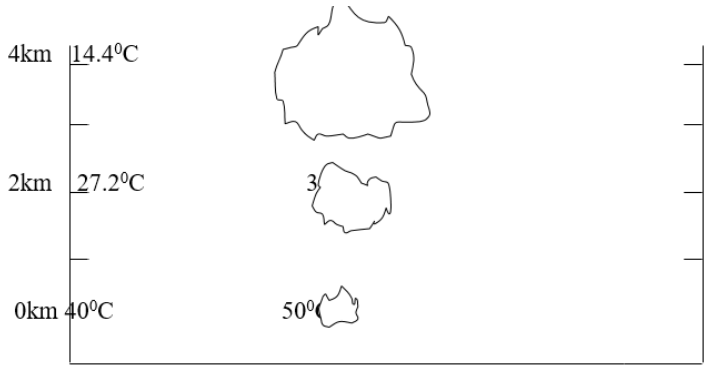


Figure 4: Temperature, Pressure and Density changes in a Parcel

Given that ELR is 6.4^0C and DALR is 10^0C, Figure 3 demonstrates in two dimensions the changes a parcel undergoes in the atmosphere as it rises aloft. A parcel leaving the surface at 50^0C will lose temperature at the rate of DALR. Notice that such parcels loses temperature at a faster rate than the environment (i.e. ELR < DALR) and will therefore become saturated in no time. Just before the height of 4km the parcel's temperature falls below that of the environment (i.e. ELR > DALR) and will begin to sink until it is at par with the environment (i.e. ELR = DALR).

2.5 Air Pollution Climatology

The circulation of air within the boundary layer is essential to the understanding of pollutant dispersal. In the troposphere, temperature decreases steadily from the ground in what is termed the normal environmental lapse rate (ELR); there is no fixed scale for this lapse rate. In the presence of moisture, the boundary layer and in fact the troposphere becomes a circulating mass in which when moisture evaporates or pollutant discharge of a known temperature is emitted, a predictable equilibrium or stability ensues. There are three possible stability situations in the atmosphere, namely; neutral or conditional stability, very unstable conditions and very stable conditions. The usefulness of the stability criteria is that it defines the nature of the atmospheric circulation and by implication the dispersal of plumes. Generally, the prevailing meteorological information is required in three general areas of air pollution as outlined in

Panofsky (1976):

a) In wind climatology for planning control measures.
b) In meteorological forecasts that can be used to vary discharges from day-to-day or within a 24- hour period. This is so because at different times, the atmosphere is able to disperse plumes much better than others.
c) In changes in the weather characteristics, which may improve or worsen air quality, essential to evaluating air pollution control.

The air pollution control regulations are usually expressed in terms of maximum permissible concentrations of pollutions as measured during fixed time intervals. Metrological analysis methods can be used to translate the regulatory standards into requirements for pollutant emission controls suitable to assure compliance with the standards. Regulatory strategy usually deals with two different situations.

a) The impact of individual sources of pollutions in the immediate vicinity of the source, and
b) The regional patterns of pollutants of pollutant concentration resulting from many sources (that is, the urban and regional control problem).

The relationship between source, transport and receptors for airborne pollutants is illustrated in Figure 5.

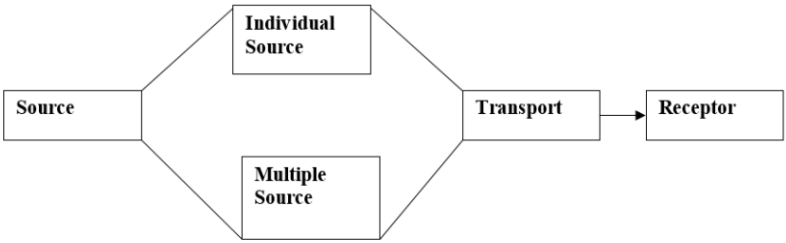


Figure 5: Pollution Source, Transport and Receptor Relationship

For individual source a micro scale analysis is frequently utilized. The analysis is frequently directed towards the specification of engineering controls required to assured compliance with the ambient standards in the neighbourhood of the facility. For the multiple source regions the micro scale details to terrain and meteorological parameters cannot usually be treated directly. Instead, model calculations of regional concentration patterns are usually based on "emission inventory" data for the region and on standard meteorological observations assume to be representative of the entire region the analysis is often directed toward evaluation of general regulatory strategy, such as changes in fuel specifications for the regions. Transportation control and the definition of industrial and non-industrial zones.

The analysis of an air pollution control problem can be developed from a three part schematic diagram. The effect of the pollutions upon receptor are generally related to the concentrations of pollutants in the atmosphere. However, the abatement of air pollution effects must be

accomplished indirectly, by reduction of emission rates from the various sources of pollutions. Air pollutant meteorology is concerned with the description of the transport of pollutants from sources of receptors, therefore meteorological, analysis. Figure 6 shows the structure of an emission model.

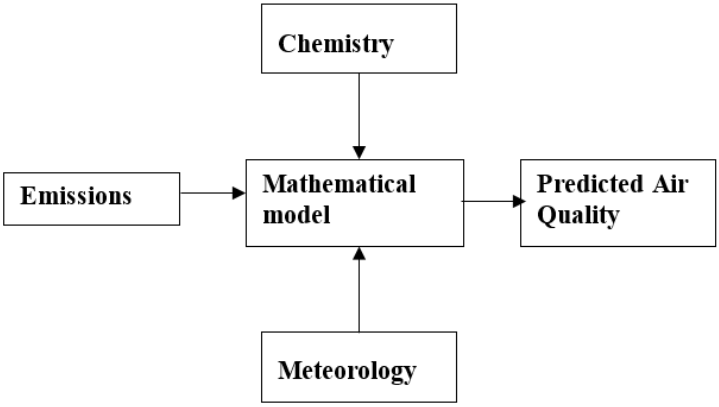


Figure 6: Structure of an Emissions Model

There are several versions of the Gaussian plume model. A classic equation is the Pasquill-Gifford model.

$$C(x,y.z) = \frac{Q}{2\pi u\sigma y\sigma z} X (exp\left(\frac{y}{n}\right) \exp\left[\frac{-y^2}{2\sigma_y^2}\right]\left\{\exp\frac{-(z-H)^2}{2\sigma_z^2} + \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right]\right\} \quad (6)$$

C = Concentration of the chemical in air [M/L^3]

Q = Rate of chemical emission [M/T]

U = Wind speed in x direction [L/T]

σ_y = Standard deviation in y direction [L]

σ_z = Standard deviation in z direction [L]

y = Distance along a horizontal axis perpendicular to the wind [L]

z = Distance along a vertical axis [L]

H = Effective stack height.

The integration of emission and weather parameters into equations with the aim of making air quality prediction is called emissions modelling. An empirical study by Ede (2000) using statistical methods procedures to compare equipment measurements and model outputs showed that there is no significant difference in the two methods. Modelling is however more versatile as it is able to recall past events and can as well make future prediction about air quality as was applied in Sonibare and Ede (2009). That was how the riddle of the black soot in Port Harcourt was solved.

3.0 THE BLACK SOOT RIDDLE

The term black soot is colloquial for black carbon. It is a form of particulate matter formed from inefficient combustion. Experimental determination of the impact of airborne pollutants on the environment is well known, and Ede *et al.* (2007) is an example of such study. Particulate matter refers to the combination of solid and liquid particles which are moist in most cases and suspended in the lower troposphere before deposition on the surface. Experts have examined the air

quality of the Niger Delta (Ede & Edokpa, 2017; Ede & Edokpa, 2015; Ede *et al.,* 2011; Tawari & Abowei, 2012; Weli & Kobah, 2014; Usang & Ikpeme, 2015). Ede (2020) noted that the Niger Delta region has poor air quality indices by the existence of the black carbon and that it is a source of apprehension to the inhabitants. The sudden appearance of black particulate matter (soot) in the atmosphere of Port Harcourt and its environs in the last quarter of 2016 led to panic and outcry both in conventional and social media. The dark particles were observed to be deposited on surfaces like cars, furniture, roof tops, floors, and vegetation; and it stained clothing, hands and feet upon contact. Public reaction to the sudden and daily doses of "*killer soot*" was hysterical and it remained the single most discussed topic in the city as at then. People's apprehension grew since experts affirmed that the soot contains carcinogenic substances which could lead to fatality both in the short and long terms. Residents began calling on the authorities to do something through writings, phone calls, and radio shows call-in. There were public demonstrations to express concerns. Also noticed was the wearing of nose mask by some residents and creation of awareness through inscription on shirts and face-caps. For health reasons, the persistence of the soot in the last six years has even brought some residents to reconsider their stay in the region.

Physically, and visibly, black carbon emissions descend

gravitationally on the surface due to the weight of the particulates while its compounds react in the air to form haze inclusive of sulphur dioxides and nitrogen oxides. This reaction mixes with atmospheric moisture to acidify precipitation. The effect of irritant particles in respiratory tract depends on the size of the particles, their solubility, penetration, deposition and clearance mechanism in in the surface, and tissue fluids of the lung parenchyma and the human respiratory tract. Fine particles may cause irritation, bronchospasm, pulmonary oedema and allergic alveolitis, while certain moulds of larger particle size cause obstructive lung disease. As the presence of finer particle size increases, the percentage of particles deposited in the upper part of respiratory tract decreases because particles are inhaled deeper. Typical particle constituents and sizes are illustrated in Figure 7.

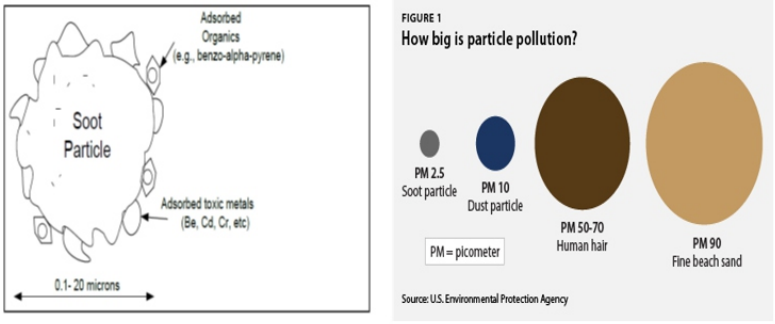


Figure 7: Nature and Sizes of Particulate Matter

Climate models have largely assumed that black carbon is the same as elementary carbon (Andreae & Gelencser, 2006). All anthropogenic sources of black carbon also emit hundreds of organic aerosols and gases. It has been shown that some of these organic substances also absorb sunlight in UV and visible wavelength and thus enhance the warming effects of black carbon (Andreae & Gelencser, 2006). The absorbing organic aerosols are popularly referred to as atmospheric brown carbon. This higher rate of organic carbon exhibited by biomass combustion encompasses supplementary means that arises from the oxygenated constituents in biomass.

3.1 Early Efforts to Unravel the Soot

Much of what is reported in this presentation obtains from the report on soot by the Government of Rivers State (Rivers State Ministry of Environment, 2019); Ede and Edokpa (2017) and Edokpa and Ede (2019). A number of questions were unanswered by 2016, after the advent of the soot, these are:

- Where is the soot coming from?
- Who is responsible for generating the soot and what is the intention?
- What is the specific fuel used in the combustion process?
- Why is it more prevalent at certain times?
- Which are the sensitive receptors?
- What mechanism transport, disperse, deposit or remove the soot?
- If we can pinpoint the source of the soot, can we also stop the soot?
- What social drivers interface with soot?

The Rivers State Ministry of Environment at the inception of the black soot received series of complaints from residents calling

for concerted action to what was described as a death threat. In December 2016, a preliminary investigation was conducted by the Ministry to determine the sources and spread of the airborne particulates (Rivers State Ministry of Environment, 2017). Early sample test reports indicated that the air particulates were from the incomplete combustions of hydrocarbons, burnings of seized crude oil by security agencies, asphalts plants, burnings of tyres at abattoirs to skin meet and also to obtain copper wire, gas flares from oil and gas installations, as well as illegal artisanal refineries littered just immediately around the city of Port Harcourt. Also, results from field sampling indicated a significant level of suspended particulate matters higher then WHO acceptable limit. This caused the Ministry declare an air pollution emergency in the metropolis. The push led to a series of stakeholders meetings with the oil multinationals, security agencies, NNPC Research and Development (R&D), Department of Petroleum Resources (DPR), Port Harcourt Refinery, traditional rulers, National Orientation Agency (NOA), abattoirs and tyre dealers, community representatives, amongst others. The meetings were able to generate significant information and stakeholders were urged to carry out their assigned functions diligently. The State Ministry of Environment disbanded firms whose facilities breed soot, engaged actively with the security agencies to curb setting recovered petroleum products ablaze, but instead deliver the crude to NNPC for proper handling and storage. The Ministry, also, advocated for the creation of modular refineries as promised by the Federal Government to replace the artisans of illegal refining.

Though the Rivers State Ministry of Environment had notified the Federal Government of Nigeria since the emergence of the soot in 2016, it was not until April, 2018 that the UNEP/WHO

Geneva delegation came to Port Harcourt on scoping mission in response to an invitation by the Federal Ministry of Health. The then Acting President, Vice-President Yemi Osibanjo in February 2017 had promised that the Federal Government will approve the licensing of modular refineries and train youths so as to stop them from engaging in illegal refining that pollutes the air. In the same vein, on the 26th of April 2018, the Federal Ministry of Environment organized a stakeholders meeting on soot at Port Harcourt NESREA office, where the Minister of State for Environment promised to set-up a comprehensive inter-ministerial investigation team and action procedure with timeline (Inter-Ministerial Committee on Black Soot).

The media played an important role in transmitting the researched knowledge of the soot by getting the public to be aware of it. There was a special report by the Daily Trust Newspaper on Saturday, July 14, 2018 with the caption "Port Harcourt Soot Darkens Skies, Endangers Lives" and The Guardian "Govts Dilly-Dallying While Toxic Smog Chokes Port Harcourt" (Sunday May, 27th 2018) as well as that of the Polity Magazine which captures it as "7-Million People Face Death in Rivers State" (the Polity Magazine, issue 01, 2018, pages 32-32 & 37-39). The international media was not left out, as the BBC, Voice of America (VOA) and Voice of Germany (DW) interviewed the former Hon. Commissioner of Environment, Rivers State on the subject on January 5th and 9th, 2018, respectively. There is also Wave FM Walk for Safety, Walk for Security hinged on soot.

In early quarters of 2018, the oil multinational companies formed the Port Harcourt Air Quality Working group (PAQWG) a combination of Shell, TOTAL, NLNG, AGIP, NNPC, former Special Adviser to the Governor on Pollution Control - Hon.

Nwuke Anucha, Chairman of the Rivers State House of Assembly Committee on Environment - Hon. Christian Ahiakwo and representatives from the security agencies, Federal Environmental regulatory agencies, the Academia and others. The group carried out daily air quality monitoring readings, and possible control measures which were never made public. There were speculations and suspicions that the multinational companies funded and led the group so as to exonerate their activities as possible sources of the air pollution. However, their interests were commendable and contributed to the efforts towards an understanding of the menace.

Though expected much earlier before 2018, the delegation of the United Nations Environmental Programme and World Health organization led by Pier Mudu who visited the State on a scoping mission and in the course paid a courtesy visit to the Governor of Rivers State, the State Commissioner of Environment, other relevant environmental regulatory agencies and selected tertiary institutions in the State. The team promised to make their findings available to the state, which never materialised. Also, the American Consulate office Nigeria, led by the Vice Consul, Naria Davy D. paid a visit to the State and discussions held between the State Ministry of Environment and the consulate on ways for partnership on the soot scourge.

3.2 Highlights of the Black Soot Study

a) Wind Climatology and Emissions Modelling

Wind speed determines the amount of initial dilution experienced from emissions. Although wind is a vector quantity and may be considered a primary variable in itself, it is more common to consider wind speed (the magnitude of the vector) and wind direction (the orientation of the vector), separately as variables.

i) Identification of Sensitive Receptors

Sensitive receptors include, but are not limited to, domestic environments, hospitals, schools, offices, market places, etc. These are areas where the occupants are more susceptible to the adverse effects of exposure to toxic chemicals and other pollutants. Extra care is taken when dealing with contaminants and pollutants in close proximity to areas recognized as sensitive receptors. Every human settlement, irrespective of size, embodies a sensitive receptor. Investigation into the black carbon showed a trajectory originating south and southwest of the Port Harcourt (Ede & Edokpa, 2017), and validated by instrumental ground level concentration analysis (SPDC, 2017). This is consistent with eye witness accounts as well as the results of other initial studies. According to Ede and Edokpa (2017), the area south and southwest of Port Harcourt has scattered settlements separated by vast mangrove swamps, therefore, the black carbon generating activity is not likely situated within an inhabited settlement but within the vast mangrove swamps south and southwest of Port Harcourt. The black carbon generating areas and the trajectories of emission transport shows that receptors downwind along the south and southwest centreline of Port Harcourt and for any other settlement in the Niger Delta constitute primary receptors and as a result were severely impacted. Wind rose (Figure 8) was used to determine the direction of the sensitive receptors.

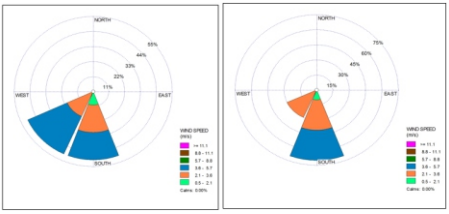


Figure 8: Typical Wind Plots along Nigeria's Coast

ii) Determination of Emission Sources and Propagation

The black carbon comprises of tiny particulate matters of proportions ranging from 2.5 to 10 microns. This particulates hover and are dispersed within the lower atmosphere under certain atmospheric conditions and when ambient concentrations are above acceptable limits, sensitive ground level receptors such as humans are exposed to severe health vulnerabilities which could cause fatality. To determine whether an air pollutant reaches sensitive receptors requires the application of air quality modelling techniques. The trajectory and dispersion pattern of the soot was evaluated using the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) developed by the United States National Oceanic and Atmospheric Administration (NOAA) in conjunction with Australia's Bureau of Meteorology. See typical output for Port Harcourt in Figure 9.

Model results indicated that the maximum and minimum spread across study area ranged from 0-0.44mg/m^3 i.e. 0-440µg/m^3 (Figures 8) for the duration assessed. The maximum concentration result achieved from the modelling analysis exceeds the annual acceptable limit for suspended particulate matter (i.e. 40-60µg/m^3) by over 200%.

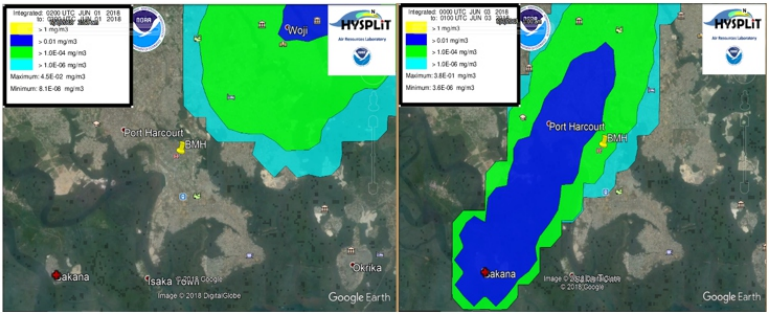


Figure 9: Typical Soot Profiles over the City of Port Harcourt

b) Soot Physico-chemistry

Laboratory analysis was used to determine if soot captured on filter papers are from refined products or crude oil. TPH was analysed in order to identify the mixture of chemicals contained in each of the samples since TPH can be divided into groups (fractions) of petroleum hydrocarbons that act alike. Common TPH constituents found in the SPM samples were diesel fuels, mineral oils, BTEX and PAHs.

i) Total Petroleum Hydrocarbon (TPH)

Crude oil contains aliphatic hydrocarbons, or hydrocarbons composed of nothing but hydrogen and carbon. The carbon atoms link together in chains of different lengths. The first four chains (C_1- C_4) are all gases whereas the chains up through C_5 - C_{18} are all liquids at room temperature, and the chains above C_{19} are all solids at room temperature. The chains in the C_5, C_6 and C_7 range are all very light, easily vaporized, clear liquids called naphtha and used as solvents. Dry cleaning fluids can be made from these liquids, as well as paint solvents and other quick-drying products. The chains from C_7 - through C_{11} are blended together and used for gasoline. All of these vaporise at temperatures below the boiling point of water. The next is kerosene in the C_{11} to C_{18} range, followed by diesel fuel and heavier fuel oils. The lubricating oils no longer vaporize in any way at normal temperatures. Chains above the C_{20} range from solids, starting with paraffin wax, then tar and finally asphaltic bitumen, which is used to make asphalt roads. All of these different substances come from crude oil. The only difference is the length of the carbon chains. As the chains or carbon number increases, the component becomes heavier. Figure 10 illustrates the range hydrocarbon fractions in soot sampled in Port Harcourt.

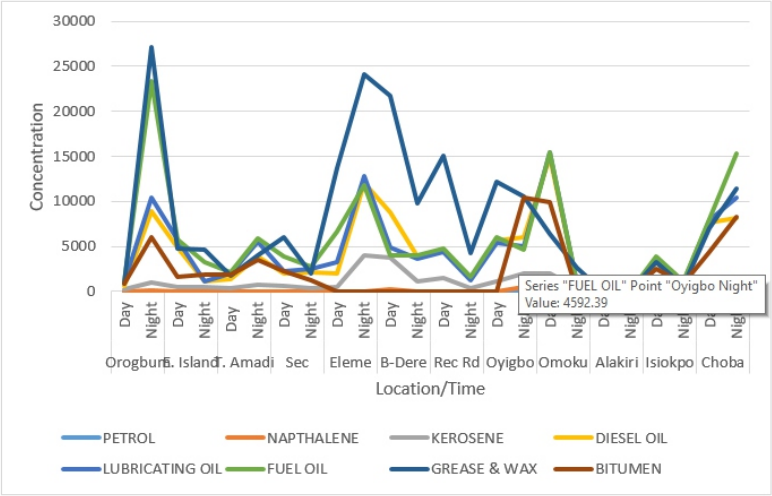


Figure 10: Carbon Chain Range for Sampled Soot

The results showed showed a low presence of C_1- C_9 and higher concentrations of C_{11} – >C_{35}. The results indicated that the particles on the filter paper from all the sampling stations were not from vehicular traffic emission or heavy duty engines but from a source which contains all the carbon chain range of crude oil. The concentration of the heavier chain carbons were higher than the lighter, thereby indicating that the suspended particle matter source was crude oil combustion. Incomplete combustion of biomass and conventional fossil fuels forms soot. The high concentration of higher carbon chain shows that the crude oil source of the particles was as a result of incomplete combustion. Conclusively, the presence of the various ranges of carbon number from Kerosene, Diesel oil, lubricating oil, fuel oil, grease and bitumnen indicates that the particles on the filter papers where from a source that contained all the components

which is crude oil.

ii) Polynuclear Aromatic Hydrocarbon (PAH)

Polycyclic aromatic hydrocarbons, also *poly aromatic hydrocarbons or poly nuclear aromatic hydrocarbons* are organic compounds that are mostly colourless, white, or pale yellow solids. They are a ubiquitous group of several hundred chemically related compounds, environmentally persistent with various structures and varied toxicity. They have toxic effects on organisms through various actions. Generally, PAHs enter the environment through various routes and are usually found as a mixture containing two or more of these compounds, e.g. soot. The mechanism of toxicity is considered to be interference with the function of cellular membranes as well as with enzyme systems which are associated with the membrane. It has been proven that PAHs can cause carcinogenic and mutagenic effects and are potent immune-suppressants. PAHs are formed both during biological processes and as products of incomplete combustion from either natural combustion sources (forest and brush fires) or man-made combustion sources. The percentage of distribution of the total PAH were between 66.67% and 33.33%. PAH concentrations in soot over Port Harcourt is presented in Figure 11.

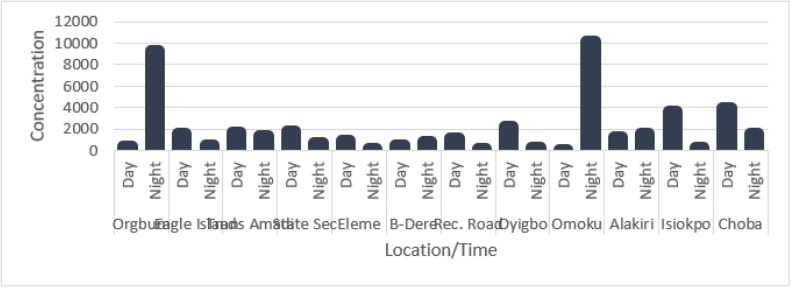


Figure 11: Typical PAH Concentration in Soot Samples

iii) Benzene, Toluene, Ethylbenzene & Xylene

Benzene, toluene, ethylbenzene, and xylene or BTEX is the term used to describe a group of chemicals related to benzene and are usually colourless, sweet-smelling liquids which evaporate easily. They mix well with organic solvents, but do not dissolve well in water (and may float on the surface before evaporating into the air). BTEX are part of the group of compounds known as volatile organic compounds (VOCs). The main sources of BTEX into the environment are petroleum and chemical industries and other combustion processes and are also released when natural materials are burned. They react with other air pollutants and are broken down, returned to the earth or involved in the formation of photochemical smog. As VOCs, BTEX is involved in the formation of ground level ozone which can damage crops and materials. BTEX is not however thought to have any environmental effects at a global level. The volatile behaviour of BTEX accounts for the 40-95 % losses of BTEX. The concentration of BTEX at all samples were <0.001 mg/m^3.

iv) Heavy Metals

Heavy metals are elements which occur naturally in the Earth's crust. They are therefore found naturally in soils and rocks with a subsequent range of natural background concentrations in soils, sediments, waters and organisms. Anthropogenic releases can give rise to higher concentrations of metals relative to the normal background values. Heavy metals are emitted into the environment from a variety of anthropogenic sources to supplement natural background geochemical sources. Combustion processes are the most important sources of atmospheric heavy metals, particularly, refining, power generation, smelting, incineration and internal combustion engine (Battarbee *et al*., 1988; Duce & Tindale, 2014; Galloway *et al.,* 1982; Hutton & Symon, 1986; Nriagu, 1989; Nriagu &

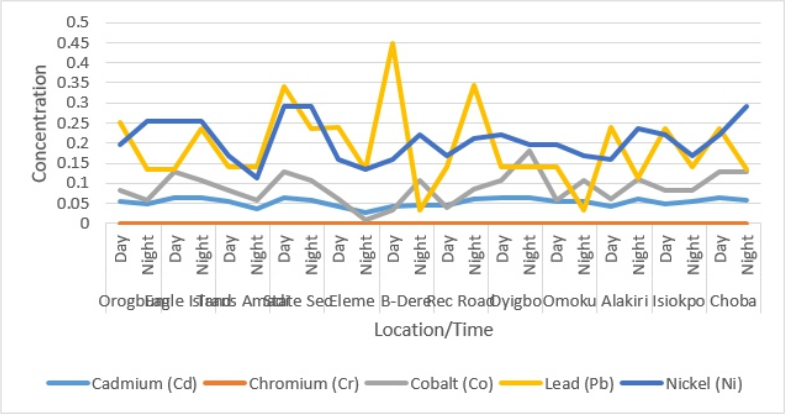


Figure 12: Heavy Metal Results of Soot Analysis

c) Health Effects of the Soot

The approach was to leverage existing interventions and availability of health services for all round health care delivery in data collection by triangulating the findings with the environmental data as it relates to the emergence of soot in 2016. Case-series with four-year trend analysis. All diagnosed cases of respiratory, cardiovascular, renal, dermatological related diseases and cancers between June 2014 and June 2018 were examined. All facilities were listed on the DHIS platform for State reporting were ranked in order of their out-patient volume according to their Local Government Areas. Non-functional facilities were rejected.

Respiratory diseases reviewed included respiratory tract infection (RTI), bronchial asthma, pulmonary fibrosis, pleural disease and sarcoidosis. However, respiratory tract infection (> 75%) and bronchial asthma (>15%) accounted for over 90% of all respiratory diagnosis. The trend of respiratory diseases (Figure 13) showed a steady increase in total number of all cases of respiratory diseases between 2014 and 2017. For bronchial

asthma there was a drop in cases in 2016 followed by a subsequent sharp increase in 2017 and 2018.

The trend for atopic dermatitis and all skin conditions and lesions showed that the lowest numbers occurred in 2016 followed by steady increases in 2017 and 2018 (Figure 14). There was no appreciable pattern or trend of note for hypertension which was the major cardiovascular disease reviewed (Figure 15). While the trend for reproductive health conditions such as miscarriages and still births steadily increased across the years with a marked increase in 2017 and 2018. Similar upward trend for reproductive and maternal health disorders were observed (Figure 16).

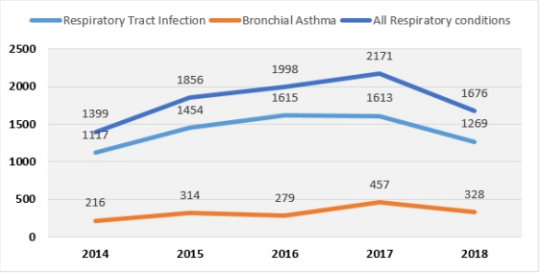


Figure 13: Trend of Respiratory Tract Infections (n=9493).

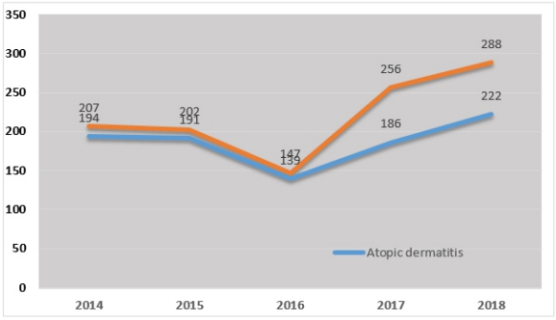


Figure 14: Trend of Skin Conditions in the Survey

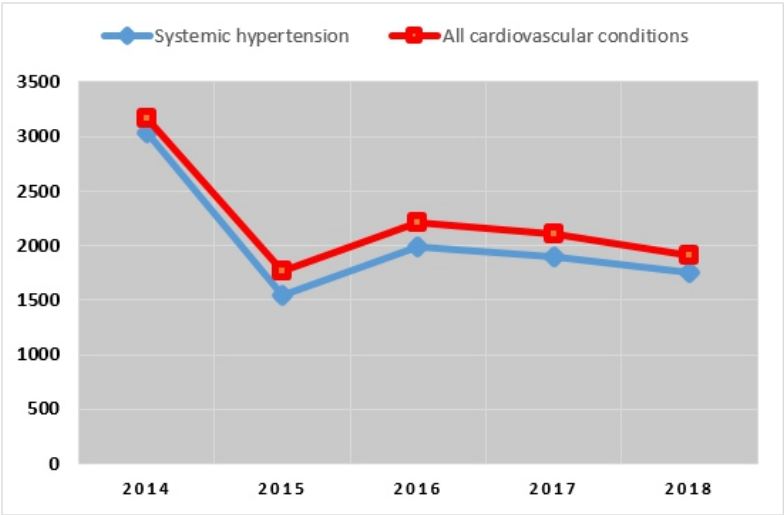


Figure 15: Trend of Cardiovascular Diseases in the Survey

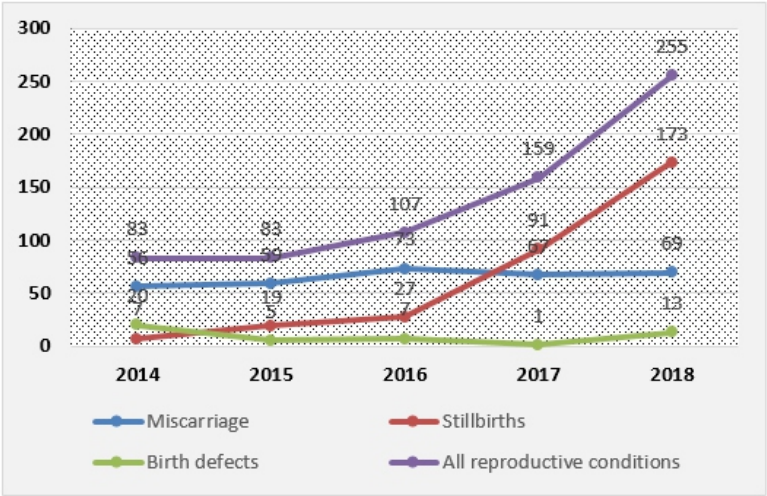


Figure 16: Trend of Reproductive and Maternal Health Disorders

That soot is responsible for the health effects observed is shown in Figure 15. Total cumulative case mortalities and mortalities from respiratory tract Infections notified before and after the soot with about 54.4 percent of cumulative notified mortality case count and 81.8 percent of mortalities from notified mortalities from respiratory tract infections, occurring after the soot was observed (Figure 17).

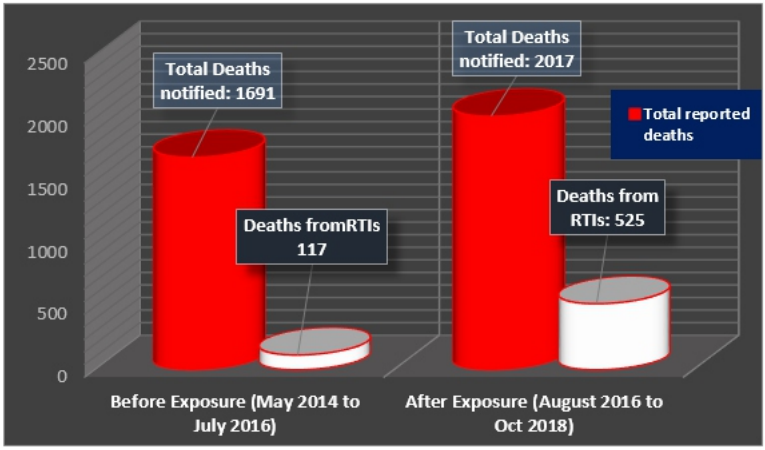


Figure 17: RTI Component of Total Mortality before and after the Soot

d) Social Impact of the Soot

The social investigation strived to achieve an understanding of the following issues:

- where the soot is coming from;
- the mechanism that generates the soot;
- raw materials used and their sources;
- who patronises the products;
- how products are transported and distributed;
- the market and economy of the business; and

- what to do if the soot is to be stopped.

Three study instruments widely used in social research, namely: key informants, focused group discussion and stakeholders meeting were used. What is reported here are opinions of those who know or are associated with activities of those who know about the soot.

In a meeting with people who petitioned Government on the claim that they know the root cause of the soot, the following remarks were made:

a). The soot arises mainly from the burning of crude stolen from strategic pipelines. The process that generates it is locally called *kpo-fire*.

b) They first noticed the soot in late 2016.

c) Setting ablaze of seized products by security agents contribute to the atmospheric loading of soot.

d) The persons involved in this illegal refining of stolen crude are mainly cult boys who are dangerously armed and ready to kill anyone who intrude into their affairs.

e) There is evidence of collaboration from the IOCs who take advantage of the situation and also serve as informants to the illegal refiners informing them of the periods of high pressure for crude bearing pipelines.

f) The *kpo-fire* activity usually commences between 4pm to 6pm and will last till dawn when pressure is high and mostly on Tuesdays and Thursdays of the week.

g). There is evidence of security agents colluding with the illegal refiners as payments are made for protection and cover up.

h) Confiscation of cargoes occur only when the security agents are not properly "settled".

i) The areas where the illegally refined products are discharged are all around waterfronts

j) There are hundreds of *kpo-fire* locations at the moment as the illegal business has now become lucrative due to shortages of petroleum products such as diesel and kerosene.

3.3 Findings on Artisanal Refinery Methods

The Old System

Initially they used to weld 3 drums together reinforced with angle iron, then use galvanised pipes from the top of the cylinder. There is a valve at the top and bottom of the cylinder. The galvanized pipe is passed through a cooling system (water pit) at the point where the product is cooled, the eight pipes are coalesced into one and channelled into a receiving container, which is heavily fanned by the introduction of air so that volatile fractions are dispersed in the air. The cooking drum also has a valve below through which sludge is drained. Mangrove wood that formed only ashes was at this time the fuel used in the boiling.

New Method as at 2016

In this method, 3-5mm thick flat steel sheets are welded into pots. There are different sizes of pot, ranging from 5 plates up to 19 plates. Steel sheets are braced with angle iron to withstand pressure. These pots are completely sealed and air tight. The pot is boiled with crude oil. The initial receiving pit is sealed and a stack 20m high is introduced to vent gases away from the fire. The pots are filled to about two-third of their capacity to give room to excess pressure during cooking. Crude oil is obtained at specific places where they are sold. Those who sell crude oil are different from those who cook to obtain products, and those who distribute refined products are separate from those who refine it. Crude oil is bought from those who extract it from the pipeline. Crude oil (also called *black oil* by those in the business) is tapped directly from crude oil trunk line in a 6 inch pipe and delivered to buyers' boat. The distance from the hook-up to

trunk lines could be more than 200m and buyers are not allowed close to the hook-up point. The valve operator and the person dispensing into the boat communicate through radio to know when to stop the valve. Crude oil is transported in wooden boats to minimize fire from boat engines. The local wooden boat used is called "*pour put*" and the crude oil in our axis is sold in a place called "*point*". A cargo of crude oil called is "*truck*" because it is estimated to be the same capacity as road tankers sells for fifty thousand (N50,000.00).

There is an association of those involved in the business and their primary responsibility is to settle security agencies. The perpetrators are familiar with the soot and they experience it from Isaka, Cawthorwn Channel to Bille. Soot comes from the boiling systems. The operation nowadays is mainly by night and it takes about 12 hours to boil a large pot and exhaust its content. The refining system begins with the filling of the cooking pot to about three quarters of its capacity with crude oil. Commercial size stove are set under the pot and ignited. Fuel for the stove comes from a blend of crude oil and residue of heavy oil from previous cooking delivered to the stoves through a small pump. The person who regulates the pump and the stove is called "*fireman*". To be a fireman is dangerous because the chances of being burnt alive while on duty are very high.

When security people from the Federal agencies accost them, they are "*well-settled*". Security cost is about 20% of total cost, 30% is spent on labour and 50% profit is usual. Isaka alone has more than 22 of these devices. Bille has over 55. In a camp, a drum of diesel is seventeen thousand (N17,000.00) especially when products are scare. A 19 plate pot produces 75 drums/night. Diesel sells at one hundred and twenty naira (N120.00) per litre in the open market, while the residue sells for sixty thousand (N60,000.00) per truck. The emphasis of the

production process is diesel because it is less volatile.

Economics and Marketing of Products

These are excerpts from fuel dump owners in Borikiri, Port Harcourt. Products come from Bile and Kalabari axis. They arrive at the depot in boats laden with products. We haggle for price usually N25,000 per drum. When there are shortages we buy N30,000. Profit depends on quality sold, ranging between N 3000 and N 5000 per drum. The boats that bring diesel use a method called "*pour put*"; some boats have up to 150 drums capacity. The diesel is siphoned with funnel and bucket. They use cart pushers to move the product from the water edge to the dump. *Siphoners* dispense the products to customers.

Customers are many and they come from all over Nigeria, sometimes from places as far as Benue, Anambra, Enugu and Kaduna. Transactions are paid for both as mobile bank transfer or cash. Typical sales is between 6 and 70 drums per day, as driven by the forces of supply and demand. Sometimes fuel tankers come to load, but that is usually in the night. Haulage firms for cement companies are one of the biggest customers, they buy for own use and re-sell. They always wash away diesel after business, if you expose yourself to diesel for a day it will cause burns and skin problems. It darkens the skin rapidly. They joined this business due to lack of job opportunity and hunger although I am trained a pipeline welder.

The business is fraught with risks; anti-bunkering security men routinely raid their premises if they are not settled. Settlement is usually more than N10,000/day. With good housekeeping (clean environment) they will not trace your business. Leaked products and dirty premises is a give-away. Around my area of operation there are over 85 dumps. Every day we pay 20k to the union chairman to settle security agencies, against intercepting us or our customers. To be in the dump business you must register

with N150,000. The union chairman receives the money. It is difficult for fish to survive near the offloading jetties due to severe contamination of soil and water.

Kerosene sells for N40,000 and demand is high. Gasoline delivery is in secured containers to protect it from vaporisation, moreover kerosene and gasoline easily evaporates, which may lead to shortages. There is expensive bleaching of products to achieve greater quality before it is sold. The quality of the fuels we sell compares well with those from conventional refineries. Weekly payment to the association chairman for dealing on kerosene and gasoline is N10,000 because their sales are low and mostly women are involved. Pushers move the products and a pusher can lift up to 29 drums on a good day. I have two *siphoners*, they take N5,000/drum siphoned. Thirty drums can be siphoned in less than 1hr by two people. Each cart carries 1 drum and is paid 300k.

A lady who supplies bagging materials for diesel was also interviewed.

I sells waterproof for wrapping diesel. They double the waterproof four times to make it durable. The bags are of 25 litres capacity. The buyers prefer bags because cars can take greater quantity with it. Camry can carry 2 and half drums and Avalon 3 drums. We get our bags from people that own bag making machines. When there is market I make up to N10,000 turnover in a day. We face risks if the bags are not durable. I don't face any risk to personal security. The air around the work environment is fouled by petroleum products' stench. It is unhealthy when diesel spills, they use foam to collect it from the ground and save what they can. In *kpo-fire* language it is called *ROB*. There is almost no personal protective equipment (PPE) used in all the process. A bundle of bag costs N5,000, after sales I make profits of N2,000 per bundle. I sell up to 5 bundles in one

day.

4.0 CLIMATE CHANGE CRISIS

Climate change is the single biggest health threat facing humanity. Climate impacts are already harming health, through air pollution, disease, extreme weather events, forced displacement, pressures on mental health, and increased hunger and poor nutrition in places where people cannot grow or find sufficient food (UN Climate Action, 2023). By 2022 the United Nations has come to the realisation that climate change is the greatest challenge humanity faces (DevelopmentAid, 2022; Hilton, 2022). This claim is promoted by DevelopmentAid, the world's premier information service provider for international development aid and economic and humanitarian assistance stakeholders. Climate change is a massive threat to human development and in some places, it is already undermining the achievement of the Millennium Development Goals (MDGs) and the international community's efforts to reduce extreme poverty. The UN Climate Action (2023) has named fossil fuels – coal, oil and gas as the largest contributor to global climate change, accounting for over 75 per cent of global greenhouse gas (GHGs) emissions and nearly 90 per cent of all carbon dioxide emissions. The major activities are: power generators, goods manufacture, deforestation, transportation, food production and over consumption. Humankind is the sole culprit in all these. As greenhouse gas emissions blanket the Earth, they trap the sun's heat. This leads to global warming and climate change. The world is now warming faster than at any point in recorded history. Warmer temperatures over time are changing weather patterns and disrupting the usual balance of nature. This poses many risks to human beings and all other forms of life on Earth.

4.1 The Sources of Climate GHGs

UNEP (2022) also observed that most emissions of GHGs come from just a few countries. The top seven emitters are China, the United States of America, India, the European Union, Indonesia, the Russian Federation, and Brazil accounting for about half of global greenhouse gas emissions in 2020. The Group of 20 (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union) are responsible for about 75 per cent of global greenhouse gas emissions.

4.2 The Evidence for Climate Change

The evidence of world climate change are many, NASA (2023) listed the following:

a) While Earth's climate has changed throughout its history, the current warming is happening at a rate not seen in the past 10,000 years.

b) According to the Intergovernmental Panel on Climate Change (IPCC), "Since systematic scientific assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact."[1]

c) Scientific information taken from natural sources (such as ice cores, rocks, and tree rings) and from modern equipment (like satellites and instruments) all show the signs of a changing climate.

d) From global temperature rise to melting ice sheets, the evidence of a warming planet abounds.

The rate of change since the mid-20th century is unprecedented over millennia. Earth's climate has changed throughout history. Just in the last 800,000 years, there have been eight cycles of ice ages and warmer periods, with the end of the last ice age about 11,700 years ago marking the beginning of the modern climate era - and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.

The current warming trend is different because it is clearly the result of human activities since the mid-1800s, and is proceeding at a rate not seen over many recent millennia. It is undeniable that human activities have produced the atmospheric gases that have trapped more of the Sun's energy in the Earth system. This extra energy has warmed the atmosphere, ocean, and land, and widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred. Ice cores drawn from Greenland, Antarctica, and Tropical Mountain glaciers show that Earth's climate responds to changes in greenhouse gas levels. Ancient evidence can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks. This ancient, or paleoclimate evidence reveals that current warming is occurring roughly 10 times faster than the average rate of warming after an ice age. Carbon dioxide from human activities is increasing about 250 times faster than it did from natural sources after the last Ice Age.

Do Scientists agree on Climate Change?

Earth-orbiting satellites and new technologies have helped scientists see the big picture, collecting many different types of information about our planet and its climate all over the world. These data, collected over many years, reveal the signs and patterns of a changing climate. Scientists demonstrated the heat-trapping nature of carbon dioxide and other gases in the mid-

19th century. Many of the science instruments NASA uses to study our climate focus on how these gases affect the movement of infrared radiation through the atmosphere. From the measured impacts of increases in these gases, there is no question that increased greenhouse gas levels warm Earth in response.

Study Smarter (2023) summarises the evidence, thus: although it is confusing and frightening to have to face the reality of climate change, there are facts that back up and are evidence for climate change.

a) There is the most CO_2 in the air in the past two million years.

b) 1.2 trillion tonnes of ice are melting each year. As a reference, a combination of all human-made things is 1.1 trillion tonnes.

c) In 2019, 302.4 billion work hours have been lost through being too hot to work.

d) Severe hot weather events used to happen on average once every 10 years between 1850 and 1900 but now likely occur 2.8 times every 10 years.

e) Heavy rains and floods have quadrupled since the 1980s and doubled since 2004.

4.3 Net-zero and its Importance

Net-zero means cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests for instance. The importance of net-zero is that science shows clearly that in order to avert the worst impacts of climate change and preserve a liveable planet, global temperature increase needs to be limited to 1.5°C above pre-industrial levels. Currently, the Earth is nearly about 1.5°C warmer than it was in the late 1800s, and emissions continue to rise. A BBC investigation reports that the world is breaching a key warming threshold at a rate that has scientists concerned. On about a third of days so far in 2023, the

average global temperature was at least 1.5 °C higher than pre-industrial levels (McGrath *et al*., 2023). Staying below that marker long-term is widely considered crucial to avoid the most damaging impacts of climate change. But 2023 is "on track" to be the hottest year on record, and 2024 could be hotter.

To keep global warming to no more than 1.5°C as called for in the Paris Agreement – emissions need to be reduced by 45% by 2030 and reach net zero by 2050. Transitioning to a net-zero world is one of the greatest challenges humankind has faced. It calls for nothing less than a complete transformation of how we produce, consume, and move about. The energy sector is the source of around three-quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change. Replacing polluting coal, gas and oil-fired power with energy from renewable sources, such as wind or solar, would dramatically reduce carbon emissions.

A growing coalition of countries, cities, businesses and other institutions are pledging to get to net-zero emissions. More than 70 countries, including the biggest polluters – China, the United States, and the European Union – have set a net-zero target, covering about 76% of global emissions. More than 3,000 businesses and financial institutions are working with the Science-Based Targets Initiative to reduce their emissions in line with climate science. More than 1000 cities, over 1000 educational institutions, and over 400 financial institutions have joined the Race to Zero, pledging to take rigorous, immediate action to halve global emissions by 2030. The growth in net-zero pledges has been accompanied by a proliferation of criteria with varying levels of robustness. To develop stronger and clearer standards for net-zero emissions pledges by non-State entities such as businesses, investors, cities and regions, and speed up their implementation, UN Secretary-General António Guterres

in March 2022 established a High-Level Expert Group on the Net-Zero Emissions Commitments of Non-State Entities. The Expert Group presented its recommendationsat COP 27 on 8 November 2022.

Commitments made by governments to date fall far short of what is required. Current national climate plans – for 193 Parties to the Paris Agreement taken together – would lead to a sizable increase of almost 11% in global greenhouse gas emissions by 2030, compared to 2010 levels. Getting to net zero requires all governments – first and foremost the biggest emitters – to significantly strengthen their Nationally Determined Contributions (NDCs) and take bold, immediate steps towards reducing emissions now. The Glasgow Climate Pact called on all countries to revisit and strengthen the 2030 targets in their NDCs by the end of 2022, but only 24 new or updated climate plans were submitted by September 2022.

The major sources of CO emissions in Nigeria are landuse changes (38%), energy use (32%), waste (14%) agriculture (13%) and industry (2%) (Climate Link, 2019) Due to relatively low economic development, Nigeria's greenhouse gas emission, carbon footprint and per capita emissions is one of the lowest in the world (see Table 1). Apart from South Africa, all other Sub-Saharan countries are similar to Nigeria. Yet Nigeria is expected to cut down on its emission because the various climate change frameworks, such as COP and IPCC prescribe so. Developing countries like Nigeria are the least able to cope with the effects of climate change. They are also the least capable in terms of capacity to adapt needed technology to transit to renewable

Table 1: Carbon Dioxide Emission by Country in 2016

Ranking	Country	CO_2 Emissions (tons, 2016)	Population (2016)	Per Capita	Share Of World
1	China	10,432,751,400	1,401,889,681	7.44	9.18%
2	United States	5,011,686,600	327,210,198	15.32	4.02%
3	India	2,533,638,100	1,338,636,340	1.89	7.09%
4	Russia	1,661,899,300	145,109,157	11.45	4.65%
5	Japan	1,239,592,060	126,993,857	9.76	3.47%
6	Germany	775,752,190	82,331,423	9.42	2.17%
7	Canada	675,918,610	36,113,532	18.72	1.89%
8	Iran	642,560,030	83,306,231	7.71	1.80%
9	South Korea	604,043,830	51,309,984	11.77	1.69%
10	Indonesia	530,035,650	261,850,182	2.02	1.48%
Highest Emitters in Sub-Sahara Africa					
15	South Africa	390,557,850	56,422,274	6.92	1.09%
43	Nigeria	82,634,214	188,666,931	0.44	0.25%
75	Angola	30,566,933	29,154,746	1.05	0.09%

Source Worldometer (2023)

The dilemma is what comes first: economic development that may enhance a country's ability to withstand climate change and alleviate burdens such as poverty, or adopt climate change mitigation measures through purchases of renewable energy technologies with scarce resources.

4.4 Climate Change in Nigeria

Evidence through a hydrological modelling of potential impacts of future climate change on Lower Niger River Basin by Okpara *et al*. (2013), the potential impacts of projected climate change on water resources of Nigerian sector of Niger River basin using both parametric and non-parametric approaches and simulation models i.e., Thornthwaite water balance accounting scheme and artificial neural networks (ANNs) was conducted. There was discernible evidence of climate change in Nigeria, adjudged by the observed changes in the onset and cessation dates of seasonal rains and the presence of trends in the hydro-climatic

series. It is further observed that apart from the Sahel region, Sudano-Guinean region or the humid portion in the lower Niger sub-basin are also vulnerable to the changing climate and its impacts. The observed changes are not unlikely to be connected to the long-time variability in the climatic variables of the region, and land use changes due to increasing anthropogenic activities and gas flaring and population pressure. Also, a future drier climate is expected to impact negatively on the runoff and invariably on the available water resources of the region. Proactive and aggressive management strategy is seriously needed to match any unfathomable impact.

4.5 Climate Change Policy in Nigeria

The Climate Change bill of Nigeria was signed into law by President Buhari in November 2021 in order to provide Nigeria with a legal framework for the country to achieve its climate goals, achieve long-term social and economic sustainability, and resilience. Following the President's commitment made at the COP 26 in Glasgow of achieving net-zero by 2060, the Act enacts an overarching objective of achieving net-zero emissions between 2050 and 2070.

Notable clauses of the Act mandate the government to set a National Climate Change Action Plan and a five-year carbon budget (with quantified annual objectives) accordingly. Both of these are to be validated by the Federal Executive Council. It creates the National Council on Climate Change and defines its members and attributions. The Council is in charge of implementing the National Climate Change Action Plan. The institution will be responsible for managing the newly-instituted Climate Change Fund. The Fund will be provisioned according to debates in Parliament, and enable the running of the Council itself as well as subventions. The Council will work with the environment ministry to organise climate action globally and

for each economic sector. It will also work on identifying and implementing priority adaptation actions

In relation to offences, the CCA states that any person, private or public entity that acts in a manner that negatively affects efforts towards mitigation and the adaptation measures made under the CCA or contravenes any obligations it has under the CCA commits an offence and is liable to a penalty as will be determined by the Council (Udoma & Osagie, (nd)).

4.6 Climate Change in the South-South of Nigeria

The Niger Delta within Nigeria's South-South geopolitical zone is located in the Atlantic coast of southern Nigeria where River Niger divides into numerous tributaries. It is the second largest delta in the world with a coastline spanning about 450 kilometres. It is the richest wetland in the world, highly diverse and supportive of numerous species of terrestrial and aquatic flora and fauna and human life. The Niger Delta is faced with myriads of environmental problems caused by climate change and the activities of multinational oil companies operating in the region. The occurrence of coastal erosion, rise in sea level, renewable resource degradation had been reported. Climate change has affected rainfall pattern with the consequent effect on vegetation, and thus agriculture. Sea-level rise and repeated ocean surges not only worsen the problems of coastal erosion that are already a menace in the Niger Delta, the associated inundation is increasing problems of floods, intrusion of sea-water into fresh water sources and ecosystems destruction thus destabilizing the mangrove, and affecting agriculture, fisheries and general livelihoods. Settlements in the coastal region, especially in Forcados, with some oil wells, have been uprooted by coastal erosion. It is predicted that Nigeria will lose about $9 billion as a result of the sea level rise while at least 80% of the people of the Niger Delta will be displaced due to the low level

of the region (Adewumi *et al*., 2018)

According to Elenwo and Akankali (2014), meteorological data showed that, temperature, rainfall and humidity have changed during a period of 10 years. This change translates to climate change because it is at least up to a decade (10-year period), and it showed a 1.5˚C rise in temperature from 2003 to 2013 and an increase of 342.2 mm in the amount of rainfall in Niger Delta. These clearly paint the picture of global warming. Furthermore, in the same period, there was a decrease of 9% in the amount of humidity in the area. Thus, it is very clear that the climate is changing over time within the South-South region.

Abade (2021) notes that oil spills and gas flares worsens climate change in the Nigeria. Echendu *et al.* (2022) linked air pollution, climate change and overall ecosystem health in the Niger Delta region of Nigeria. This is particularly pertinent due to the ecological sensitiveness of the region and the high dependence of the indigenes on the land and water. The region's ecosystem is becoming more and more threatened as pollution increases and the climate changes further. Nigeria's position as the largest oil producer in Africa and the sixth largest in the world is due to the oil and gas reserves of its Niger Delta region. The findings of a study by Ikehi *et al.* (2014) revealed that the extent of impacts of climate change on farmers and the farming families in Niger Delta region of Nigeria are moderate

Vulnerability to climate change depends on a number of factors, the most important of which are: the ecological zone, level of technological advancement, resources, especially finance and the level of resilience of the victims. Onwuemele (2015) observed that more than 80% of the households in the region have diversified their livelihoods into the non-farm sector with serious implications for food security. Ikehi *et al.* (2014) found that most farmers agree to continue cultivation even with the

observed impacts of climate change. It concludes that farmers in the region should be encouraged by providing incentives and subsidizing inputs for them by Federal and State governments as well as other non-governmental organizations, as this will go a long way in improving production.

4.7 Drivers of Climate Change in the Niger Delta, Nigeria

The drivers of climate change according to Ede *et al.* (2016) are listed below:

a) *Deforestation:* this has been going on rapidly in the region. The primary ways by which it comes about are:
   - Rapid urbanisation and other forms of settlement expansion, especially the sprawl of the largest cities, such as Port Harcourt, Benin, Calabar and Uyo
   - Massive reclamation in the mangrove and freshwater swamps axis.
   - Harvesting of timber as fuel and input to construction. The depletion of forest which reduces the volume of plants that serve as sink for carbon dioxide (CO_2) in the atmosphere.

b) *Bush burning:* This practice is common in hunting and so called "slash and burn" agriculture; sometimes there could be wildfire in the dry season. Burning of bush contribute to air pollution and CO_2 emissions that drive climate change.

c) *Life style:* The way people conduct their life has climate change implications. Their clothing, feeding, mode of transportation and energy use can all have consequences. If for instance people feed heavily on

meat, they will be encouraging meat production which is as important source of methane, a substance responsible for about 21 *per cent* of green-house gases.

d) *Overdependence on fossil fuel:* Nigeria depends on fossil fuel for its energy need. This source of energy powers all the public power plants in and there are more than six of them. Virtually all automobiles use diesel or gasoline. Boats, power equipment and generators are all powered with derivatives of fossil fuel in the region. Fossil fuels are the primary sources of greenhouse gases.

e) *Propellants and refrigerants:* The use of propellants in aerosol cans is prevalent. The urban areas as places of ostentation and consumption are major contributors of chlorofloro-carbon (CFC) and related chemicals, similarly air conditioning and refrigerants already banned elsewhere are still being used due to obsolete equipment or lack of sufficient disposable income to patronise new technologies.

f) *Excavation of chikoko mud*: Studies by Obunwo, Ede and Jegede (2009) have shown that peaty soils associated with swamps in the Niger Delta store many gases, particularly methane and carbon. Local land reclamation practices in the mangrove swamps excavates these peaty, bog-like soil, after ridding the surface of its natural mangrove vegetation, thereby releasing greenhouse-gases that were otherwise trapped in the atmosphere.

g) *Sewage management and waste disposal practices:* The

largest city in the region is Port Harcourt with the population of the greater area being over three million. No neighbourhood scale piped sewage management system exist and publicly owned sewage treatment plants operate as pilot schemes (Ede & Edokpa, 2010a). Sewage is a source of many gases especially methane which is a more lethal green-house gas than CO_2. Similarly, domestic, farmyard market and other forms of degradable wastes are simply evacuated and dumped. The dumps are not lined, nor are they covered up with soil when filled. This is another source of green-house gases.

h) *Gas flare:* Nigeria is reputed to be a country that flares associated gas the most by its petroleum industry after Russia. The abundance of natural gas over crude oil in Nigeria's petroleum reserves, and the low level of gas utilization encourage flaring. Associated gasses are usually up to 85 *per cent* methane; the combustion process releases CO_2, while un-combusted methane is freely released into the atmosphere as drivers of climate change. There is very little independent data on gas flaring volumes and it is known that some of the reported volumes are low (NGDC, 2011). In 2004 Nigeria's volume of gas flared was equivalent to one-sixth of total gas flared in the world. Globally, the volume of gas flared between 1996-2006 (during which time awareness of the detrimental impact of flare emissions on the global climate grew) remained relatively constant, ranging between 150-170 billion cubic meters (BCM). Nigeria's share of the total volume is approximately 24.1 BCM of gas. By comparison, the

U.S. flared 2.8 BCM during the same time period (JINN, 2010).

i) *Conflict:* The South-South region has been experiencing low-intensity conflicts for many years. The root of the conflict is the agitation for greater local control of the petroleum resources and a widespread feeling of being left behind economically. There is also a high-level criminality of uncertain causes that may seem to be politically and economically induced. The atmosphere of conflict restricts the possibility of enforcing environmental regulations, mitigation and adaptation of climate change effects.

j) *Agricultural productivity and food security:* Related to a high level hydrocarbon pollution of lands (see UNEP, 2011) report on Ogoni, for instance) and water in all parts and the lingering conflicts are reductions in agricultural productivity and food security. Available lands and water bodies are almost not usable or being utilized more intensively as a result.

4.8 Effects of Climate Change

a) Hydrological balance
b) Temperature rise
c) Coastal erosion
d) Threats to coastal infrastructures
e) Threats to coastal settlements
f) Livelihoods
g) Extreme storm surges
h) Surface and sub-surface water resources
i) Conflicts

j) Food security
k) Fire hazards
l) Demographic changes
m) Economic disruptions
n) Technical Disruptions, alternative energy and automation
o) Health effects
p) Ecological effects
q) Flooding
r) Prevalence of diseases
s) Heat stress
t) Diet and nutrition

Using the above list the effects were grouped into sectorial categories as presented in Figure 18.

Figure 18: Sectoral Categories of Climate Change Impacts

(1) Infrastructure
(a) Threats to Coastal Infrastructure
(b) Threats to Coastal Settlements
(c) Technical Disruption/Technology

(2) Social
(a) Livelihood
(b) Conflict
(c) Food Security
(d) Demographic Changes
(e) Fire Hazards
(f) Economic Disruptions

(3) Environment
(a) Hydrological Balance
(b) Temperature rise
(c) Coastal Rise
(d) Extreme Storm Surge
(e) Surface and Sub- Surface Water Responses
(f) Fire Hazards
(g) Ecological Effect

(4) Technology
(5) Health
(a) Physiological Effect
(b) Diet & Nutrition
(c) Diseases

4.9 Mitigation and Adaptation Options

Mitigation options for climate change focuses not only on the effects, but on climate change processes. Surface morphology induces flooding in the Niger Delta, yet there has been limited

examination of the terrain and how it affects flooding as a consequence of climate change (Ede, 2013). The mechanism of climate change is such that green-house gasses, mainly CO_2 and methane component introduced by human activities trap solar radiation in the atmosphere. This causes temperature rise by forcing the atmosphere into a green-house. If the earth's flora is preserved and increase, it is hoped that much of the CO_2 in the atmosphere will be absorbed through plant respiration. Unfortunately, deforestation is increasing very rapidly as the need to preserve the forest is urgent. The question is what can we do to preserve the forest and stop deforestation? Obviously tree planting, forest reserves and the substitution of wood in human constructions are options. Biomass as a source of energy has to be drastically reviewed so alternative energy can take hold.

These comprise all regulations activities and plans that will enable the society cope with the effects of climate change; prevent or ameliorate them. The more visible one includes:

a) Various national and international frameworks and agreements that Nigeria has signed on to.
b) Nigeria national climate change related policies.
c) Various master plans that pertain to flooding, erosion, urban and regional development.
d) Vulnerability assessments and mapping.
e) National disaster emergency framework.
f) Disaster recovery and reconstruction system.

There is a correlation between flood sensitivity and flood vulnerability. Nigeria has a Flood and Erosion policy. which was published by the Federal Government but it has not been fully implemented.

There is a National Emergency Management Agency (NEMA). The military, paramilitary, NGOs, Civil Defence and Red Cross

are all trained for such emergencies. Vulnerability mapping for climate change effects should include the physical area that is vulnerable. The scope of mapping will include heat stress, flooding and fire in relation to climate change. It is suggested that all local government areas (LGAs) should have these maps to show land topography. This will further guide on response to climate change effects. In Nigeria there is some form of recovery management system anchored on NEMA. In other advanced countries there is Crises Management Team (CMT) and Crises Communicator. Nigeria may need to consider such a model.

Figure 19: Components of Adaptation Framework

Flooding

- Early Warning and record keeping needs to be improved (Ede *et al.,* 2018)
- Instrumentation – need for gauging stations; this does not exist in most rivers in Nigeria.

Imbalance in Hydrological Systems

The Niger Delta is made up of a network of rivers and islands.

Every island is vulnerable to flooding.

- Increase the holding capacity of the river by dredging. The water that flows from the river is reduced and the efficiency is increased. This will lead to increased base level.

Saline Water Intrusion

Regulation of the amount of fresh water abstraction through bore-hole sources that recharge aquifers. Also, through abstraction and intrusion, which can be achieved with deep wells as source of ground water.

Temperature Rise

Being selective of the type of dwellings we live in, design and the building materials used.

- Medical Emergency/Service need to be prepared to handle health challenges related to rise in temperature which leads to heat strokes and heat waves. Breeding pattern of pathogens is altered.
- Advocacy – the masses need to be educated about the global rise in temperatures in recent years and how to protect themselves.
- Water fountains should be introduced across the region during the hot season
- Dressing – Clothing that are conducive to our climate should be worn

Coastal Erosion

Coastal erosion is upset from the seashore and river banks.

- Adjustments should be made for settlers to move to higher ground.
- Protection of beach ridges

- Shore protection
- Do not temper with the mangrove
- Preservation of natural coastal structures
- Natural vegetation preservation

Frequent Storm Surge

Increased storm surge leads to degradation of the rivers and eventually to the formation of new rivers. In the process there is destruction of life and ecosystem.

- Modify damp design to allow for filtration and to de-silt
- Early warning signs should be adhered to
- Cultivate resilience
- Population resilient
- Do not disturb beaches and the sea next to it
- Planting trees around the seashore
- Flood Avoidable Indexation

Livelihood

- Diversification of sources of income and less dependence on agriculture
- Technologically engineered agriculture, introduction of better quality of crops that can tolerate floods, grow faster before the floods start, better yield as well as improved yield and longer shelf life.
- Ability to eat other varieties of food apart from those grown in your locality.
- Adapting new varieties of crops and food to local diet.
- Relocate to other settlements
- Urban gardening, which will allow for green areas in the city as well as conserve energy.
- Adhering to early warning signs
- Creating reserves for forest and wildlife

- Identify higher grounds as potential camps for evacuees
- Irrigation for periods when there is short fall in rainfall
- Revival of traditional approaches of food production and preservation.

Surface and Sub-surface Water Resources
During flooding, surface water is contaminated, saline water diluted.

- Improve alternative water resources such as rain water harvesting (trapped rain)
- Use water in a sustainable way.
- Improved technology water treatment; reversed Osmosis – the emergency kit for water purification

Conflicts
Coastal flooding causes internal displacement of settlement which sometimes results in communal conflicts. Southward migration of herdsmen is another potent source of conflict.

- Resettlement schemes
- Restriction of herders movement

Food Security

- Prevent food shortages, scarcity and poor crop yield
- Storage facilities such as grain silos, preservation, improved shelf life
- Technology driven agriculture

This thirteenth edition of the Emissions Gap Report is testimony to inadequate action on the global climate crisis, and is a call for the rapid transformation of societies. Since the twenty-sixth United Nations Climate Change Conference of the Parties (COP 26), there has been very limited progress in reducing the

immense emissions gap for 2030, the gap between the emissions reductions promised and the emissions reductions needed to achieve the temperature goal of the Paris Agreement Globally, members are far behind in delivering on their mitigation commitments for 2030, causing an implementation gap (UNEP, 2022).

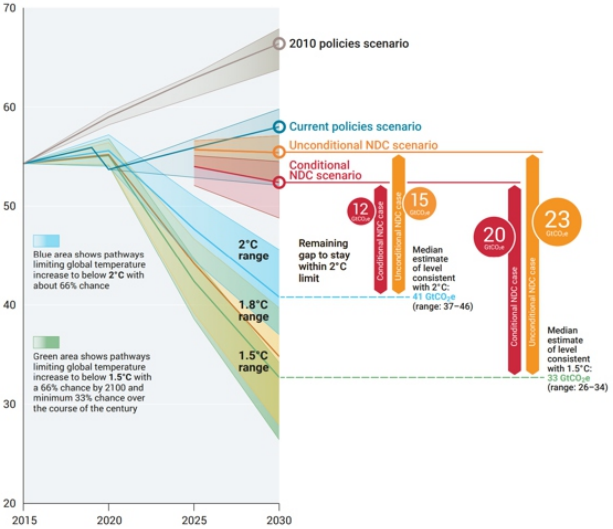


Figure 20: Global GHG emissions under different scenarios and the emissions gap in 2030 (median estimate and tenth to ninetieth percentile range) (UNEP, 2022).

Other Suggestions on the way forward

a) Elenwo and Akankali (2014) suggests that to abate the impact of climate change in the region require the introduction of new water management reform and policy implementation, and carbon sequestration amongst others. .
b) Onwuemele (2015) called for support for local farmers

to enhance their capacity to adapt to climate change to improve their agricultural practices.

c) Although, there is a growing trend in the pattern of consideration of climate change in the EIA procedures, researches have shown that EIA has, so far, struggled in the attempt to incorporate climate change into its procedures. Climate change incorporation in environmental assessment is a growing research area, particularly following the Paris agreement. Environmental Impact Assessment (EIA) is considered in many quarters to be an important tool in factoring climate-related components in the planning and design of a project. The study by (2019) shows that there is a poor political will to address climate change, as reflected in the absence of climate change requirements in the EIA guidelines of Nigeria.

d) The key role the ecosystem plays in climate change mitigation makes it imperative for local policies geared toward resolving both local and global environmental issues to come in place. Decision-makers need to adopt an approach that will satisfactorily address the environmental justice concerns that further perpetuate pollution and urgently bring an end to the gas flaring that is the norm rather than an exception in the region (Echendu *et al.*, 2022).

e) Balogun and Onokerhoraye (2022) conducted a climate change vulnerability mapping across ecological zones in Delta State, Niger Delta Region of Nigeria. The study recommends that climate change interventions be delivered across communities in the Niger-Delta Region based on variations of the indicators of vulnerability.

f) Mainstream climate change policies, such as those of the

Delta State and the Federal Government

g) From the SDGs, Goal 13 aims to combat climate change and its impacts by taking urgent action. Climate change and environmental degradation are equity issues that undermine the rights of every child, especially the most disadvantaged. The realization of children's rights, as embedded throughout the SDGs, are contingent on taking action to address and adapt to climate change

4.10 Geographic Imperatives of Climate Change

Geographic imperatives refers to the often applied spatio-temporal dimensions as it addresses the unique perspective and aspects to geographic analyses. Having a perspective means looking at our world through a lens shaped by certain experience, selective information, and unique evaluation. The perspectives and the questions to which they lead distinguish geography from other approaches. Spatial significance, patterns, trends, and their interrelationships underpin geographic perspective. Climate change is equally a major problem caused by the impact of human activities leading to several direct and indirect effects on livelihoods, environment and health. Extreme changes in climate have a direct impact on local infrastructure and indirectly produce social conflicts affecting the access to basic needs of food, housing and health. Geography plays a significant role in shaping climate patterns, and changes in the physical features of the Earth can dictate extent of climate change. For example, deforestation can lead to a rise in temperatures and decreased rainfall, contributing to climate change. Climate imperative focuses on the near-term policy decisions on major greenhouse gas-emissions that offer the greatest emissions reductions alongside important health, environmental, and equity benefits. Alternative energy

production, carbon capture, afforestation and international agreements are all examples of social actions to mitigate climate change.

My most challenging concern in writing this lecture is as to how geography births new discipline that go on to flourish while keeping a distance from the parent discipline. Climate change and how to tackle the change has become the most significant geographical question of our time. Can a very geographical topic as climate change be rebranded and given an independent status? In traditional geography, climate change is not a sub-discipline, rather it is a topic under climatology. What will await graduates of climate change? Will they be recognised as climatologists? Will Association of Nigerian Geographers admit them, knowing that their curriculum will never be as vast as that of regular geography? The issues surrounding climate change will remain cogent for many generations to come. If practitioners of the science of climate change form a critical mass and initiates a professional group, will they admit climatologists or even geographers? *Here lies the geographic imperatives!* What is it about geography that endows it to spinoff so many disciplines? We have seen these spinoffs in urban and regional planning, transport, demography and population, geomatics, meteorology, epidemiology and climate change is coming. Most of these new disciplines carve their own niche and earnestly exclude geographers. They start as geography and later exclude geography from their fold, why? Geography as the precursors of all spatial subjects has a unique way of exploring things on the earth surface. All the disciplines that were previously under it still utilises spatial analytical frameworks, but with greater rigour and the integration of human-environment dimensions in explanation that geography has so perfected.

5.0 ACADEMIC MILESTONES AND ACHIEVEMENTS

In the course of my career, there are many things I am proud of. Geography equipped me to do many things which still amazes me. For reasons of client confidentiality I will not go into specifics. It is therefore hard for me not to use this occasion to showcase the deep, penetrating achievements I scored so far in my modest academic career.

5.1 Emissions Modelling

I, and later my team, have used many modelling tools. In the early years of 1990s, modelling was carried out through manual calculations. For my masters dissertation that translated into hundreds of discrete calculations, each of which lasted a couple of hours. I used to wake up to do 5 – 6 hours every day. The availability of computers later transformed what used to be a drudgery into a delightful experience. Advances in graphical interface increased utility by providing 2-D views of model output. Yet, more advances in the 2010s allowed 3-D depths with superimpose choropleths unto maps, thereby mimicking live pictures. It was this capability that inspired my team to determine every parameters of the black carbon (soot) of Port Harcourt between 2016 and 2018. Recall that UNEP and WHO sought and had the attention of the State Governor on the matter, many things we know about the "black soot" menace in Port Harcourt today is based on the work I pioneered and led. Between 2017 and now I have led a team of researchers to produce a string of publications on the phenomenon black soot, including: Oloyede & Ede (2020); Kanee *et al*. (2021); Stephen *et al*. (2021); Stephen *et al*. (2021a); and Kanee *et al.* (2022), Abdullahi (2023; 2023a).

We were the first to define:

⇒ Where the soot was coming from
⇒ How it travels or is propagated
⇒ Its diurnal circle
⇒ Its composition
⇒ Its complete epidemiology
⇒ Associated *kpo fire* technologies
⇒ The economic and commercial side of it
⇒ Suggestions on how to manage the problem.

5.2 Determination of Gas Flare Parameters

I was once invited for an Environmental Evaluation Report (EER) somewhere in Bayelsa. Before proceeding to the field I was told to present the scope of meteorological study, but when I mentioned that I will protect temperature sensitive instruments from the flare, the project supervisor interjected that they also wish to know the temperature and radiation properties of the flare. I protested that their request is outside the ambit of meteorology, but they insisted that it should be done if I feel I have the capacity. In my introductory climatology class I have been taught radiation laws and that the radiation of any object is equal to the 4^{th} power of its temperature. With this, we calculated the absolute temperature of the sun. I therefore had no hesitation to calculate the temperature of the flare that was requested of me, and with it established the radiation of the flare. I did not only establish flare temperature, but other characteristics such as luminescence, combustion efficiency, chemistry of emission, and radiation in the infrared

In the mid-1990s the World Bank (1995) published a seminal work on the Niger Delta entitled "Defining an Environmental Development Strategy for Niger Delta". The publication lamented the ubiquitous flaring of gas in the region and the environmental consequences. It equivocally noted nobody has yet determined the flares' parameters, including the temperature.

The solution I had in mind was anchored on the black and grey body radiation principles and with a simple thermometer, flare radiation for any facility was determined. Working backwards their temperatures were as well estimated. Years later, the experiment was repeated with the automated Ultimax non-contact infrared thermometer to confirm that indeed the original measurements were accurate. We can categorically say that flare temperatures in the Niger Delta is 1300 ^{o}C +-50, depending on the intensity, ambient conditions, stack design, stack orientation, and gas flowrate. We did not only determine the temperature, but established the energy relations of gas in Ede and Johnson (2001).

Prior to the year 2000, the only record of gas flare temperature in the Niger Delta is the results of my survey of fifty flare sites. Expectedly, facility owners wanted more; including flare radiation, noise, luminescence and combustion efficiency. They also requested data on all chemical emissions such as CO, CO_2, NOx, SOx, NH_3, BTEX (benzene, tulene, ethylene, & xylene) and THC (Total hydrocarbon), particulates and over ten heavy metals. The interesting aspects of these studies was that they were experimental in nature because the regulators wanted to determine the most sensitive methods for estimating the concentration of these emissions in the atmosphere. Upon presentation to highest level of management of the recipient firm, there was a wide acclaim of the effort.

5.3 Numerical Modelling for Air Quality

My academic endeavour produced many first: I pioneered the deployment of numerical models in Nigeria to estimate emissions. The study of Idu by Edokpa and Ede (2013) is an example in such numerical modelling approach. The use of multiple methods in the determination of emissions parameters was also pioneered by me. In most part I provided leadership to

solve real environmental challenges. Gas flares, for instance, are common in the Niger Delta. In Ede, Seiba and Igwe (2006) that their deficiencies were first reported, based on measurements. This level of investigation is rare these days due to cost cutting, insecurity and a general lethargy towards cross-cutting and cutting edge investigations because a wary industry is mindful of bad press and possible used of the results for litigations against it in the court of law by aggrieved parties. This is one of the reasons the problem of "black soot" persisted. A problem traceable to asset owners but brushed aside with lame excuses such as:

a) It is caused by miscreants not oil companies, so they ignored their asset ownership responsibility.
b) They install security gadgets and signs around company facilities that scare both potential intruders and innocent natives going about their business
c) They believe the problem will not last, so they hide their head in the sand, but it has persisted for so many years already, and by what I now know, it cannot be stopped soon because the socio-economic and commercial imperatives underlying it remain very strong.

5.4 Influence on Public Policy

In Ede and Edokpa (2017) we became the first to characterise the black soot that ravaged the atmosphere from 2016. We showed authoritatively the source of the soot, the distance it travels to get to Port Harcourt and the concentrations downwind. Remember that when the soot ensued, nobody could explain it until we did. The absence of an explanation caused fears and street protests. There were visits from foreign missions, UNEP, WHO and the international media like DW and VOA beamed their search light on Port Harcourt. When the Government of Rivers State made me Chairman, Technical Committee on Soot, I and the team that

was assembled, nearly all of whom are from Rivers State University did not only unravel the mystery behind the soot, but we proffered solutions that yielded bountiful results to the benefit of Port Harcourt residents and Nigeria at large. The report entitled: A Study of Airborne Particulates Black Soot in Port Harcourt and its Environs had 20 recommendations, a sample of such recommendations reads:

> *Health Effects*: Noting that soot particles are well documented causes of respiratory illnesses, some cardiovascular conditions and most especially in the long term, they are also implicated in the development of cancer of the skin, lung, renal, prostate, etc. consequently, the following is suggested for ease of accessibility of treatment and rehabilitation services when required by any affected resident:
>
> The establishment and equipment of the state-of-the-art cardio-respiratory centre to manage and diagnose all forms of cardio-respiratory conditions will be of great advantage to residents of the State. Similarly a cancer treatment centre in the state will raise the bar on the standard of medical treatment centre in the State will raise the bar on the standard of medical treatment services …. (Government of Rivers State, 2019).

That Government established cardiovascular and cancer treatment centres are testimonies to the influence of our study which was presented to State Executive Council.

5.5 Recollection of Tank Farm Explosion Emission Spread

The atmospheric emissions transfer and air quality impact arising from three crude oil tank fire explosions at Ebocha Oil

Centre and Operational Facilities which took place on the 28th of June, 2015, and lasted for about 3 days before it was put off are here evaluated. The assessment of the explosion area was necessary in order to determine the air quality impact and possible contribution of the tank explosion on the air quality of the atmosphere of surrounding settlements. Google Image plot of the Oil Centre is presented in Figure 21.

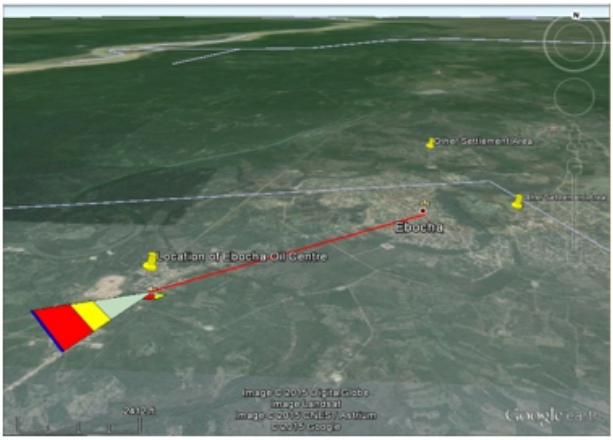


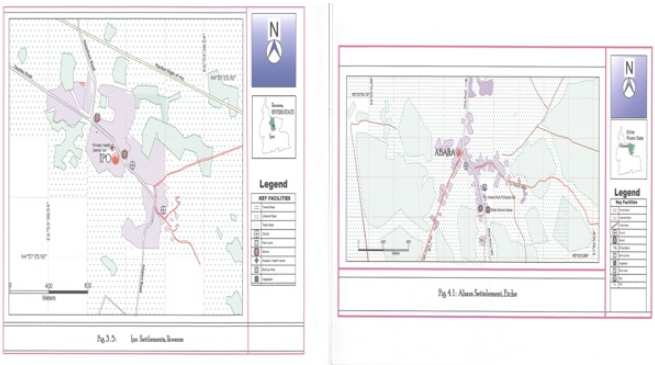
Figure 21: Google Map Image of Ebocha

The built-up area of the settlement begins at 3km with Ebocha community from the tank explosion point and luminous glare from the explosion site was felt from every position in the nearby communities. The wind trajectary (coming from southwesterly) of Ebocha Oil Centre relative to the north and northeastern directions of major human settlements is illutrated in Figure 19. The choropleths from AirWare model outputs show that the entire distance downwind falls within the maximum impact range of 100 km as obtained from the modelling. This implies that the numerous human settlements in the north and north-eastern directions of the Ebocha Oil Centre

where the tank explosions took place impacted up to 100km downwind. Suspended smoke and particulate matter which were over 96% higher than the national and international ambient permissible limits for hourly and daily average values were heavily loaded into the atmosphere and transferred to these settlements. Also, NO_x concentrations were higher than the ambient standards for the hourly average, while that of SO_x and CO were higher than the national and international permissible limits for daily averages from hourly values. The adverse effects of these pollutants on human health were as well highligted in this study. These conclusions are presented in Ede and Edokpa (2017a)

5.6 GIS Mapping for Epidemiological Survey

As part of the implementation of malaria control interventions, the Rivers State Government through the State Ministry of Health in conjunction with the World Bank-supported Nigeria Malaria Control Booster Project (MCBP) saw to embark on an Indoor Residual Spraying (IRS) activities in two local government areas; namely, Ikwerre and Etche, with Emuoha serving as control. The greatest achievement of this mapping exercise was the production of over 50 original maps in the local government areas surveyed.



Figures 22 & 23: Two Map Samples in the Study

In broad terms, the Geographic Information System obtained in this work achieved the required objectives.

- Identifying suitable locations that have relevant attributes. For example, finding a suitable location where an airport, a plantation, forest, a clinic, schools, town halls, ponds, etc. are located in the LGA's.
- Querying the geographical attributes of the specified location. For example, examining the roads in a particular locality, to check road density or find the shortest path, and so on.

The field exercise achieved 100% milestone as at the end of the project, all settlements in Ikwerre and Etche LGA were enumerated. Maps for the various settlements in the two LGAs were completed alongside quality checks. Similar operations were conducted by Ogbonna, Ede and Okeke (2006) using satellite imagery interpretation and ground survey of erosion sites in Isuikwuato area of Abia State.

5.7 Critical Decision Support Surveys

Every business organisation needs to appraise its operating environment from time to time in order to ascertain possible threats and opportunities for its continuous sustainable progressive advancement. In this instance the survey focused on determining the dynamics of changing perceptions within and amongst host communities. It assessed the impact of the initiative and how to engender improved perception within the communities where they operate. In addition, the findings helped to do a trend analysis of perceptions expressed in the present and previous surveys, so as to facilitate their trust rebuilding efforts in the host communities. The study further investigated what changes form the attitude of respondents, why

there is no trust, the biggest single thing that can build trust, mutual respect and friendliness.

The general perception of the firm as a body-corporate is that they have not changed their attitude of making promises and not fulfilling them. This is the main reason most of the respondents in the communities studied have distrust for the company and look forward to improvement.
The innovation in this study was the introduction of the "traffic light" system in Table 2 to simplify and grade changes of trend in community responses.

Table 2: Actual Reproduction of a Traffic Light

							option 1		option 2
B1 Has SPDC delivered benefits?	B2 Has SPDC harmed your community?	B2.1 Has it repaired the damage?	B3 Do you trust SPDC?	B4 Does SPDC fulfi promises?	B6 Should SPDC stay or leave?			numerical average	most common response
3.0	3.0	5.0	3.0	5.0	1.0		20.0	3.3		
3.0	5.0	5.0	5.0	5.0	1.0		24.0	4.0		
5.0	1.0	5.0	3.0	3.0	1.0		18.0	3.0		
1.0	3.0	5.0	3.0	3.0	1.0		16.0	2.7		
5.0	1.0	5.0	3.0	5.0	1.0		20.0	3.3		
5.0	3.0	5.0	3.0	3.0	1.0		20.0	3.3		
5.0	1.0	5.0	5.0	5.0	5.0		26.0	4.3		
5.0	1.0	5.0	3.0	5.0	1.0		20.0	3.3		
5.0	3.0	5.0	5.0	5.0	1.0		24.0	4.0		
5.0	1.0	5.0	5.0	5.0	1.0		22.0	3.7		
5.0	3.0	5.0	5.0	5.0	3.0		26.0	4.3		
5.0	3.0	5.0	3.0	3.0	1.0		20.0	3.3		
3.0	1.0	5.0	3.0	3.0	1.0		16.0	2.7		
5.0	1.0	5.0	3.0	3.0	1.0		18.0	3.0		
5.0	1.0	5.0	5.0	5.0	1.0		22.0	3.7		
5.0	3.0	5.0	3.0	3.0	1.0		20.0	3.3		
5.0	1.0	5.0	3.0	5.0	1.0		20.0	3.3		
5.0	3.0	5.0	3.0	5.0	1.0		22.0	3.7		

Recommend **option 2** (ex. Ekugba has 4 reds and numerical average = orange so think more accurate to go for a majority of opinion = option 2)

Key questions from questionnaire relating to relationshipo with SPDC used

System used is based on NUMBERS of people who feel unfavourbale, not on intensity of their feelings

red		5
orange		3
green		1

5.8 Cumulative Impact Assessment Studies

Through modelling cumulative impacts can be assessed (Ede & Sonibare, 2009; Sonebare and Ede, 2009; Ede *et al*., 2011; Ede & Edokpa, 2010, Ede *et al.,* 2011). Air quality assessment addressing effects arising from proposed projects and other past, existing, and proposed projects in a project's area can be evaluated.

The purpose of modelling air quality and impact evaluation is to identify the cumulative effects of emissions of criteria air pollutants. The specific objectives are usually to:

a) Identify sources of air emissions originating from a project.
b) Identify the other projects with specific sources of air emissions located around the project area
c) Estimate the emission rates of air quality parameters from each of the identified sources
d) Predict ground level air quality changes at some important receptor locations
e) Assess the potential human health and aesthetic effect of the air emissions at some important receptor locations.

The Industrial Source Complex (ISC) air dispersion modelling tool was employed using air pollutant emissions from the project with some operation scenarios. The ISC is an air dispersion model from the United States Environmental Protection Agency (US EPA) which can be used to determine the concentration of air pollutants around industrial sources. The magnitude of this concentration is used to determine whether or not the human health or welfare will be adversely affected. The model was used to predict the magnitude of air quality parameters from point sources in the project area within some defined distances. The identified primary sources include fired heater stacks, gas flares, power plant stacks, and the

compressor stacks.

With the background concentrations obtained from a project's approved environmental impact assessment (EIA) reports, the obtained concentrations from the project area are compared to the Federal Ministry of Environment and the World Bank Standards to the determine the carrying capacity of the project area in terms of air pollution. Fugitive emissions are also given due consideration. A cumulating to predict a noise impact is presented in Figure 24.

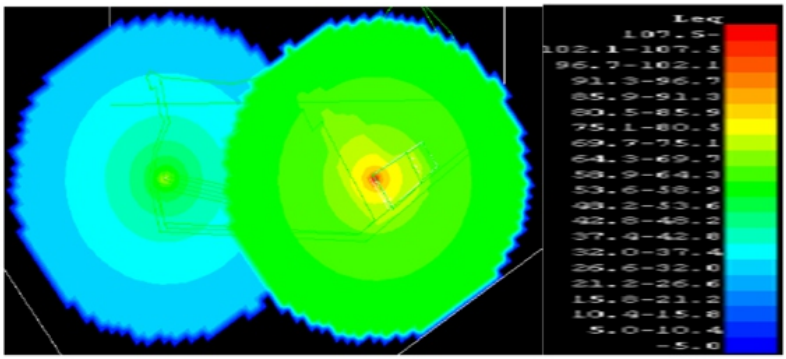


Figure 24: Typical Interacting Model Output (Source: Ede & Sonibare, 2009)

5.9 Climate Change Study of Rivers State

First comprehensive appraisal climate change Drivers, risks, vulnerability and mitigation in Rivers State was published by Ede *et al.* (2016). Climate change is a cogent threat to human development and in some places, it is already undermining the achievement of the Millennium Development Goals (MDGs) and the international community's efforts to reduce extreme poverty. The world is now warming faster than at any point in recorded history. Warmer temperatures over time are changing weather patterns and disrupting the usual balance of nature. This

poses many risks to human beings and all other forms of life on Earth. UNEP (2022) also observed that most emissions of GHGs come from just a few countries. The evidence of world climate change are many, but actions to stem it through the Paris Accord of 2015 has been very slow. In response, Nigeria has promulgated a Climate Change Act of November 2021 in order to provide a legal framework for the country to achieve its climate goals, achieve long-term social and economic sustainability, and resilience. Vulnerability to climate change depends on a number of factors, the most important of which are: the ecological zone, level of technological advancement, resources, especially finance and the level of resilience of the victims. Extreme changes in climate have a direct impact on local infrastructure and indirectly produce social conflicts affecting the access to basic needs of food, housing and health. Geography plays a significant role in shaping climate patterns, and changes in the physical features of the Earth can dictate extent of climate change. For example, deforestation can lead to a rise in temperatures and decreased rainfall, contributing to climate change

5.10 Institutional Planning Frameworks

Through numerous institutional collaborations and synergy, we bridged the gap between the town and gown in the planning of Greater Port Harcourt (Ede, 2008, Ede, Owei & Akarolo, 2011). In the drafting of the "Green Book" on environmental regulations in Rivers State (Ede, 2010). A memorandum on the status carbon emissions to the International Society of City and Regional Planners, The Hague, Netherlands (Ede & Owei, 2009). A security agency was also advised and trained on mapping and target location in law enforcement (Ede, 1995a). Other institutional advice were given to Rivers State Sustainable Development Agency (2008); the Niger Delta

Development Commission (2006) and the National Emergency Management Agency (2017), also in Ede *et al.* (2018) for emergency early warning system. In Ede, Edokpa and Aminigbo (2022) a role for air quality in Port Harcourt's physical plans was advocated in view of the huge impact of air pollution on urban dwellers in the region.

6.0 CONCLUSION

Vice-Chancellor Sir, ladies and gentlemen, if it is academics only, I have done more than my fair share and was rewarded handsomely. As at today, and for a large part of my life I feel inherently fulfilled in the direction my academic efforts has taken. My purpose here today is to speak to you about geography, as an academic discipline and my contributions through applied climatology. To share with you the wonders of it and the fortune it confers; and I am certain that I have proven myself. What I am now is what I have always wanted to be. Study a course that I have a passion for, hope that it translates to a thoroughly fulfilled life that may pay my bills. I happily announce that that is exactly where I am now. I may find it difficult to convince my audience that this is how it is, but that is how it is anyway. I can only advice those coming after me not to remove commitment, hope and passion from their lives. I stand before you today to demonstrate how concerted academic effort produces practical solutions and explanations to the problems humankind face and I did my fair share as an academic in my field when challenged to. Poor air quality has introduced a new dimension to the commercialization of life. In many places on earth people breath unwholesome air. An igneous entrepreneur in India has even introduced oxygen kiosks in Delhi. BBC REEL November 21, 2019: the Bar Selling Oxygen to Check City Air Pollution www.BBC.com. It is no more futuristic

thinking that the rich influence the air quality around them, they are already able to modify it through air conditioning, while the poor can be trapped in poor air quality. In many instances, I analysed the trajectory of emissions and found that it targeted the deprived locations as sensitive receptors. Air quality is fast becoming an economic variable whereby the rich and most endowed has the capacity to modify and ameliorate poor air quality, while the wretched are left to a miserable fate. Major international news outlets like CNN now broadcast update on air quality as they do for weather using the principle of air quality index (AQI), which we have variously applied in Kanee *et al*. (2020). You cannot stand on this podium as I am doing this moment without realising how fortunate life is. I am fortunate to earn a good education, I am enriched by the profound intellectual attainment that education offered. Learning changed me mentally and materially and gave me a broader view of the universe. I am indebted to the vision of the world and knowledge geography provided. I am not a professor because I read geography, I am because geography gave me tools to break intellectual barriers.

6.1 Recommendations

The manmade atmospheric crisis is a product of modern lifestyle and development. Individuals, society and government can do a lot to reverse the negative trend as listed below.

What you can do as an individual

- Conserve energy - at home, at work, everywhere.
- Look for the ENERGY STAR label when buying home or office equipment.

- Carpool, use public transportation, bike, or walk whenever possible.
- Follow gasoline refuelling instructions for efficient vapour recovery, being careful not to spill fuel and always tightening your gas cap securely.
- Consider purchasing portable gasoline containers labelled "spill-proof," where available.
- Keep car, boat, and other engines properly tuned.
- Be sure your tires are properly inflated.
- Use environmentally safe paints and cleaning products whenever possible.
- Mulch or compost leaves and yard waste.
- Consider using gas logs instead of wood.

*On Days when High Ozone Levels are Expected, Take these Extra Steps to Reduce Pollution***:**

- Choose a cleaner commute - share a ride to work or use public transportation.
- Combine errands and reduce trips. Walk to errands when possible.
- Avoid excessive idling of your automobile.
- Refuel your car in the evening when its cooler.
- Conserve electricity and set air conditioners no lower than 78 degrees.
- Defer lawn and gardening chores that use gasoline-powered equipment, or wait until evening.

On Days when High Particle Levels are Expected, Take these Extra Steps to Reduce Pollution:

- Reduce the number of trips you take in your car.
- Reduce or eliminate fireplace and wood stove use.
- Avoid burning leaves, trash, and other materials.
- Avoid using gas-powered lawn and garden equipment

What Nigeria Can Do to Beat Air Pollution

- Fuel subsidy as practiced in Nigeria is not only a drain on the economy because it distorts the urgently needed energy mix for the country.
- Nigeria ought to show leadership on issues of air pollution since so many of its citizens die from it.
- A national emissions inventory database and directory should be published.
- National and regional air quality targets should be instituted with firm commitments to limits, targets and strategy
- There are no statistics on emissions, air quality trend and related indicators; if you want to know about the impact of air pollution in Nigeria approach WHO and its database.
- No clear-cut vehicle emission standards, maximum allowable sulphur content in fuel in Nigeria

7.0 ACKNOWLEDGEMENT

Let me begin by thanking the Vice-Chancellor of this great University, Professor Nlerum S. Okogbule, FArb, DSSR, for giving me this platform to showcase my academic achievements through this inaugural lecture. Since I am still working under him, and there is more to learn from his I will leave further comments about his immeasurable support to me for a future occasion.

I am privileged to have His Royal Majesty, Eze Uche Eliku, the paramount ruler of Port Harcourt and his entire cabinet in attendance. Your Majesty Sir, your being here in person has bestowed an uncommon honour to me.

I do not have any person who taught me in this University, however, my teachers made me. As good as my character can be while growing up, my teachers at all levels ignored my lapses and nurtured the best side of me that I today apply in situations that require tough decisions.

There are people in life your thoughts go to when you are challenged. These are your role models or mentors. I have many of such people in my life. One of such persons is Professor Opunebo Binya Owei, the former Acting Vice-Chancellor of this Great University, she is my God mother. Do not take my case to her because you are certain to loose. Another is Professor T. K. S. Abam, an unassuming academic giant. Professor Abam presided over all my promotions in this University, even before he became a Director, but my greatest debt to him is that he believes I am better than I think I am.

I have real friends and that is a privilege. Somebody is your friend because he cares, even when he has nothing to gain for doing so. I am blessed with many of such people, including so many that are here. I started making the list but dropped the idea because if I missed one of you out, it will be very painful to me.

Secondly the list grew too long.
In spite of my stern reputation with students, half of the people I call my friends are my students. There is hardly an establishment where I do not meet at least one of them and they are spread across the country and the world. Again the list is too long for me to read out here.
On many occasions in the last four weeks people have frowned for not being included in my inaugural working committee. We started with a handful of staff in Geography Department to over ten committees and about 200 membership. I was expelled from the committee at the first meeting because they told me not to raise a finger to do anything as far as my inaugural lecture was concerned. For a person like me you can imagine my anxiety if left in the dark for a project of this magnitude. All members of my inaugural lecture committee carried out their assignment so well that I will forever owe them gratitude.
Family is what I live for. In them I find a reason to go the extra mile. I therefore thank my children: Lambert, Oma, Huoma, Emily, Mich and Nkanuye for their care and love.
Finally, I glorify God for making this day possible. There is nothing in my past that suggest that I will someday become a professor, yet I am and I have tested my capacity in far too many platforms, home and abroad, to convince myself that I am. Only God knew, even before I was born that I can become and here I am. I therefore give Him the greatest acknowledgement and all the glory.

REFERENCES

Abade, E., (2021). Gas flares, oil spills worsen climate change in Niger Delta communities. The Guardian. https://guardian.ng/property/gas-flares-oil-spills-worsen-climate-change-in-niger-delta-communities/ accessed Jul 10 2023.

Abdullahi, Y. M., **Ede, P**., Ordinioha, B., & Jaja, B., (2023). Systematic Review on Common Diseases Associated with Crude Oil Exploitation in Niger Delta Nigeria OIRT Journal of Medical and Health Sciences, 3 (3) 62-66 DOI: https://dx.doi.org/10.53944/ojmhs-2341 https://journals.otuirt.com/index.php/OJMHS

Abdullahi, Y. M., **Ede, P**., Ordinioha, B., & Jaja, B., (2023). Exploring Hazards in Oil-Bearing Communities in Niger-Delta Region of Nigeria: A Comprehensive Study on Water, Soil and Health. OIRT Journal of Scientific Research, 3 (3): 53-61 DOI: https://dx.doi.org/10.53944/ojsr-2331 https://journals.otuirt.com/index.php/OJSR

Adewumi, A. A., Ogunbiade, O. R., Longe, O. O., Fadiya, O. O. & Adewumi, I. K. (2018). Climate change and the Niger Delta Region. *Advances in Social Sciences Research Journal* – 5 (9) 176-185.

Africa Union (2023). The African Leaders Nairobi Declaration on Climate Change and Call to Action. Nairobi, Kenya, September 6, 2023, 8pp.

Air Quality Life (2019). Can air pollution be predicted? https://www.iqair.com/international/blog/air-quality/can-air-pollution-be-predicted

Akinro, A. O., Opeyemi, D. A. & Ologunagba, I. B. (2008). Climate change and environmental degradation in the Niger Delta region of Nigeria: its vulnerability, impacts

and possible mitigations. *Research Journal of Applied Sciences* 3 (3): 167-173.

Amakiri, A. O.; A. Monsi, S. C. Teme, **P. N. Ede** (2008). Performance of broiler chickens exposed to flames and fumes from simulated crude petroleum burning. *Nigerian Journal of Animal Production* 35 (2) 170-177.

Amakiri, A. O. Monsi, A. and **P. N. Ede** 2008. Hormonal Response of Broiler Chickens exposed to simulated crude petroleum flame emissions. *Tropical Journal of Animal Science,* 10 46-49.

Amakiri, A. O., A. Monsi, S. C. Teme, **P. N. Ede**, O. J. Owen and E. M. Ngodigha (2009). Air Quality and micro-meteorological monitoring of gaseous pollutatnts/flame emissions from burning crude petroleum in poultry house. *Toxicological & Environmental Chemistry.* 91 (1-2) 225 – 232.

Andreae, M.O. & Gelencser, A. (2006). Black carbon or brown carbon? The nature of lightabsorbing carbonaceous aerosols, *Atmos. Chem. Phys.,* 6, 3131–3148.

Balogun, V. S. & Onokerhoraye, A. G. (2022). Climate change vulnerability mapping across ecological zones in Delta State, Niger Delta Region of Nigeria. *Climate Services*, 27: 1-16

Battarbee, R.W., Anderson, N.J., Appleby, P.G., Flower, R.J., Fritz, S.C., Haworth, E.Y., Higgitt, S., Jones, V.J., Kreiser, A., Munro, M.A.R., Natkanski, J., Oldfield, F., Patrick, S.T., Richardson, N.G., Rippey, B. & Stevenson, A.C. (1988) Lake Acidification in the United Kingdom 1800-1986

Climate Link (2019). Greenhouse emissions factsheet: Nigeria. climatelink.org, USAID.

Dawes S. (2013). Socioeconomic benefits of adding NASA

satellite data to AirNow. https://www.ctg.albany.edu/publications/reports/sti_finalreport

DevelopmentAid (2022). World's biggest problems on the UN list. https://www.developmentaid.org/news-stream/post/147458/top-10-world-problems-and-their-solutions. Accessed 13 October, 2023.

Duce, R. A. & Tindale, N. W. (2014**).** Atmospheric Transport of Iron and Its Deposition in the Ocean**.** *Limnology and Oceanography* 36, 1715-1726

Echendu, A. J., Okafor, H. F., & Iyiola, O., (2022). Air pollution, climate change and ecosystem health in the Niger Delta. *Social Sciences*. 2022; 11(11): 525. https://doi.org/10.3390/socsci1111052

Ede, P. N., (1995). An Analysis of the Atmospheric Impact of Gas Flaring in Rivers State. An unpublished MSc Dissertation, Department of Geography, Faculty of Social Sciences, Universty of Port Harcourt, Choba, Port Harcourt.

Ede, P.N., (1995a). 'Performance in service organizations: A focus on locating the target', in *Man and Society in Industrial Organizations*. P.B. Johnnie (ed.), Behaviour Systems and Publications, Port Harcourt. pp 229-244

Ede, P. N. & Asuebegun, A. (1995). Hydrogeomorphic considerations for the sitting of landfill in the coastal plain sands of Nigeria, *Journal of Geographic Thought,* 1 (2), 49-53.

Ede, P.N**.** (1998). Environmental degradation, oil wealth and poverty in Nigeria. *Nigerian Journal of Oil and Politics*, 1 (2), 5 -10.

Ede, P. N. (1998). Pollution and the Rivers State environment. *Nigerian Research Review*, 1 (1), 81-89

Ede, P. N. (1999). 'Air Pollution', in *Port Harcourt Region*, C.

U. Oyegun & A. Adeyemo, eds. Dept. of Geog. & Envir. Mgt., Uniport, Pub. Series; No.1 pp 229 – 244.

Ede, P. N. (2000). Estimation of atmospheric pollutants: a comparison of two methods. *Innovation and Discovery*, 12 (3), 158-162

Ede, P.N. & Johnson, G. A. (2001). Energy relation of gas estimated from flare radiation in Nigeria. *International Journal of Energy Research,* 25, 85-91.

Ede, P. N., Seiba, I. H., & Igwe, F. U. (2006). Combustion efficiency determined for selected flare points in the Niger Delta Area. *Afr. J. Environ Pollut. Health,* 5 (2), 19-25.

Ede, P. N**.,** A. O. Amakiri, A, Monsi and S. C. Teme, (2007). Growth performance Traits of Broilers Exposed to Crude Oil Flame Emissions. *Animal Production Research Advances,* 3(1): 69-77.

Ede, P. N., Wemedo, S. A. and Chuku, A. (2008). Building Design, ventilation and micro-climate: Implications for comfort and indoor air quality. *Journal of Nigerian Environmental society*. 4(2) 44 – 50.

Ede, P. N. (2008). SEA – Air Quality for Port Harcourt, Nigeria. Annexure A (Strategic Environmental Assessment, Greater Port Harcourt City Development Plan. Vol. 1: Urban Development Framework, Arcuss GIBB – Rivers State Government. pp68-84.

Ede, P. N. and J. A. Sonibare, 2009. Cumulative impacts of an integrated oil and gas project on the ambient noise of Niger delta area. *Journal of the Nigerian Society of Chemical Engineers.* 24 (1&2) 16 – 27

Ede, P. N.; Amadi-Alolote, I. & D. O. Mac-Barango (2009). A bioclimatic approach to shelter design in Nigeria. *The Nigerian Journal of Environmental Sciences*, 3 (1) 295-

323.

Ede, P. N. & O. B. Owei (2009). International Society of City and Regional Planners (ISOCARP) Low Carbon Project: The NIGERIA Experience. pp 41-44

Ede, P. N. & D. Edokpa (2010). Screening for air quality impact from a Rotary Kiln Incinerator in Port Harcourt. *Journal of Nigerian Environmental Society,* 5 (3) 88-98.

Ede, P. N. & Edokpa, D. (2010a) An analysis of current practices and future direction of sewage management in Port Harcourt. *Journal of Nigerian Environmental Society,* 5 (4), 29 – 42.

Ede, P. N., Obunwa, C. C. & S. C. Nlerumchi (2010). Air quality studies around some local palm oil mill plant at the northern fringes of the Niger Delta Area, *Nigeria. Journal of Chemical Society of Nigeria*, JCSN, 35 (2) 6-10

Ede, P. N. *et al.* (2010). Chapters 6, 16 & 20 of the Guidelines and Standards on Environmental Pollution Control and Management in Rivers State.

Ede, P. N., Edokpa, D and C. Israel-Cookey (2011). The Relative Contribution of an LNG Plant Emission to the Regional Air Quality of Nigeria. *Journal of the Nigerian Society of Chemical Engineers*. 26 (1) 1-11

Ede, P. N., D. O. Edokpa and O Ayodeji (2011). Aspects of Air Quality Status of Bonny Island, Nigeria Attributed to an LNG Plant. *Energy & Environment.* 22 (7) 891-909

Ede, P. N., Owei, O. B., & Akarolo, C. I. (2011, October). Does the Greater Port Harcourt Master Plan 2008 meet Aspirations for Liveable City? Proceedings of 47th Congress of International Society of Urban & Regional Planners (ISOCARP), Wuhan China

Ede, P. N. (2012). *Research in Environment.* Lambert

Publishers, Berlin. 212pp

Ede, P. N. & Pere, Y. (2013). Lung function of traffic wardens linked to airborne particulates in Nigeria. *Life Sciences Journal*, 10(4).

Ede, P. N. & Oriji, I. B. (2013). Emissions from Private Power Generating Equipment in Port Harcourt, Nigeria. *Nature and Science*, 2013;11(4) 59-64,

Ede, P. N. (2015). Morphometric features of a low-elevation urban catchment and the implications for flooding. *Global Journal of Geological Sciences,* 14, (20), 9-14.

Ede, P. N. & Edokpa D. O. (2015). Regional Air Quality of the Nigeria's Niger Delta. *Open Journal of Air Pollution*, 4, 7-15

Ede, P. N., Gobo, A. E., Eze, C. L., A. Ayotamuno, & T. K. S. Abam (2016). *Scenario Planning for Climate Change Mitigation and Adaptation in Rivers* State. Kantz Repronics Company, Port Harcourt, 71pp

Ede, P. N. & Edokpa, D. O. (2017). Emissions dispersion simulation for a crude oil tank farm explosion in the Niger Delta of Nigeria. *Journal of Nigeria Environmental Society*, 11 (1) 1-16.

Ede, P. N. & Edokpa, D. O. (2017a). Satellite determination of particulate load over Port Harcourt during black soot incidents. *Journal of Atmospheric Pollution*. 5 (2).

Ede, P. N., Mmom, P. C., & Edokpa, D. O. (2018). An exploratory flood early warning system for the Niger Delta. *Journal of Nigeria Environmental Society*, 12(1): 10-15.

Ede, P. N., Ubong, I. U. & Osuagwu, O. N. (2018). Lichen as indicator for air pollution in Port Harcourt City. *Journal of Geosciences and Environmental Research,* 1(1): 70-75.

Ede, P. N. (2020). Air pollution in the Niger Delta. In Akpokoje, E. G. & A. Derefaka (eds), *The Niger Delta: An Environmental Perspective*. Onyoma Research Publications, Port Harcourt, pp 112-116

Ede, P. N., Edokpa, D. O., Aminigbo, L. M., (2022). A role for air quality in Port Harcourt's physical plans, in Landuse Planning and Environmental Management in Nigeria. A festschrift for Professor Opuenebo Binya Owei, Ede, P. N. and Nwokaeze, E. C. (eds). Department of Urban and Regional Planning, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, pp 63-73.

Edokpa DO and **Ede, P. N**. Challenge of Associated Gas Flaring and Emissions Propagation in Nigeria. *Academia Arena* 2013; 5(4) 28-35

Edokpa, D. O. & **Ede, P. N**. (2018). An evaluation of the carbon dioxide emissions of a liquefied natural gas plant in Nigeria. *American Journal of Environmental Engineering and Science*, 5(3): 27-32.

Edokpa, D. O. & **Ede, P. N**. (2019). Preliminary air quality index estimates of particulates concentration in Port Harcourt during soot incidents. *International Journal of Innovative Studies in Sciences and Engineering Technology, IJISSET,* 5(5), 25-29.

Elenwo, E. I. & Akankali, J. A. (2014). Impact of climate change on aquatic fauna of economic importance in Niger Delta, Nigeria. *Atmospheric and Climate Sciences* 4, 710-720.

Forouz M. (2016). Global burden of diseases, injuries, and risk factors study 2015. https://www.ncbi. nlm.nih. gov/pubmed/27733284

Galloway, J.N., Thornton, J.D., Norton, S.A., Volchok, H.L., & McClean, H.L. (1982). Trace metals in atmospheric deposition: A review and assessment. *Atmospheric*

Environment 16, 1677-1700

Hadlington, S. (2015). Air pollution model predicts 6.6 million deaths by 2050. *Chemistry World.* https://www.chemistryworld.com/news/air-pollution-model-predicts-66-million-deaths-by-2050-/8956.article

Hartman, B. (2017). Scientists Say Air Pollution Will Be Our Top Killer by 2050. http://longevityfacts.com/scientists-air-pollution-top-killer-2050-global-warming-health/

Hilton, B., (2022). Is Climate change the greatest threat facing humanity today? https://80000hours.org/problem-profiles/climate-change/

Hutton, M. & Symon, C. (1986). The quantities of cadmium, lead, mercury and arsenic entering the UK environment from human activities. *Science of the Total Environment* 57,129-150

Ikehi, M., Onu, F., Ifeanyieze, F. & Paradang, P. (2014) Farming families and climate change issues in Niger Delta Region of Nigeria: extent of impact and adaptation strategies. *Agricultural Sciences*, 5 (12): 1140-1151.

JINN (2010). *Gas Flaring in Nigeria: An Overview*. Justice in Nigeria Now. online

Kanee, R. B., Adeyemi, A., Edokpa, D. O., & **Ede, P. N**. (2020). Particulate matter-based air quality index estimate for Abuja, Nigeria: Implications for Health. *Journal of Geoscience and Environment Protection,* 8, 313-321. https://doi.org/10.4236/gep.2020.85019

Kanee, 1. R., **Ede, P. N**., Maduka, I. O., Owhonda, G., Aigbogun Jr., E., Alsharif, K. F., Qasem, A. H., Alkhayyat, S. S. & Batiha, G. E. (2021). Polycyclic aromatic hydrocarbon levels in wistar rats exposed to ambient air of Port Harcourt, Nigeria: an indicator for tissue toxicity. *International Journal of Environmental*

Research and Public Health, 18, 5689 1-21

Kanee, R., **Ede, P.,** Gobo, A., Maduka, O., Owhonda, G., Eric, A., Usman, I. (2022). Histopathological evaluation of Wister rats exposed to particulate matter polluted ambient air of Port Harcourt metrolpolis, Rivers State, Nigeria. KIU Journal of Health Sciences, 2(1) 13-25

Kelly F. (2015). Air pollution and public health: emerging hazards and improved understanding of risk. DOI: 10.1007/s10653-015-9720-1

Larsen, B., Hutton, G., & Kkanna, N. (2008). *The Challenge of Air Pollution*. Copenhagen Consensus Center. http://www.jstor.org/stable/resrep16379. Accessed 8 October, 2023.

McCollum, D. L., Krey, V. Riahi, K. Kolp, P. & Makowski, M. (nd) Climate policies can help resolve energy security and air pollution challenges. International Institute for Applied Systems Analysis, IIASA.

McGrath, M., Poynting, M., Dale B., & Tauschinski, J (2003). World breaches key 1.5C warming mark for record number of days, BBC Science. **https://www.bbc.com/news/science-environment-66857354** Accessed 8 October, 2023.

Mission (2015). Air Pollution Solutions, Mission 2015: Biodiversity. http://web. mit.edu/12.000/www/m2015/2015/airpollutionsolutions.html

National Geographic (2019). National Geographic Environment: Air Pollution. National Geographic, Washington DC. https://www. nationalgeographic.org/encyclopedia/air-pollution/

National Geographic (2022). On January 13, 1888, the National Geographic Society was founded. https://education.nationalgeographic.org/resource/national-geographic-

society-founded/ Accessed 13 October, 2023.

NASA (2023). Global Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/evidence/#:~:text=Scientific%20information%20taken%20from%20natural,signs%20of%20a%20changing%20climate. Assessed 10 July, 2023.

Newair, (2019). Air Pollution: Understanding the Problem and Ways to Help Solve It. https://www. newair.com/blogs/learn/air-pollution-understanding-the-problem-and-ways-to-help-solve-it

NGDC (2011). *Global Gas Reduction Estimates*. NOAA National Geophysical Data Centre: Earth Observation Group.http://www.ngdc.noaa.gov/dmsp/interest/gas_flares_countries.php

Nriagu, J.O. (1989**)** A global assessment of natural sources of atmospheric trace metals. *Nature* 338, 47-49.

Nriagu, J.O. & Pacyna, J.F. (1988). Quantitative assessment of worldwide contamination of air, water, and soils by trace metals. *Nature* 333, 134-139

Nwagwu, C., **P. N. Ede**, Okoli, I. C., Chukwuka, O. K. & Okoli, G. C. (2010) Study on Late Rainy Season Aerial Pollutant Gases Concentrations in Tropical Poultry Pen Environment in Nigeria. *International Journal of Tropical Agriculture and Food Systems*, 4(3): 188 – 194.

Nwagwu, C., **P. N. Ede**, Okoli, I. C., Chukwuka, O. K. & Okoli, G. C. (2011) Evaluation of aerial pollutant gases concentrations in poultry pen environments during early dry season in the humid tropical zone of Nigeria. *Nature and Science,* 2011;9(2) (USA)

Nwagwu, C., **P. N. Ede**, Okoli, I. C., Chukwuka, O. K., Okoli, G. C. & Moreki, J. C. (2012). Effect of Environmental Factors and Structural Dimensions on Aerial Pollutant

Gas Concentrations in Tropical Poultry Pen in Nigeria. *Int J App Poult Res*, 1(1): 15-20

Obunwo, C. C., **Ede, P. N.,** & Jegede, M. (2009). Estimation of methane from two mangrove habitats in Port Harcourt of the Niger delta area, Nigeria. *International Journal of Chemistry*, 1 (1) 62 – 65.

Okpara, J.N., Tarhule, A. A., & Perumal, M. (2013). Study of climate change in Niger River basin, West Africa: reality not a myth, in Bharat Raj Singh (ed.) *Climate Change.* InTech. doi: 10.5772/55186

Ogbonna, U. F., **Ede, P. N.,** & Okeke, F. I (2006). Satellite imagery interpretation and ground survey of erosion sites in Isuikwuato area of Abia State. *JOGET*. 7 (1&2) 68-80.

Ogundipe, S. (2019). Air pollution: Nigeria ranks 4th deadliest globally. *Vanguard,* September 1, 2018

Oloyede, M., & **Ede, P. N**. (2020). Source apportionment and risk assessment of polycyclic aromatic hydrocarbons in black carbon monitored in Port Harcourt, Rivers State, Nigeria. *International Journal of Innovative Science and Research Technology*, 5 (8): 653-663.

Onwuemele, A. (2015). Livelihood responses to climate change in the Niger-delta: implications for food security in Nigeria. *International Journal of Development and Management Review.*10, 125-135

Panofsky, H.A., (1976): "Air pollution Meteorology" *Encyclopedia of Environmental Sciences and Engineering*. Pfattlin and Ziegler ed. Vol. 1 Gorden and Breach Science Publishers, New York.

Prüss-Ustün A. (2016). Preventing disease through healthy environments.http://apps.who.int/iris/bitstream/10665/204585/1/9789241565196_eng.pdf

Schwartz, J. (2007). Future air pollution levels and climate change: a step toward realism. *World Climate Report: Environmental and Energy Economics*. https://sciencing.com/future-effects-pollution-16270.html

Rivers State Ministry of Environment (2017). Report on Particulate Matter (soot) Analysis on Some Parts of Port Harcourt. Government of Rivers State of Nigeria, Port Harcourt. 16pp.

Rivers State Ministry of Environment (2019). *A Study of Airborne Particulates "Black Soot" in Port Harcourt and its Environs*. Government of Rivers State of Nigeria, Port Harcourt, 139pp.

Sonibare, J. A. and **Ede, P. N**. 2009. Potential impacts of integrated oil and gas plant on ambient air quality. *Energy and Environment.* 20 (3) 331 – 345. Multi-Science Publishing Co. UK

SPDC (2017). Soot Report: Ambient Air Characterisation of Selected Areas in Port Harcourt. Shell Petroleum Development Company of Nigeria, Port Harcourt.

Stefan, I. A. & Filip, F. G. (2011). Emergent frameworks for decision support system, *infomatica Economica*, 15(1): 92-103.

Stephen, Y. R., **Ede, P. N**., Amakiri, A. O., & Igwe, F. U. (2021). A review of the prevalence and effects of particulate air pollution in Port Harcourt metropolis, Rivers State, Nigeria.

Stephen, Y. R., **Ede, P. N**., Igwe, A. O. & Amakiri, A. O. (2021). Effects of petroleum-based particulate air pollutants on lipid profile of adult wister rats in Port Harcourt metropolis, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology,* 15(8): 19-24.

StudySmarter (2023). Evidence for Climate Change: Explained.

https://www.studysmarter.co.uk/explanations/geography/living-with-the-physical-environment/evidence-for-climate-change/#:~:text=5%20pieces%2 Assessed July 10, 2023

Superprof (2021). How Many Gods Are There In Japanese Mythology? https://www.superprof.com/blog/how-many-gods-are-there-in-japanese-mythology/#:~:text=Kami%20are%20the%20divine%20spirits,in%20Japanes Accessed: October 23, 2023.

Tawari, C. C. & Abowei, J. F. N. (2012). Air pollution in the Niger Delta area of Nigeria. *International Journal of Fisheries and Aquatic Sciences,* 1(2), 94-117.

Udoma, U, & Osagie, B. (nd). The Climate Change Act 2021: Key Points for Consideration. 5pp. https://uubo.org/wp-content/uploads/2023/01/THE-CLIMATE-CHANGE-ACT-2021-KEY-POINTS-FOR-CONSIDERATION.pdf Assessed July 27, 2023

Ujile, A. A. & **P. N. Ede** 2012. Sensitivity analysis of pollutants formation from wick-burnt kerosene fired flame to ambient air. I*nternational Journal of Academic Research*. 4 (5) 204-210

US EPA (2018). Actions You Can Take to Reduce Air Pollution. United States Environmental Agency, Region 1: EPA New England. Last updated September 27, 2018.

UN Climate Action (2023). Causes and effects of climate change. https://www.un.org/ en/climatechange/ science/causes-effects-climate-change. Accessed 10 July 2023.

UN Climate Action (2023). For a livable climate: Net-zero commitments must be backed by credible action. https://www.un.org/en/climatechange/net-zero-coalition **Climate Action** Assessed 10 July 2023

UNEP (2011). *Environmental Assessment of Ogoniland.* United Nations Environmental Programme, Nairobi. 262pp

UNEP (2019). China to host World Environment Day on Air Pollution. Press Release, 19 March, 2019. https://www.unenvironment.org/news-and-stories/press-release/china-host-world-environment-day-2019-air-pollution

United Nations Environment Programme, UNEP (2022). *Emissions Gap Report 2022: The Closing Window — Climate crisis calls for rapid transformation of societies*. Nairobi. https://www.unep.org/emissions-gap-report-2022

Usang, E.E. & Ikpeme, N.J (2015). The Niger Delta oil rich region: the paradox of fascination and horror. *Academic Journal of Interdisciplinary Studies,* 4 (1), 117-124.

Wang H. (2016). Global, regional, and national life expectancy, all-cause mortality, and cause- specific mortality for 249 causes of death, 1980–2015. DOI: 10.1016/S0140-6736(16)31012-1

Weli, V.E. & Kobah, E. (2014). The air quality implications of the SPDC-Bomu Manifold fire explosion in K-Dere, Gokana LGA of Rivers State, Nigeria. *Research Journal of Environmental and Earth Sciences*, 6 (1): 1-9.

Wemedo, S. A., **Ede, P. N.** & Chuku, A. (2012). Interaction between building design and indoor airborne microbial load in Nigeria. *Asian Journal of Biological Sciences,* 5 (4),183-191.

WHO, 2007: Estimated deaths and DALYs attributable to selected environmental risk factors by WHO member state in 2002. World Health Organization. Geneva. www.who.int/quantifying_ehimpacts/countryprofilesebd.xls

WHO (2019). How air pollution is destroying our health. *WHO News & Event*, Geneva

World Bank (1995). Defining an Environmental Development Strategy for Niger Delta: Volume II Industry and Energy Operations Division West Central Africa Department. The World Bank, Washington DC, 153pp

Worldometer (2023). Carbon Dioxide (CO2) Emissions by Country – Worldometer. https://www.worldometers.info/co2-emissions/co2-emissions-by-country/ Accessed November 1, 2023.