Environmental and Health Effects of Air Pollution in Port Harcourt, Nigeria

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ABSTRACT

The paper examined environmental and health impacts of air pollution in Port Harcourt using cross-sectional research design. Concentration levels of major air pollutants ($PM_{2.5}$ & $PM._{10}$, CO_2, CO including black soot, SO_2, NO_X, and VOC) were determined using Met-One GT-321 Hand-held Particle Counter; and Extech Digital Hygro-thermo-Anemometer 45170 for meteorological data. The study revealed that air pollution in Port Harcourt causes metal corrosion, reduction in visibility; eye irritations, bronchial and respiratory disorders. The main responsive pollutant is $PM_{2.5}$. Air Quality Index (AQI) is mostly unhealthy (100-221) in the morning hours and moderate (60-98) in the evening. The level of pollution is higher in the dry seasons than in the rainy seasons. Total village and Trans-Amadi I.A. are the most polluted areas (AQI range of 80 and above). AQI is moderate (40-94) at D/Line and Old G.R.A; while Onne area is the least polluted zone with AQI of 24-45 (good). Mean values in the ***morning hours*** *are: $PM_{2.5}$ (30µg/m^3), PM_{10} (38.5µg/m^3), SO_2 (41ppb), NO_X (5ppb), VOC (98.5µg/m^3);* ***evening hours:*** *$PM_{2.5}$ (32.8µg/m^3), PM_{10} (43µg/m^3), SO_2 (28.5ppb), NO_X (5.8ppb), VOC (14.25µg/m^3), and* ***night hours:*** *$PM_{2.5}$ (32.8µg/m^3), PM_{10} (43µg/m^3), SO_2 (28.5ppb), NO_X (5.9ppb), VOC (14.25.5µg/m^3).* ***Wind directions*** *in the morning is 16^0 (S-W), speed 1.2m/s. From 6pm to late nights, it changes to 2150 (N-E), speed 5.3m/s. Most discomforting nights in Port Harcourt occurs when wind direction shift to 2610 eastward at 0.6m/s (still air). The paper recommended for strict monitoring of air-pollution related activities.*

Key Words: *Port Harcourt; air pollutants; effects; Air Quality Index (AQI)*

INTRODUCTION

Planet Earth for now, is the only place man can comfortably dwell, because of the abundance of life-supporting elements and mineral substances such as free oxygen and adequate water supply. Thus, a sustainable environment is a prerequisite for man's continual stay on earth. This imply that the symbiotic relationship and spatial interaction between man and his environment must be in constant 'check and balance' in the course of every developmental strives. The principles of environmental justice and fairness, and resources protection and conservation (such as atmospheric and water resources protection) must be consciously observed at all times. In a nutshell, the earth environment is the home of mankind and other living matter. This 'earth environment' is in constant change due to threats from man's activities.

The main sources of environmental contamination and pollution are from both natural and anthropogenic sources but with the latter being the main cause of air pollution. However, it is important to remind us here that both contaminants and pollutants are physical, chemical, biological or radiological substances or matter (e.g. heat) that poses some level of effects on soil/land, water or air. They are either natural or anthropogenic in origin [Ukpere & Wabah, 2016]. **Example of Air Contaminants common in Port Harcourt region** include toxic metals in fine particulate form from metallurgical operations (along Trans-Amadi IA, Industry road, East-West road), large quantities of CO_2, CO and SO_2, from coal and fuel burning processes, certain chemical substances like nitrates, sulfates, phosphates, surfactants and hydrocarbons, and other organic components from chemical and petrochemical industries (around Rumuolumeni axis, Trans-Amadi IA, Aba road and Eleme bloc, etc.).

Pollutants common in Port Harcourt region- Most of the dangerous pollutants found in water, soil or atmosphere are mainly from anthropogenic sources. For example, power generating plants, commercial and domestic heating units as well as transport vehicles release a lot of gaseous pollutants. These air pollutants are from inorganic or organic sources. Inorganic pollutants include SO_2, Cl_2 NH_3, CO_3 and ions like halides, NO^-_3; trace metals such as As, Bi, Co Cr, Cu, Fe, Hg, Mo, Ni, Pb, Sb, Se, Sn and volatile organic pollutants which are mostly hydrocarbons e.g. polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), organic solvents, organometallic compounds, pesticides, and surfactants [Ukpere, 2017; Narayanan, 2011; Kaushik & Kaushik, 2008].

CONCEPTUAL UNDERPINING

The concept **'environment'** is used in different fields (environmental sciences, physical and natural sciences, social sciences, engineering, medicine, creative arts and the humanities). Thus as a concept, it has varied definitions based on the fact that 'environmental science' as a discipline, is a multi-disciplinary field with different approaches to the study of the different facets of the environment which cut across biogeochemical processes and social systems. These various approaches to the study of the environment have also led to the emergence of different concepts with multiple explanations and definitions. Nevertheless, there is always a common front as long as the key ingredients or elements of the concept are captured in any definition or description [Ukpere, 2017; Ukpere & Wabah, 2016].

Environmental pollution is simply the introduction of any biological, chemical, physical or radiological substance into any of the component parts of the environment (air, water, land or soil) at a rate faster than and higher than the carrying capacity of the receiving environment. That is, at the rate more than the environment can naturally accommodate it through the processes of absorption, dispersion or decomposition (breaking down). Hence, environmental pollution threatens life or the survival of man, plants and animals or any biotic system on earth. In other words, environmental pollution is any undesirable change in the biogeochemical processes of the earth that may pose potential danger on the health and survival of humans and other living organisms. That is, any alteration in the physical, chemical or biological characteristics of the air, water or land/soil and that will harmfully affect the survival or activities of man and other flora

and fauna or any abiotic system can be viewed as environmental pollution [Ukpere, 2017; Ukpere, 2014; Narayanan, 2011; Srivastava, 2011; Kaushik & Kaushik, 2008].

Another closely related concept that is loosely used or interchangeably used with pollution is contamination. Environmental contamination on the other hand, is the release of unwanted substances (contaminants) into the environment, but may not necessarily cause any serious adverse effect (i.e. they do not pose any danger or threat to man or other living things) whereas pollutants do. However, when contaminants are allowed to stay in the environment or there is an increase in their occurrence or level of concentration, they therefore lead to pollution. Both the level of concentration and condition of the receiving medium (soil, water or air) can enhance the chances of a contaminant becoming a pollutant in the environment. For instance, sulfur dioxide (SO_2) is more corrosive and reactive in an aqueous or humid environment. In the same vein, other substances are more reactive under reducing atmosphere while others are more reactive in oxidizing atmosphere. This implies that atmospheric contaminants can graduate to become pollutants under certain conditions even at trace level concentrations [Ukpere, 2016; Narayanan, 2011].

METHODOLOGY

This study applied the cross-sectional research design where both primary and secondary data were used. The main (primary) data were generated through the use of field surveys/observations, oral interviews and two sets of semi-structured questionnaires (*A*-for residents; *B*-for hospitals and Doctors) administered on 2000 randomly selected respondents (1000 patients and 1000 non-patient residents) and 50 doctors (from 25 public and 25 private hospitals) in 10 stratified selected locations (Ogbonabali and Trans-Amadi IA, Rumukwurushi and Shell IA, Choba-Alakahia axis, NPA-Aggrey road area, Rumueme, Mile 1-3 Diobu, Rumuolumeni-Nkpor axis, Rukpokwu-Eneka-Eliozu area, Mbuogba-NTA area, and D-line axis). The interactions and questionnaire were used to gather socio-economic data from the residents e.g. common airborne-related diseases/illnesses.

The monitoring, collection and analysis of atmospheric gases (air pollutants) between 1-350m altitudes above the ground level were carried out on hourly basis 4-6days per week for 15months cutting-across both dry and rainy seasons (2019-2020). Five zones (Total village, Trans-Amadi I. A., Old G.R.A,D/line and Onne) were used for the study in order to collect data on major air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_X, VOC, and Air Quality Index (AQI). Meteorological data on wind direction, speed and temperature were also collected on hourly basis.

Air quality impact assessment (AQIA) for the concentration levels of the major air pollutants were determined using a multiple of instruments and techniques. These include automatic sampling analyzer (ASA), absorption and reflective spectroscope, Met One GT-321 Hand Held Particle Counter, Photoionization detector and Absorption and reflective spectroscope to monitor and take hourly records. Major techniques adopted in the analysis include separation techniques (e.g. gas chromatography, mass spectrometry (MS), electrophoresis), electro-analytical techniques and spectroscopic analysis. Meteorological data were collected using Extech Digital Cole Parmer Combination (Hygro-thermo-Anemometer) model 45170.

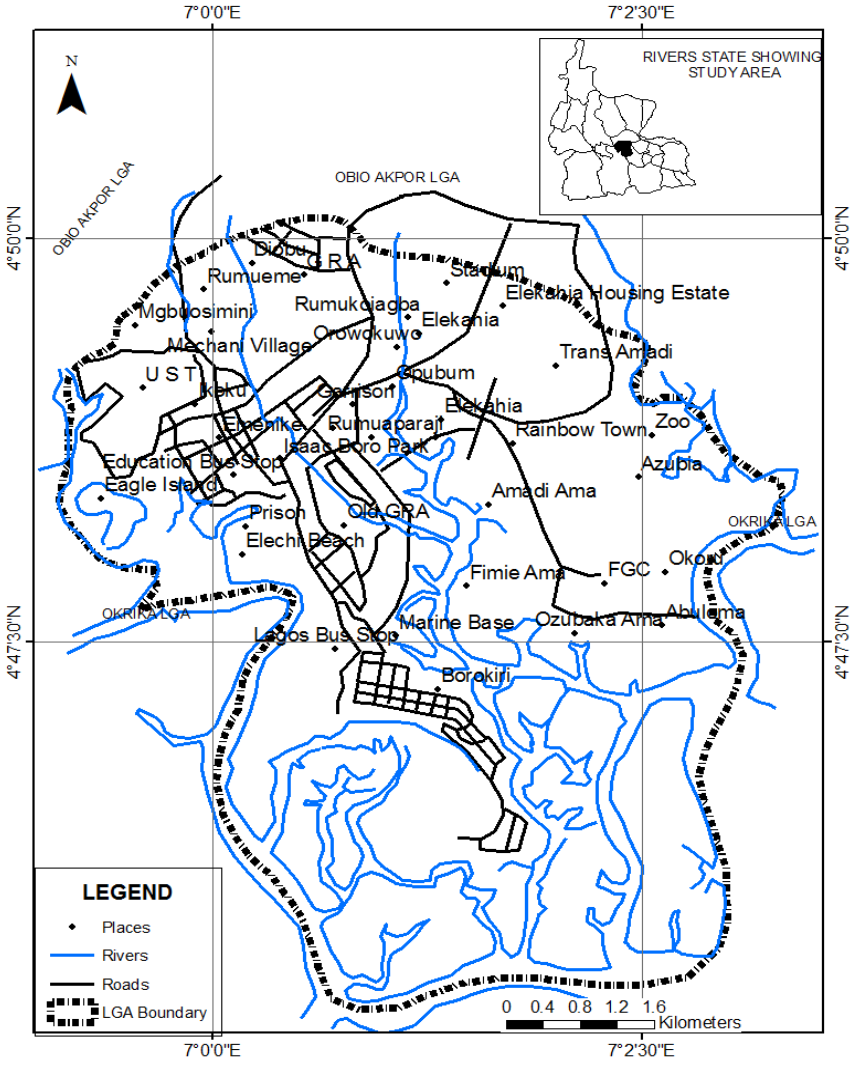

Figure 1: The study Area-Port Harcourt showing settlements

RESULT AND DISCUSSION

Major Sources of Pollutants Common in the Port Harcourt Region

The major sources of air pollutants common in Port Harcourt area are:

(i) Oxygen demanding organic wastes (mostly from domestic, municipal/urban and industrial activities).
(ii) Pathogenic/infective agents (e.g. bacteria, viruses, protozoa).
(iii) Plant nutrients (mostly nitrate and phosphates).
(iv) Certain organic chemicals (mostly from petrochemicals, artisanal refining of crude oil, insecticides, pesticides, herbicides, detergents and carcinogens).
(v) Minerals and trace metals

(vi) Radioactive minerals and compounds (e.g. through the use of certain radioactive materials by hospitals and radioactive explosives like dynamites in both fishing and crude oil prospecting).

In terms of **origin of air pollutants,** there are three main origins of air pollutants**.** These are:

i) Point sources – stationary objects that releases pollutants into the atmosphere e.g. industrial factories (especially metallurgical and chemical industries), smokestacks, thermal and nuclear power plants, oil refineries, and refuse incinerators. Others are particulate matter released during volcanic eruptions with complex chemical composition (e.g. oxides of sulfur and fluorine compounds).

ii) Non-point Sources – these are mostly from residential neighbourhoods, hospitals, forest fires, agricultural activities, utility and waste disposal sites.

iii) Mobile sources – these are mostly from transportation vehicles using fossil fuels such as coal, diesel and gasoline or premium motor spirit (PMS).

These various sources and their respective effects is been influenced by the earth's systems.

The Earth's Environmental Systems and Cycles and their Pollution Effects within the Port Harcourt Region

The earth is made up of three main component parts namely the lithosphere with land/soil being its main component; the hydrosphere which is composed of all the water bodies; and the troposphere, which is the lowest layer of the atmosphere, is composed of air and water vapour. The interaction of these three main components or physical systems produces a fourth component known as the biosphere which is composed of living organisms (biota) and non-living (abiotic) factors from which the biotic factors derive their energy and nutrients. See the diagram below.

1. Lithosphere
2. Hydrosphere
3. Troposphere
4. Biosphere

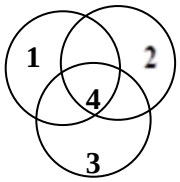

Figure 1: Earth's physical systems interacting with one another

Within the biosphere, exist inter-related environmental cycles of processes taking place. These cycles and the reaction or interaction they produce, lead to the release of certain pollutants in the environment. Popular among these systems of environmental cycles are the carbon cycle (C), Nitrogen cycle (N), sulfur cycle (S), Hydrogen cycle (H) and nutrient Cycles.

Classification of Air Pollution within the Port Harcourt Air Space

There are two main classes. These are primary and secondary pollutants:

(a) Primary Pollutants

These are those that are emitted directly into the atmosphere. They include sulphur dioxide, nitric oxide and carbon monoxide (see Table 1). These primary pollutants are further classified as follows:

(i) Particulate Matter (or Aerosols) – they are very small particulate matter that floats in the air. They are caused by both natural and human activities. Examples are dust, smoke, fog, smog (which is a mixture of both smoke and fog). These can cause discomfort (cough, catarrh) and respiratory disorders in Port Harcourt especially during the dry season.

(ii) Oxides of carbon (CO_2 and CO). CO is produced as a result of incomplete combustion and mostly from automobiles, domestic fires, power plants, burning of coal etc. CO_2 is mostly from the burning of fossil fuels, open burning of refuse dumpsites, bush burning and industrial plants.

$2C + O_2 \longrightarrow$ 2CO (incomplete combustion)

$C + O_2 \longrightarrow$ CO_2 (Complete combustion)

(iii) Oxides of Nitrogen (NO_2, NO) produced mostly through thunder strikes and lightening discharges and stratospheric oxidation of ammonia.

(iv) Oxides of Sulphur (SO_X and SO_2) - Sulphur dioxide, hydrogen sulphide (H_2S) and sulphate particles are the three forms of sulphur found in the atmosphere. The chief source of SO_2 and H_2S are mostly emissions from open burning of waste dumpsite and fossil fuels (e.g. coal), smelting of sulphur containing ore and chemical industries which produces fertilizers and sulphuric acid. This is why the Eleme area near Port Harcourt is highly polluted as a result of the presence of chemical and fertilizer industries.

(v) Hydrocarbons which include methane, ethane, toluene, n-butane, iso-bentane, acetylene coming mainly from automobile industrial exhausts and decomposition process.

(vi) Halogens in the atmosphere in the form of chlorine (Cl_2) and fluorine coming mainly from caustic soda industries for Cl_2 and smokes from brick kiln and iron and steel industries.

(b) Secondary Pollutants

These are those air pollutants formed by the photochemical reaction of primary pollutants. A good example is smog – which is a combination of smoke and fog. Smoke is made up of carbon particles whilst fog consists of water vapour in air. Acid rain which is formed by a combination of sulphur dioxide and water vapour is also a secondary pollutant and this affects house roofs, and contaminates water. See tables below.

Table 1: Main Classes of Air Pollutants within the Port Harcourt Airspace

Primary Pollutants	Secondary Pollutants	Type of Reaction
Acid + Alkali	Salt	Acid-Base reactions
$SO_2 + H_2O$	H_2SO_4	Oxidation
$NH_3 + SO_2$	$(NH_4)_2SO_4$	Oxidation
$NO + O_2$	NO_2	Photochemical
$NO+O_2$+HC (Hydrocarbons)	O_2+Free radicals	Photochemical

Source: Researchers' field analysis, 2019-2020

Table 2: Broad Classification of Air Pollutants within the Port Harcourt Airspace

Major Class of Pollutants	Subclass	Examples
Inorganic	Gases	SO_x, NO_x, CO_X, NH_3
	Acids	HF, HCl, H_2SO_4, HNO_3
	Mineral compounds	Oxides, chlorides, sulfate. silicates, fluorides, phosphates
Organic	Hydrocarbons, acids, aldehydes, ketonnes, alcohols, etc	Benzene, toluene, hexane, acetone Benzaldyhyde, alcohol, etc
Particulates	Dust, smoke, fumes	Mist, fog, etc

Source: Researchers' field analysis, 2019-2020

Health Effects of Air Pollution on Residents of Port Harcourt and Environment

Although not all air pollutants have adverse effects on man, most air pollutants do. The magnitude of effect of air pollutants depend on the level of concentration of the particular pollutant and the duration (i.e. the time frame) of the pollutant in the air as well as the duration of exposure of man or property to the said pollution. Air pollutants pose different level of effects on man, plants and animals, ecosystem, material objects (such as building roofs and floors, metal objects, sculptures, etc). They therefore pose physical, photochemical, physiological, and physicochemical effects on all living organisms but of different magnitude. The general effects of atmospheric pollutants are on both living and non-living things in the environment. The effects of these pollutants can be localized, regionalized or globalized depending on the magnitude of the pollution and nature of pollutant. Broadly speaking, their effects are summarized in Table 3 below. During the two years period of this study, hospitals were visited to find out possible correlation between residents and patients' claims and actual hospital records and Doctors' opinion.

Table 3: Commonest Airborne Diseases Suffered by Port Harcourt Residents due to Air Pollution

Disease	Frequency per 1000 Recorded cases	%
1.Flu (influenza)	2	0.14
2.Common cold	345	24.26
3.Chicken pox	23	1.62
4.Measles	16	1.13
5.Mumps	36	2.53
6.Whooping cough(Pertussis)	223	15.68
7.Coronavirus	134	9.42
8.TB	43	3.02
9.Diphtheria	21	1.48
10. Itchy eyes/eye irritations (Ocular Pruritis, allergic Conjunctivitis)	456	32.07
11. Others	123	8.65
Grand total	**1,422**	**100**

Source: Authors' field work, 2019-2020 Culled from Hospital records

Table 3 above presents some of the commonest airborne diseases in Port Harcourt due to air pollution within the region. Among these diseases, eyes irritations such as itchy eyes, redness of eyes (i.e. allergic conjunctivitis and Ocular Pruritis, etc.) are the most frequent ailment suffered by Port Harcourt residents arising from the impacts of air pollutants in the area. Others include common cold, whooping cough, and coronaviruses (including the latest Covid 19 global pandemic). These figures were collated from few (50) hospital records in the area and interactions with 50 medical Doctors.

Table 4: General Effects of Atmospheric Pollutants in Port Harcourt

Pollutants	Effects
Particulates	Reduces visibility, causes road accidents; damage to materials; ill-health such as bronchial disorders
Oxides of Sulfur(SO_X)	Causes metal corrosion, damage to buildings and properties/material objects; stunted growth and death of plants; causes ill-health such as upper respiratory tract disorders
Oxides of Nitrogen (NO_X)	Damage to plants and vegetation; causes ill-health such as eye and nose irritations Causes ill-health such as headaches, nausea and even deaths
Carbon monoxide (CO)	Damage to plants and the environment; also causes carcinogens
Hydrocarbons (HCs)	Damage to materials, plants and vegetation; causes ill-health such as
Oxidants	eyes, throat and lungs irritations

Source: Authors' field survey, 2019-2020

We shall now examine the general effects of air pollution on and the environment.

1. Effects of Air Pollutants on Man and Animals within Port Harcourt

High level concentration of air pollutants plus pro-longed stay of these pollutants in our bodies can be disastrous. Smaller particles of air pollutants passed through the hairs and sticky mucus in the lining of our nose down to our lungs through the tracheobronchial system and can adversely affect our bodies' defense system and also cause lung cancer, asthma, chronic bronchitis, and emphysema (damage to air sacs) which leads to loss of lung elasticity and acute shortness of breath [Narayanan, 2011].

Also, suspended particulates can cause damage to long tissues and illnesses such as asthma, bronchitis, and cancer. SO_2 causes respiratory disorder including bronchitis. NO_2 also causes lung irritations which can result to chronic bronchitis and emphysema. CO reaches the lungs and combines with blood haemoglobin to form carboxyl-haemoglobin which may result to suffocation. CO also causes dizziness, unconsciousness and sudden death. Benzene (mostly from unleaded petrol), formaldehyde, poly chlorinated biphenyls (PCBs), and toxic metals and dioxins (mostly from burning polythenes) can cause mutations, reproductive problems and cancer [Narayanan, 2011].

In the same vein, toxic and hazardous materials like Asbestos, Beryllium, Mercury, and Arsenic etc. can cause lung diseases and destroys essential organs such as kidney, liver, spleen, and brain. Some of the medical records and oral submissions of some of the Doctors in both public and private hospitals confirmed this finding.

2. Effect of Air Pollutants on Plants (vegetation) within the Port Harcourt Region

Pollutants in the air enter plants' bodies through the leaf-pores (stomata) destroying chlorophyll and therefore affect photosynthesis. They also erode away the waxy-coating of plant leaves (i.e. the cuticle) which help to prevent the plants from excessive loss of water and damage from diseases, pets, frost and drought or excessive heat. The damage on plants leaf by air pollutants (i.e. necrosis), which are dead areas of leaves, chlorosis (i.e. loss of chlorophyll) causing yellowing of plant leaves, epinasty (i.e. downward curling of leaves) and abscission (i.e. dropping of leaves). These four effects of necrosis, chlorosis, epinasty, and abscission were observed on some of the trees/plants at the Isaac Adaka Boro Park, Pleasure Park and other tress along the Old G.R.A., Township Park, and G.R.A. Phases I and II, Shell R.A. and Trans Amadi I.A. and Port Zoological and Botanic Gardens.

Particulates on plant leaves cause plugging of the stomata which lead to reduction of amount of sunlight and sudden death of plants. Also, SO_2 causes bleaching of leaves, chlorosis, injury and necrosis of leaves. NO_2 causes increased in abscission and suppressed growth. O_3 causes flecks on leaf surface, premature aging, necrosis and bleaching. Peroxyacetyl nitrate (PAN) causes silvering of lower surface of leaves, damage to young more sensitive leaves and also suppressed growth. Fluorides cause necrosis of leaf-tip. Finally, ethylene results in epinasty, leaf abscission and dropping of flowers.

3. Effects of Air Pollutants on Aquatic Life

We stated earlier in this work that, virtually all pollutants from either soil or atmosphere find their way into water bodies. Air pollutants get mix-up with rain causing high acidity which results in the formation of a weak-acid solution which falls into surface waters. This acid rain lowers the pH of freshwater streams and this affects aquatic life (mostly fishes) causing stunted growth and sudden deaths.

4. Effects of Air Pollutants on Materials Objects and Properties

Materials (especially metal products) exposed on the earth's surface, are often affected by air pollutants. SO_2 and moisture accelerates corrosion of metallic surfaces through the formation of sulphuric acid affecting building roofs (as noticed on building roofs in Diobu, Town and Borikiri, Rumukwurushi, Elokhohia and Rumuomasi, Woji, Trans Amadi, Eastern-by pass, Oginigba and Ogbonabali areas, Eagle Island, Rumueme and Nkpor areas of Port Harcourt) vehicles, bridges, railway tracks, wires, statues and sculptures made up of marble and limestone. SO_2 also affects fabrics, leather materials, paint and paper. O_3 in the atmosphere cause cracking of rubber materials thus affecting tires while oxides of nitrogen and ozone (O_3) also cause fading of cotton and rayon fibers.

We shall now consider the roles of the different air pollutants in atmospheric destabilization and their individual effects. Thereafter, we shall examine the strategies to adopt in checkmating air pollution.

Roles of the Different Air Pollutants in Port Harcourt

Let us now examine the contributions of the various air pollutants in atmospheric destabilization and environmental degradation**.**

a) Particulates

These are complex mixtures of organic and inorganic substances from primary and secondary sources. They are made up of sediments and 'suspended' particles. They include smoke, soot, dust and other floating particles. They occur in liquid, solid or a combination of both forms. Their sizes range between 0.1- 10µm. These substances find their way into the atmosphere due to man's land use activities mostly from mining, metallurgical, industrial, construction, agricultural activities, and forests fires, combustion of fossil fuels, vehicular exhausts, hydrocarbons, lead compounds, and metal fumes. These particulate matter remained in the stratosphere (>10km) for a very long time as a result of poor vertical mixing. The recent (from 2013) and frequent occurrence of black soot in Port Harcourt (mostly in the dry seasons) is a good example, with very deleterious health effects on residents; defacing of floors, cars, buildings, etc.

Although, particulate matter may not cause serious (adverse) physiological effects, they do pose some effects on our health and degradation of the environment. These particulate sediments stains and defaces surfaces and cause physical and structural deterioration. Specifically, cement dust causes eczema on the skin, sand dust causes silicosis; asbestos causes' asbestosis, smoke, soot and dust cause respiratory disorders and other health challenges. It is imperative to state here that health hazards of particulate matter depend on the size of the particulate matter. For instance, particulate matter with diameter of >20mm is easily filtered out of the nose and throat and does not enter the lung system.

However, sub-micron range particulate matter ($PM._{10}$ to $PM._{2.5}$ range) causes pulmonary health challenges. This is because they are small enough to penetrate deep into the lungs. Particulate matter above the 2.5µm range ($PM._{2.5}$) is removed by ciliary action of the epithelial cells. But those in the range of 0.5-2.0 µm (< $PM._{2.5}$) can reach the lung lymph nodes and can cause impairment in the functions of the lung. Also, Particulates of < 0.5 µm can cause bronchitis while particulates of the size $PM._{10}$ may carry surface-absorbed carcinogenic compounds into lungs.

a) Aerosols

Aerosols are liquid and solid 'suspended' particles or sediments in the atmosphere. Solid aerosols are mixtures of dusts, smokes, soot and fumes. Suspended particles in the atmosphere reduce visibility and quality of the air. Aerosols absorb and disperse both solar and territorial radiation thereby affecting the earth's heat- balance system. They also serve as nuclei for condensation of water vapour and cloud formation by initiating and controlling precipitation.

It is important to state here that the back scattering of solar radiation increases the reflectivity of the atmosphere. Again, aerosols reduce the process of terrestrial scattering of infrared (IR) radiation into space and also help to absorb some solar radiation. However, the effect of aerosols on solar radiation is greater than they are on the infrared radiation from the earth to space; and this cause a decrease in atmospheric temperature with increase in aerosol content in the atmosphere. In order words, the net effect of an increase in particulate matter in the atmosphere is to cool the earth. Aerosols have a longer residence time (i.e. they can stay for

months or years) in the atmosphere especially within the stratosphere and mesosphere [Narayanan, 2011; Srivastava, 2011; Kaushik & Kaushik, 2008].

b) Gaseous air pollutants

These too are small molecular mass of organic and inorganic compounds coming from both primary and secondary sources. Primary pollutants include SO_X, NO_X, CO_X, H_2S, HF. Secondary pollutants include H_2SO_4, Hydrocarbons, PAN, lead and arsenic compounds. The most important are the primary pollutants of SO_X, NO_X, and CO_X (i.e. the criteria pollutants). Some of them are examined below:

(i) Oxides of Sulfur (SO_X)

Sulfur dioxide is a primary pollutant whose chief source is from the combustion of sulfur containing fossil fuels, smelting of sulfide-containing ores (e.g. FeS_2, PbS, HgS), manufacture of elemental sulfur and sulfuric acid, conversion of wood pulp to paper and incineration of refuse. It is estimated [Narayanan, 2011] that 50 per cent of annual global emission of SO_X is from coal burning, 25 to 30 from oil burning and 20 to 25 per cent from volcanoes and forests fires. Sulfur dioxide is oxidized in the atmosphere to sulfuric acid by hydroxyl radicals (OH) which is produced by photodecomposition of ozone (O_3).

$$HO + SO_2 + M \quad HSO_3 + M$$
$$HSO_2 + O_2 \longrightarrow SO_3 + HO_2$$
$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Both wet and dry deposition of oxides of sulfur damages buildings such as corrosion of roofs, destruction of vegetation and soil degradation. SO_2 pollution is a major problem in areas where coal is been used for domestic and industrial heating and power stations. Hence, to reduce SO_2 pollution, the use of low-sulfur fuels as well as locating power plants away from residential areas should be encouraged.

(ii) Oxides of Nitrogen (NO_X)

Basically, Nitrogen is the chief constituent of the atmosphere, occurring in its molecular state as NO_2. The main oxides of nitrogen are N_2O (nitrous oxide), NO (nitric oxide) and NO_2 (nitrogen dioxide). NO_2 is a pungent irritating gas which is absorbed in the green region of light, often displays with a reddish-brown colour; NO_x helps in the formation of ozone in the troposphere but also reduces the ozone in the stratosphere. NO_2 reacts with hydroxyl radicals in the gas phase to form nitric acid leading to the formation of acid rain with its antecedent side effects. Acid rain is common in Port Harcourt and its effects is easily noticed on house roofs especially around the waterfronts, Diobu area, Woji and Elelenwo areas, Trans Amadi I. A. and Oginigba, Marine Base, Aggrey/Industry road and Borikiri axis, Mgbosimini and Nkpor areas.

(iii) Photochemical Smog

Photochemical pollutants (e.g. ozone) are formed when in the presence of sunlight, NO_2 reacts with hydrocarbons leading to the formation of photochemical smog (reddish-brown haze) which affects most urban centres. The main sources of NO_2 are microbial processes, power generation plants, nitric acid factories and automobiles. NO_2 is a good absorber of Infra-Red radiation, hence, it is a greenhouse gas.

(iv) Ozone (O_3)

Ozone ((O_3) is a tri-atomic molecule containing three atoms of oxygen (o-o distance=0.128nm) with sp^3 hybridization (O-O-O=116.5^O). It is produced by photochemical reactions taking place at the lower part of the stratosphere. It helps to protect the earth's surface from the direct effects of the sun's ultraviolet radiation at wavelengths between 200 to 320nm. At the troposphere, ozone is produced from two main sources namely: from downward movement from the stratosphere, and from direct photochemical production within the troposphere. The ozone layer is very important for the survival of living things on earth because at the mesosphere-stratosphere boundary, it absorbs much of the ultraviolet (UV) rays of the solar radiation. This absorption of the UV radiation by O_3 (and O*) at the upper regions of the stratosphere provide protective blanket cover against the UV rays from reaching the earth's surface. Regrettably, this important layer is suffering depletion by the activities of chlorofluorocarbons, discharges from supersonic airplanes and nuclear weapons' testing and space craft emissions [Narayanan, 2011; Kaushik & Kaushik, 2008].

(v) Chlorofluorocarbons (CFCs)

Chlorofluorocarbons (CFCs) are industrially produced chemicals which do not occur in nature e.g. aluminum industries expel fluoride dust, plastics foam industries expel chlorine, fluorine, and carbonaceous organic compounds. Chlorofluorocarbons (CFCs) are mostly from the family of inert, nontoxic, and easily liquefied chemicals. Chlorofluorocarbons (CFCs) moved upwards easily into the upper atmosphere where their chlorine destroys ozone, and therefore they pose serious threat to ozone layer depletion. It is argued [Narayanan, 2011]) that, fluorocarbons undergo photolysis to produce oxidants, free radicals and other secondary pollutants as expressed below:

$$CF_2Cl_3 \xleftrightarrow{hv} CF_2Cl_2+Cl^+$$
$$CF_2Cl_2 \xleftrightarrow{hv} CF_2Cl+Cl^+$$
$$Cl^*+O_3 \longrightarrow ClO+O_2$$

(vi) Oxides of Carbon (CO_X)

These include: **(i)** Carbon monoxide **(CO)** (which is a colourless and odourless greenhouse gas with physiological effects originating from both natural and anthropogenic sources. About 90% of CO is produced from traffic emissions and generating plants; and **(ii)** Carbon dioxide **(CO_2)** which is produced in the complete combustion of carbonaceous materials and from the respiration of living organisms. One good thing about CO_2 is that it is used by plants during photosynthesis. Its increase concentration in the atmosphere poses serious climate problems like climate change and global warming because CO_2 absorbs infrared radiation at 1.5-15m range. This absorption effectively reduces the heat loss from the earth and forces the temperature at the troposphere to increase; leading to what is known as 'greenhouse effect' [Narayanan, 2011]. Table 4 below shows a sample study of the mean occurrence of the major air pollutants within the Port Harcourt air space monitored from four different occasions in hourly basis.

The Menace of Black Soot in Port Harcourt: A Growing Challenge

Black soot as noted before is normally a black colloidal substance which is principally made up of amorphous carbon originating from burning of fossil fuels and industrial manufacturing especially chemical plants. Its occurrence in Port Harcourt is a recent development (around 2013) however, its consequences are severe ranging from immediate health discomforts to chronic ailments in later years. It is physically observable by using a white handkerchief to wipe ones nostril in the morning, and by the black coloration of house roofs, house floors, cars, etc, forcing residents to often clean these surfaces.

Many speculators, residents and scholars in Port Harcourt have attributed the black soot occurrence in Port Harcourt to the activities of illegal refining of crude oil in the creeks of the area and other forms of burning of fossil fuels like burning of tires by abattoir operators. This may not be true bearing in mind that these activities have been in existence in the region for decades and there has not been such occurrence until recently about 2013 when the problem was widely noticed within Port Harcourt and its environs.

Again, from available studies, there are more of such illegal refineries in Delta and Bayelsa states than in Rivers state yet, there are no reported cases of black soot in either of Bayelsa or Delta state. It is possible that the black soot problem in Port Harcourt region is primarily due to the manufacturing activities of some of the major industrial plants such as oil refining and chemical plants at the Eleme axis where we have refineries, fertilizer and chemical manufacturing plants like the Port Harcourt Refinery, Ndoroma Facilities, etc. Detail, independent and transparent investigation is needed to actually unravel this mystery in Port Harcourt because of its deleterious effects on the health of residents and on the environment as a whole.

Main Findings of the Study

The study revealed that air pollution in Port Harcourt causes metal corrosion, reduction in visibility; affects plants growth; causes health challenges e.g. bronchial and respiratory disorders, eye irritations. Major air pollutants include CO_2, CO including black soot, SO_2, NO_X, VOCs. The main responsive pollutant is $PM_{2.5}$. Air Quality Index (AQI) is mostly unhealthy (100-221) in the morning hours and moderate (60-98) in the evening hours (6:00 - 8:00pm). The level of pollution is higher in the dry seasons than in the rainy seasons. Total village and Trans-Amadi I.A. are the most polluted areas (AQI range of 80 and above). AQI is moderate (40-94) at D/Line and Old G.R.A; while Onne area is the least polluted zone with AQI of 24-45 (good). Mean values in the **morning hours** are: $PM_{2.5}$ (30µg/m^3), PM_{10} (38.5µg/m^3), SO_2 (41ppb), NO_X (5ppb), VOC (98.5µg/m^3); **evening hours:** $PM_{2.5}$ (32.8µg/m^3), PM_{10} (43µg/m^3), SO_2 (28.5ppb), NO_X (5.8ppb), VOC (14.25µg/m^3), and **night hours:** $PM_{2.5}$ (32.8µg/m^3), PM_{10} (43µg/m^3), SO_2 (28.5ppb), NO_X (5.9ppb), VOC (14.25.5µg/m^3). **Wind directions** in the morning is 16^0 (S-W), speed 1.2m/s and temperature 24.8^0C. From 6pm to late nights, wind directions changes to 2150 (N-E), speed 5.3m/s and temperature 28.6^0C. Most discomforting nights in Port Harcourt occurs when the wind direction shift to 2610 eastward at 0.6m/s (still air) at temperatures 23.5^0C.

In a nutshell, the most responsive air pollutant in the Port Harcourt region in the morning and evening hours is $PM_{2.5}$ whiles at night, SO_2 dominates the atmosphere in some cases. Also, while temperatures are relatively low in the morning, (24.8^0C) it increases in the evening hours

(28.6^0C) and falls down again (between 25.5^0C to 26.5^0C) by late night hours. Again, winds direction is mostly south-west wards in the morning hours with a mean speed of 1.2M/S; and north-east wards in the evening and night hours with mean speed of 5.3M/S.

Table 5: Air Quality Index in the Five Sampling/Monitoring Points

Area	AQI Range	Classification
1. Total Village	80-110	High
2. Trans Amadi I. A.	80-120	High
3. D/Line	40-94	Moderate
4. Old G.R.A/Forces Avenue	40-94	Moderate
5. Onne	24-45	Good

Source: Authors' field work, 2019-2020

Table 6: Concentration Levels of Major Air Pollutants within the Port Harcourt Region

Time	LOCATIONS				
	Major Pollutants	**1.Total Village**	**2.Trans-Amadi I.A.**	**3.Old G.R.A.**	**4.Onne**	**Mean**
6am	$PM_{2.5}$	39 µg/m^3	5 µg/m^3	56 µg/m^3	20 µg/m^3	30 µg/m^3
	PM_{10}	50 µg/ m^3	12 µg/ m^3	66 µg/ m^3	26µg/m	38.5 µg/m^3
	SO_2	85ppb	79ppb	-	-	41ppb
	NOx	7ppb	3ppb	10ppb	-	5ppb
	VOC	0 µg/ m^3	0 µg/ m^3	394 µg/ m^3	-	98.5 µg/m^3
	Air Quality Index	108-unhealthy	102-unhealthy	150 –unhealthy	66-Moderate	107-unhealth
	Responsive Pollutant	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$
	Meteorological Data					
	Wind Direction	↓ 16^0	↓ 16^0	↓ 16^0	↓ 16^0	↓ 16^0
	Wind Speed (m/s)	1.2M/S	1.2M/S	1.2M/S	1.2M/S	1.2M/S
	Temperature (^{O}C)	24.8^{0}C	24.8^{0}C	24.8^{0}C	24.8^{0}C	24.8^{0}C
6pm	$PM_{2.5}$	34 µg/m^3	33µg/m^3	33 µg/m^3	31 µg/	32.8 µg/m^3
	PM_{10}	44 µg/ m^3	43 µg/ m^3	43 µg/ m^3	42 µg/ m^3	43µg/m^3
	SO_2	111ppb	1ppb	1ppb	1ppb	28.5ppb
	NOx	9ppb	5ppb	5ppb	4ppb	5.75ppb
	VOC	30 µg/ m^3	14 µg/ m^3	11 µg/ m^3	2 µg/ m^3	14.25 µg/m^3
	Air Quality Index	97- Moderate	95- Moderate	94- Moderate	66- Moderate	88- Moderate
	Responsive Pollutant	$PM_{2.5}$	SO_2	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$
	Meteorological Data					
	Wind Direction	↑ 215^0	↑ 215^0	↑ 215^0	↑ 215^0	↑ 215^0
	Wind Speed (m/s)	5.3M/S	5.3 M/S	5.3 M/S	5.3M/S	5.3M/S
	Temperature (^{O}C)	28.6^{0}C	28.6^{0}C	28.6^{0}C	28.6^{0}C	28.6^{0}C
12am	$PM_{2.5}$	5µg/m^3	3µg/m^3	10 µg/m^3	0 µg/m	32.8 µg/m^3
	PM_{10}	9 µg/ m^3	5 µg/ m^3	20 µg/ m^3	0 µg/ m^3	43µg/m^3
	SO_2	1000ppb	84ppb	0ppb	17ppb	28.5ppb
	NOx	36ppb	5ppb	8ppb	5ppb	5.75ppb
	VOC	66 µg/ m^3	0 µg/ m^3	436 µg/ m^3	55µg/ m^3	14.25 µg/m^3
	Air Quality Index	111-unhealthy	104- unhealthy	40- Good	24-Good	88- Moderate
	Responsive Pollutant	↑ SO_2	↑ SO_2	↑ PM2.5	↑ SO_2	↑ SO_2
	Meteorological Data					
	Wind Direction	201^0	201^0	201^0	201^0	↑ 215^0
	Wind Speed (m/s)	2.2M/S	2.2 M/S	2.2 M/S	2.2M/S	5.3M/S
	Temperature (^{O}C)	25.5^{0}C	25.5^{0}C	26.5^{0}C	26.5^{0}C	28.6^{0}C

Source: Authors' Field Study, 2019-2020

Control/Prevention of Air Pollution in Port Harcourt Region

The following techniques or methods can be adopted for the control of air pollution in Port Harcourt in particular and in the Niger Delta in general:

1. By enacting good laws and strictly implementing these laws.

2. Discouraging (through public enlightenments) the burning of tires by abattoirs as well as eradicating illegal refining of crude oil (artisanal refining).

3. By conducting a thorough environmental audit and environmental impact assessments (E.I.A) of proposed projects before sitting certain industries.

4. Reduction in activities that may likely cause air pollution such as the use of fossil fuels by transportation vehicles.

5. Modification of industrial plants and machinery to use other forms of energy that will emit little CO_2

6. By total ban or reduction in gas flaring by oil companies.

7. By discouraging bush burning by farmers.

8. Through the use of advanced technology for the reduction or removal of particulate matter by gravitational settling camber, cyclone separator, fabric filter, electronic electrostatic precipitator and wet scrubber.

9. Gaseous pollutants can be controlled through the use of absorption in liquid absorption on solid surface, chemical alteration of pollutants through combustion or catalytic treatment.

10. Through the use of de-sulphurised fuel.

11. By absorbing toxic pollutant gases in different solutions.

12. By forestation programme of regeneration because plants need CO_2

13. By using excessive free air to control NO_X.

14. By building higher smoke stack facilities that can help discharge pollutants farther away from ground level.

15. Through the use of biological filters and bio-scrubbers.

16. By controlling the use of certain vehicles that emit out too much CO_2 or CO; and also by limiting the use of power plants (e.g. generators) at homes and offices. Solar energy should rather be used.

CONCLUSION

Air pollution is fast becoming a serious problem within the Port Harcourt Region. Air pollutants causes environmental and deleterious health effect on the residents of the area hence, there is urgent need to tackle all issues bordering on air pollution. The researchers therefore suggest that all concerned-the three tiers of government, industries and organized private sector, NGOs, professional bodies, residents and the communities, need to brace-up immediately. The government must demonstrate the right political will and provide good atmosphere for smooth implementation of policies. The authors hereby recommend for the immediate adoption of the above itemized proactive (control) measures aimed at reducing air pollution in the region so as to ameliorate the people's suffering from air pollutants.

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