SPATIOTEMPORAL ASSESSMENT OF AIR QUALITY IN SELECTED LGA IN RIVERS STATE.

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B.Tech (FUTO), Reg. No: 20164024548

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (MSc.) IN ENVIRONMENTAL MANAGEMENT

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CERTIFICATION

This is to certify that this research titled **"Spatiotemporal assessment of air quality in selected LGAs of Rivers State"** was carried out by Ukaegbu Kingsley Ogochukwu E. (20164024548) in partial fulfilment for the award of the degree of masters of science at the Department of Environmental Management, Federal University of Technology Owerri (FUTO), Imo State.

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DEDICATION

This MSc thesis is dedicated to my dear wife, Uchechi and my sponsor, Prof. Scott Madry, for believing in my potentials. May God bless and reward them.

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LIST OF ABBREVIATION

ADMS	Atmospheric Dispersion and Modelling System
AQI	Air Quality Index
CO	Carbon Dioxide
DPR	Department of Petroleum Resources
EDAMS	Emission Dispersion and Modelling Systems
EPA	Environmental Protection Agency
ESMF	Environmental and Social Management Framework
FMEnv.	Federal Ministry of Environment
GIS	Geographic Information Systems
GPS	Global Positioning System
IDW	Inverse Distance Weighted
NAAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen Oxides
O_2	Ozone
PM	Particulate Matter
SGCBP	State Governance Capacity Building Project
SO_x	Sulphur Oxides
TSP	Total Suspended Particles
VOCs	Volatile Organic Compounds
WHO	World Health Organization

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ABSTRACT

The pollution of ambient air has long been revealed as the most fatal form of environmental pollution. The levels of air pollution vary from one location to another and from time to time. The aim of the study is to assess the spatiotemporal distribution of air pollutants in selected LGAs in Rivers State. Nine points in the study area were sampled within two peak-periods (8.00 am and 4.00 pm), based on high industrial clusters, high vehicular traffic, and rising human population density. The concentrations of $PM_{2.5}$, PM_{10}, CO, SO_2, and NO_2 were measured using a hand-held gas analyzer. A handheld Germin-300 GPS device was used to record the GPS coordinates of the sampling points which aided the data processing, to develop spatial interpolation maps in ArcMap. The results of air quality parameters were above the WHO and FMEnv air quality standards. $PM_{2.5}$ and PM_{10} have a maximum value of 159.23 and 378.39 respectively which is higher than the WHO and FMEnv Standard limits for 24 hours exposure. The recorded exceedance is 68.5ppb, 28.7ppb and 113.7ppb for SO_2, NO_2, and CO respectively, in the wet season. 71.1ppb, 15.31ppb and 58.9 ppb for SO_2, NO_2, and CO respectively in the dry season, are higher than WHO and FMEnv limited. Based on these, it is recommended that the populace of Port Harcourt city should limit their exposure especially in the dry season.

KEYWORDS: Air Quality, Sulfur Dioxide, Port-Harcourt, Spatiotemporal, Air Pollution, Nitrogen Dioxide, Carbon Dioxide

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Air pollution occurs when excessive/harmful substances are introduced in the atmosphere which lowers the quality of air and affects the quality of life, and the environment. The pollution of ambient air has long been revealed as the most fatal form of environmental pollution. This is because of the increasing pollution levels resulting from urbanization, industrialization and growing population. This is a major source of concern to both developed and fast-growing cities especially in developing countries like Nigeria. Ambient air pollution can be hugely triggered by anthropogenic activities or natural processes (such as the volcanic eruption of gases, forest fires, and photochemical pollutants e.g. NOx from electrical discharges in thunderstorms). Part of the major anthropogenic sources of air pollution includes but not limited to industrial processes like gas flaring, pipeline explosion, bush burning, vehicular emissions, quarry activities, and industrial construction processes.

In an industrial evolution, the emission of air pollutants from anthropogenic activities involving the conversion of energy is the major cause of environmental degradation in a developing urban city. Urban air contamination is a source of numerous problems in the developing cities including; materials damage due to accelerated corrosion, smog within the polluted area, loss of vegetation, buildings, and monuments deterioration, health damage due to inhalation of gases and particles and so many other problems.

World Health Organization (WHO, 2010) has said that environmental hazards are responsible for approximately 25 out of a hundred of the entire burden of disease worldwide.

Lots of substances that are considered as air pollutants are found in the atmosphere and many of these substances are released to the air, during anthropogenic activities for example, complete and incomplete combustion of fossil fuel in industries, gas flaring, pipeline explosion, and in transportation processes.

The United States Environmental Protection Agency (US EPA) groups and reviews National Ambient Air Quality Standards (NAAQS) for the six principal pollutants which are called “criteria pollutants: ozone (O_3), Nitrogen dioxide (NO_2), Sulphur Dioxide (SO2), Carbon monoxide (CO), Lead (Pb), and Particulate Matter (PM), concentrations in Lima Ohio using the US EPA recommended software. The study utilizes Geographic Information Systems (GIS) to visualize predicted concentrations of air pollutants for a desired geographic area and prepare maps to categorize the ambient air quality according to NAAQS and the World Health Organization (WHO) guidelines.

The pollution of air globally has gotten significant attention from global and local communities. Many developed cities have build monitoring stations for air quality except underdeveloped cities in developing countries like Nigeria, nevertheless, these stations are not quite distributed accordingly and do not provide substantial tools for mapping pollution in the atmosphere since the quality of air is extremely variable (Khare, 2012). Remote sensing has served as an important tool for mapping and assessing air pollution. The use of satellite images in providing synoptic views of study areas in a scene. Using ground monitoring stations for earth observation enables users to confirm the concentrations of air pollutants by measurements from the space. The advanced ground systems are used for measurements in the field, for instance, the Lidar system, automatic and handheld sun-photometers, among other systems. The increasing use of GIS technology and its extensive disciplines enables air quality modelers with a powerful tool for developing new analysis capability. Spatiotemporal air pollution distribution maps can be developed with geospatial information. The grouping of data by location allows a variety of data from numerous sources to be easily aligned in a uniform spreadsheet or framework. Geographic Information System makes it easy to fill the gap amongst the analysts and decisionmakers for the comprehension of the information analyzed. The driving forces of ambient air pollution (from anthropogenic activities) are urbanization, developments, transportation, energy consumption, and rapidly growing population (Nwachukwu, Chukwuocha, and Igbudu, 2014). Atmospheric pollutants vary in concentration with space. This study investigated the level of ambient air pollutants in some parts of Rivers State, mainly Port Harcourt City; with high industrial activities, high vehicular and human traffic density.

1.2 Statement of the Problem

The negative effects of vehicular emissions, legal and illegal refineries and the use of generating sets to the quality of atmospheric composition in Port Harcourt city are currently disastrous to human health and the environment. Effects of extended or long-term exposure to air pollutants with diseases prevalent in cities are yet to be categorized. There exist three dimensions of problems connected to air pollution; the first is the economic problems related to air pollution. The second is the environmental problems and the third was about social equity related problems. To overcome the growing problem of air pollution, it is important to consider all these factors as they are inter-related. If there is one dimension of improvement, another dimension will deteriorate, and the situation will entirely worsen. In developed nations like the United States, Pollution from coal-burning power plants is responsible for more than 13,000 premature deaths and 20,000 heart attacks and hundreds of thousands of asthmas attack every year (WHO, 2010). However, the problem in the study area was identified to be sourced from the burning of crude oil by artisanal refineries and the use of generating sets and vehicular emissions. These concerns will be investigated in this research using a spatial variation of the two seasonal emissions in the city. The key air pollutants in most developing cities include carbon monoxide (CO), nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Ozone (O3), Particulate matter, including diameter ≤ 10 µm (PM_{10}) and PM_7 µm ($PM_{2.5}$), in addition to reduced visibility. Air pollution was classified among the top ten sources of the global burden of disease by the WHO. The health impacts of ambient air pollution investigated by many studies as you will see from the literature. It was discovered that there are limited spatial data to assess the seasonal variation of air pollution in the study area. The control measures slated for air pollution in Nigeria have been ineffective and unenforced. The investigations done in this study was based on the above facts. This study further suggested some preventive and monitoring measures utilizing GIS as a tool for analysis. The study was on seasonal sooth precipitation and the spatial distribution of air pollutants in the study area, with a specific interest in the following pollutants; NO_2, CO, PM_{10}, $PM_{2.5,}$ and SO_2.

1.3 Aim and Objectives of the Study

1.3.1 Aim

The aim of the study is to assess the spatiotemporal variation of ambient air quality in Port Harcourt. The aim is achieved using the underlisted objectives.

1.3.2 Objectives

To attain the aim, the underlisted objectives were actualized.

a) To assess the seasonal variation of air quality parameters in the study area.

b) To analyze the spatial variability of air pollutant concentration in both wet and dry.

c) To correlate the air quality index of both seasons within Port Harcourt to generate spatiotemporal maps.

d) To visualize the spatial distributions of air pollutants (NO_2, SO_2. CO, PM_{10}, and $PM_{2.5}$)

1.4 The Scope of the Study

The study focused on the spatiotemporal assessment of the ambient air pollution in some selected hotspots of some LGAs surrounding Port Harcourt Metropolis. These parts include Port Harcourt and surrounding Local Government Areas (LGA) that make up the major Port Harcourt city, including some parts of Obio/Akpo, Eleme, Oyigbo, Okirika, and Degema. This study was based on two seasonal purposeful samplings within the location defined above. The sampling covered the two LGAs selected from the surrounding Capital City of Rivers state. Coordinates of the locations of the study locations were also recorded during field data gathering for both the dry season, which was carried out in early January 2018 and wet season which was carried out in September 2018. The parameters considered in the study are NO_2, CO, PM_{10}, $PM_{2.5}$, and SO_2. The concentrations of these air quality parameters were measured at in-situ in the study area using a handheld air quality monitoring equipment. The data are recorded at daily intervals for the selected nine sampling stations. This was monitored for five days per season. The data collected from the nine monitoring points within the study area were used to develop an inverse distance weighted interpolation analysis, and result statistics were summarized based on the attributed features of the data.

Trends were discovered by comparing the monitoring results of the wet and dry season results at the same points for 2018 using ArcGIS 1.0; buffers were generated around the 9 monitoring points.

1.5 Relevance of the Study

This study was carried out to help contribute to the country's view in attaining sustainable environmental development especially having contributed to monitoring the air pollution problems in the country's heart of economic resources; Port Harcourt. To achieve this, the study focus at monitoring the levels of atmospheric pollutants in Port Harcourt and environ by the adoption of scientific models, GIS-base analysis and statistical means of evaluating the variation in the level of atmospheric pollution in the study locations, determining the components and values of the atmospheric pollutions; through the use of the best modern technological means available, to measure the atmospheric components within the study locations. However, this study was done to serve as a baseline study for the seasonal variation of air quality in the study area. This was to support the Environmental Protection Agencies and other environmental standard organizations to enhance the knowledge for policies on sustainable environmental management plans.

CHAPTER TWO

LITERATURE REVIEW

2.1 Air pollution

Air pollution has been described to have negative effects on plants, animal life, humans, materials, and structures. According to US EPA, air pollution is defined (Rohde and Muller, 2015): “An air pollutant is any substance in the air that can cause harm to humans or the environment. Pollutants may be natural or manmade and may take the form of solid particles, liquid droplets or gases. These compounds pollutants are divided into various groups, including particulate matter, volatile organic compounds (VOCs) and halogen compounds. Also included are commonly-known pollutants such as lead, mercury, and asbestos(Akuro, 2012).” “Air pollution is the degradation of air quality resulting from unwanted chemicals or other materials, which are higher than its own natural concentration, occurring in the atmosphere that may result in adverse effects on humans, animals, vegetation, and/or materials”.

2.1.1 Sources of air pollution and their classes

The emission sources of air pollutants can be classified into line, point, area or volume sources:

1. A point source can be used to identify factory stack; Point sources are considered by the volume of emission, stack diameter. and stack height

2. The emissions from vessels and vehicles denote the line source for the seas, street or road. It is a one-dimensional source of air pollutant emissions.

3. An area source is also known as the two-dimensional source of air pollutant emissions. Port Harcourt is an example also inclusive is the domestic emissions from households.

4. A three-dimensional source is also known as a volume source of air pollutant emissions. A volume source can be used in describing emissions from three-dimensional sources, for instance, an open limestone mine (Chinedu and Nwinyi, 2011).

2.2 Global Air Pollution Studies

studies carried out in recent years, investigated the cusses of air pollution and their control measures in coping with the public health-related challenges. The studies proved that air pollution has critical health effects on humans. The effects include asthma, bronchitis, respiratory infection, cardiovascular diseases, nervous system disorders, and lung cancer. These health effects increase the mortality and morbidity rate. Globally both industrialization and urbanization, joined with increasing vehicular emissions have significantly led to these problems. The history of air pollution has dated long from the industrial revolution also the same as the first European settlement was established in Australia (Khaled, 2010).

Transportation has both negative and positive effects by causing pollution emissions and by providing access to employment, social activities, leisure, goods, and services respectively. Mudu *et al.*, (2014) projected that the traffic volume will be created in the next 25 years; hence, without substantial improvement in policies on transportation, transport will increase its negative effects on human health and the environment. In the 20th century, there were improved transport technologies in most developed cities, and the finest interstate ships were built in the 1930s to expand the transportation systems options available in cities. For instance, railways were built starting in the 1830s to provide better transportation to people, over a century before the establishment of long-distance sleeping car trains. A good instance of the use of scientific knowledge during the 1960s was the dawn of jet-age. While railways today are the main form of inland transportation for heavy and bulky goods, road transport is used for the movement of smaller goods and personal movement (Khare, 2012; Ogwu, Peters, Aliyu, and Nuzhat Abubakar, 2015; Rohde and Muller, 2015; Uddin, 2006; Zagha and Nwaogazie, 2015).

In history, the grim consequence of exposure to high levels of urban ambient air pollution is the loss of human lives. The notorious London “Killer” Fog of 1952 lead to many deaths. Air pollution in urban areas is the outcome of combustion, a process creating a complex mixture of pollutants with both primary emissions and the outcome of atmospheric transformation. For instance, the use of sulphur-containing fuel releases sulphate particles which is harmful to human health and the ozone layer (Mudu *et al*., 2014). Fossil fuels have many uses like for; power generation, transport, and other non-domestic and domestic purposes. The effects of exposure to air pollution are an increase in morbidity and mortality rates but then again there is no consensus among scientists concerning the threshold below which the adverse effects of pollution do not become obvious. According to a WHO report (Breuer, 2009) on 'global surveillance, prevention, and control of chronic respiratory diseases', the respiratory health effects resulting from air pollution are evident in the following ways:

I. The commonness of cancer cases; frequency of indicative asthma attacks,
II. Cases of lower respiratory infections,
III. Exacerbations of disease in people with cardiopulmonary diseases,
IV. Hospitalization, both in duration and frequency,
V. Amount of visits to the emergency units or medical doctors,
VI. Need for pulmonary medicine; decreased pulmonary function, g. incidence or prevalence of chest tightness,
VII. Prevalence of wheezing in the chest apart from colds, i. incidences of a cough or phlegm production,
VIII. Cases of acute upper respiratory infections, and
IX. Nose, eyes, and throat irritation.

According to WHO, (2009), the above health scenarios interfere with normal human life events. If constantly exposed to air pollution over the long-term, it will result in an abridged life expectancy due to combustion-related and particulate matter air pollution is a critical environmental risk factor for cardiac, lung cancer and pulmonary deaths (Brook, *et. al*., 2004). Recently, it was estimated that atmospheric air pollution causes about 5% of trachea, bronchus, and lung cancer diseases, 2% of cardiorespiratory deaths and about 1% of respiratory infection death globally (Mudu *et al*., 2014). The above estimates take into account deaths from air pollution, and not air pollution incidence and deaths from other burdens of disease would be greater (Dora and Phillips, 2000).

2.3 Rationale and Existing Knowledge Base

The investigation into the relationship between air pollution, mortality and morbidity have been carried out within many epidemiological studies globally, there have been steady links between the most identified pollutants, for example, in aerodynamic diameter and cardiorespiratory morbidity. Rohde and Muller, (2015) reviewed the interactions that exist between nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3). Obviously, from this review and similar studies (Kelly and Fussell, 2015; Khare, 2012), air pollution was seen to have the likelihood to cause cardiorespiratory morbidity/mortality cases in most cities. Nevertheless, only very few studies have considered the spatial distribution and concentration of air pollutants and their health-related problems. There are many knowledge gaps known to be filled in air pollution research. These knowledge gaps are the rate of exposure and spatial distribution according to location; geospatial analysis and understanding of the connection between air pollution and health effects; and the incorporation of geographic information system in Spatiotemporal approaches to understanding the distribution of the concentrations and other environmental health concerns. This study is aimed to cover the gap relating to the spatial distribution of air pollutants in relation to human exposure and the level of health hazards.

2.3.1 Spatial Statistical Analysis

Geographic Information Systems (GIS); a tool used for analyzing geographic information with the wider application of computer technology. GIS is an information system computerized for data processing to yield information. (Matejicek, Krause, Kralisch, and Flügel, 2005) It can handle a huge volume and complex datasets in a short while making it convenient. It can be visualized as an integrated assemblage of computer hardware and software, spatially referenced data and the human operator. It allows the human operator to bring together data from numerous sources in a composite form.

There has been an increase in air pollution studies in the past decade, New approaches are incessantly developed for analyzing varying levels of air pollution. These new approaches range from mathematical models and statistical analysis to using Cox's regression techniques for parameters estimation of pollutants (Aliyu, Musa, and Jeb, 2014). The analysis of spatial statistics is the use of statistical procedures to describe and model primary and secondary spatial data. geospatial approaches, such as buffering, identify clusters by measuring data quality, data mapping, and spatial distribution patterns assessments. Their implementation is very simple compared to the three procedures used by researchers: (1) Kernel density; (2) Empirical Bayes; and (3) Locally weighted regression. Many studies of air pollution have used a few of these procedures, in monitoring air pollution in many locations. Also, to assist in making spatial forecast maps of air pollution (Anthony, Chibuzo, Hippolitus, and Chima, 2017; Enkhtur, 2013; Komolafe, Abdul-Azeez, Biodun, Omowonuola, and Rotimi, 2014). Though, due to the simplicity of the above procedures and straightforwardness, analysis of GIS spatial buffer was determined as suitable for this research. The various applications of GIS are discussed in section 2.5. A major significant discussion in air pollution is the emission procedures and the appropriate analytical techniques. The method of analysis adopted by this study is completely different as this study looks at the spatiotemporal distribution of pollutants while much other research reviewed in this study did not.

Thus, in the transport system, together with the manufacture and management of vehicles and their accessories, there is possible pollution of the environment. One instance was cited by the United Nations Development Programme (UNDP, 2006), about 60-65% of life-cycle greenhouse gases released from vehicles using engines running on petrol are CO_2 emissions from the exhaust during the use of these vehicles, with a further 10 % being non-CO_2 exhaust emissions. The other 10 % is connected to the car's manufacturer, furthermore, the 15-20% is emitted during the mining, refinery and transport of the fuel (JICA *et al.*, 2014; UNDP, 2006). In this study, the application of spatial techniques will synchronize the wet and dry season data acquired to assess the spatial distribution of air quality parameters within the two seasons in the study area. Here field analysis covered the entire area sampled in the wet and dry season.

2.4 Air Pollution and Human Health

Quite a lot of authors have studied about health effects of air pollution across the globe; Khaled, in 2010 applied geospatial techniques and statistical analysis to map the impacts of air pollution on human health. The study focused on epidemiological and laboratory investigations and they developed the link between air pollution and asthma. Though, their results are diverse because other studies were not focused on linking the asthma prevalence in relation to the existing level of air pollution in their study areas (Solvang, 1999). Other studies revealed that long-term exposure to air pollution caused asthma and other respiratory diseases to most of the population exposed (Richard and Ubong, 2009; Uddin, 2006; Zagha and Nwaogazie, 2015). In addition, previous studies have also assessed if air pollution can affect human health by causing asthma or not. Anderson (1997), for instance, stated in his study that air pollution could barely be considered as a contributor to asthma endemic. This was due to the concentrations of the particle mass, sulphur dioxide, or nitrogen dioxide were reduced in the period when asthma rates increased in developed countries (Orogade *et al*., 2016; US-EPA, 2018).

Diesel and petrol-fueled vehicles most times pollute the clean air in different ways and emit different various groups of pollutants. Diesel fueled vehicles release fewer carbon monoxides and hydrocarbons compared to petrol-fueled vehicles but emit high fine particles and oxides of nitrogen. The majority of these particles are very tiny sized particles of about or less than 0.01mm, they have the capacity to traveling deeper part of the lung and its tissues of human bodies. Fine particulates have been reported to affect human health causing health-related problems like aggravation of pre-existing respiratory problems or inflammation of the lung tissue. They have been recorded to contribute to the haze that afflicts urban environments. Diesel fuel contains more energy per liter than petrol fuel but then again, there is no addition of lead in diesel fuel as did petrol fuels for motor vehicles (Fagbeja, Chatterton, Longhurst, Akinyede, and Adegoke, 2008). Diesel-fueled engines emit pollutants like; hydrocarbons, carbon monoxide and nitrogen oxides are lower compared to vehicles using petrol without an exhaust catalytic converter, but also diesel engines emit very high nitrogen oxides, sulphur and particulate matter.

The six major pollutants were termed “classic” air pollutants by WHO namely lead (Pb), carbon monoxide (CO), total suspended particles (TSP), sulphur dioxide (SO_2), ozone (O_3), nitrogen dioxide (NO_2) and other air toxic elements (Dora and Phillips, 2000; WHO, 2010). Recent studies of air pollution have established relationships between deaths caused by chronic obstructive pulmonary disease mortality, pneumonia, lung cancer, and cardiac disease (Kelly and Fussell, 2015; Khaled, 2010). Analysis done for long-term exposure has argued that there exist positive associations among annual average particulate pollution levels (PM_{10} or $PM_{2.5}$) and all-cause mortality yearly, cardiopulmonary mortality and lung cancer (Chattopadhyay, Gupta, and Saha, 2010; Ibe, Njoku, and Opara, 2016; Richard and Ubong, 2009).

2.4.1 Human Health Effects of Carbon Monoxide Exposure

CO is emitted primarily by motor vehicles during the fossil fuel combustion processes, is also an odorless and colorless gas. This becomes hazardous when a vehicle is in motion or left steaming within a confined garage or space, mainly if large volumes fumes are emitted. It decreases the circulation of oxygen in the bloodstream by interacting with haemoglobin in the human blood. People with chronic heart disease and experiencing cardiovascular diseases may experience chest pains when CO levels are high. According to WHO (2006), at high levels, CO impairs vision and manual dexterity and can lead to unconsciousness and death. 9.0 ppm (parts per million) is the CO ambient air quality standards in

Australian measured over an eight-hour period (Khaled, 2010; Molina, 2010; Mudu *et al*., 2014).

The single largest global contributor to the pollution of the ambient air is the combustion of fossil fuels by motor vehicles in developed cities as they release a lead and oxides of nitrogen and carbon monoxide and around 50% of the hydrocarbons. The extent and type of pollutants of the ambient air depend on the type of fuel the vehicle uses, for instance, petrol, diesel and Compressed Natural Gas (CNG). In the process of petrol combustion, the emission from the car exhaust includes carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter and evaporative emission like unburnt fuel vapors deposing into the atmosphere. Additionally, the bulk of these emissions of the above pollutants are caused by old or unmaintained vehicles as they no longer meet the manufacturer's specifications.

2.4.2 Health effects of Ozone in Humans.

oxidants or the photochemical smog are composite of gaseous chemicals formed in the atmosphere with the presence of solar energy; Ozone (O_3) is a major type of such example. Ozone is known with a colorless, odorless and highly reactive gaseous properties with a sharp odor that obviously occurs, 15-20 km above the ground level protecting the Earth from harmful sun’s ultraviolet radiation in the stratosphere. In the lower atmosphere, ozone is a secondary pollutant and are formed due to certain meteorological conditions in the presence of sunlight. Air quality standards for ozone is 0.10 ppm for one-hour exposure and 0.08 ppm for 4-hour exposure (Okonkwo, Okpala, and Opara, 2014). Ozone decreases the pulmonary function of exposed humans taking light-to-heavy exercise with transitory effects on the human respiratory system. Quite a lot of studies have linked premature mortality and other diseases to ozone (Danish, 2013; Fagbeja et al., 2008; Kelly and Fussell, 2015; Richard and Ubong, 2009; Zagha and Nwaogazie, 2015). With the supply of high energy, oxygen atoms combine with oxygen molecules to form ozone. That means ozone's formation occurs when oxygen molecules break down to oxygen atoms. The oxygen atoms will react with the oxygen molecules to form ozone (Schwartz, Coull, Laden, and Ryan, 2008). The ozone has injurious effects on humans which includes reducing visibility and damage to the vegetative cover. Additionally, ozone is component of the photochemical smog. Nitrogen oxides and volatile organic compounds (such as aromatics with two or more alkyl groups and olefins) that react photochemically are the two predecessors of ozone. gasoline and diesel-fuelled vehicles nitrogen oxides, while VOCs are released in considerable quantities by gasoline-fueled vehicles. It is thus, necessary to investigate the atmospheric chemistry of cities and know the chemical constituents. This is because VOC concentrations may have an adverse impact on ambient ozone concentrations in a NOx-limited category (Schwartz et al., 2008).

2.4.3 The Effects of Sulphur Dioxide on Human Health

It has been published that air quality has adverse impacts on human health, this assertion was also confirmed by (Khaled, 2010). Their study confirms that residents in economically developed areas and some parts of rural areas depending on the anthropogenic activities, are likely to be exposed to divers' levels of air pollutants and they relate to mortality and morbidity. The overall impact of air pollution in developed cities, in conjunction with recent policies, have not been campaigned for public comprehension within the exposed population. There are lots of misunderstandings among populace regarding air pollution, this includes the enforcement of established guiding rules for controlling the pollution in the atmosphere and their compatibility with trends across other developed cities. Studies have suggested that it is very important to support air pollution awareness campaigns across the globe to help reduce exposure and avoid the possible adverse health effects. Furthermore, other studies have suggested also, that it is vital to keep track of the health burden of air pollution from hospitals and also consider air pollution and their effects on making future policies. Sulphur dioxide (SO_2) is one of the typical examples (Zagha and Nwaogazie, 2015).

Sulphur dioxide (SO_2) is an irritating and strong colourless gas; the gas is formed during burning fossil fuels or other anthropogenic activities like sulphur-containing coal, gas or oil. In developed nations like Australia, Sulphur dioxide has not raised much concern. The major sources of SO2 are smelters, power plants and refineries (Akinfolarin, Boisa, and Obunwo, 2017; Fett et al., 1992; Khaled, 2010). It has been discovered that Sulphur dioxide has adverse impacts on human health as long-term exposure affects the respiratory system. However, in Port Harcourt, there are gigantic power plants for electricity generation, for instance, the Afam Power Plants and the Port Harcourt refinery. The emission of sulphur in the atmosphere can cause adverse changes in the function of the lungs of exposed persons with asthma which exacerbates respiratory symptoms in sensitive individuals. In a chemical reaction, SO_2 is transformed into Sulphuric acid which contributes to acid rain and to the formation of particulate matter. Ambient air quality standards for SO_2 are 0.20 ppm averaged over a one-hour exposure; 0.08 ppm averaged over a 24-hour exposure; 0.02 ppm averaged over a one-year period. (Breuer, 2009; Danish, 2013; Ibe et al., 2016).

2.4.4 Lead Effects on Human Health

Lead (Pb) is known as a soft grey metal, it affects human health by penetrating the nervous system, specifically causing disorders in the development of young children. Lead has a negative impact on human health when released in the environment. Lead is composed of fine particles and can penetrate the respiratory system to cause negative health effects. There is a possibility of increased number of hospitalized persons for heart and lung diseases. The studies revealed that there is recorded premature death associated with ($PM_{2.5}$) particulate matter exposure

(Platzer, Blake, and Snelling, 1997; Ras, 1990). Emission records of most developed cities are estimated about 90% of Pb in ambient air. It has been suggested by experts and literature that this was released from vehicles including major point sources like lead-related anthropogenic activities. In any 90% of the airborne, Pb is associated with particles of fine size (particles with diameters up to 2.5 µm) (Nwachukwu et al., 2014; Uddin, 2006).

2.4.5 Particulate Matter and Human Health Effects

Different sizes of particulate matter have been noted by different researchers to have different effects on human health, from many studies it has been shown that the tendency to cause health effects increases as the size of particles decreases. Particles suspended in the atmosphere which appear smaller than 10 µm in diameter (PM_{10}), are called inhalable particulate matter. Whereas the particles that appear smaller than 2.5 µm ($PM_{2.5}$) are referred to as respirable particulate matter. (Khaled, 2010; Molina, 2010). Particles above 10 µm in size are stuck in the nose and throat, whereas particles smaller than 1µm travels to the lower regions of the lungs(Kozáková et al., 2018).

A significant statistical relationship exists between ambient $PM_{2.5}$ and PM_{10} also has negative effects on health and (Canepari, Farao1, Marconi, Giovannelli, and Perrino, 2013; Richard and Ubong, 2009).

Most areas that are congested with traffic and smog released from cars and trucks, these were recorded as sources of two-thirds of pollutants. If such pollutants are inhaled, can block oxygen transportation in human bodies (Khare, 2012). The gaseous emissions also reduce visibility effectively. The sources of these particles are associated with combustion activities including wood-heaters, industrial combustion processes, bush burning and controlled burning of waste materials or other items, and vehicular emissions- mainly diesel-fueled vehicles. The ambient air quality standards for particles as $PM_{2.5}$ are: 25µg/m^3 averaged over a 1-day exposure, and 8 µg/m^3 averaged over a 1-year exposure (Greenbaum, Bachmann, Krewski, Samet, and White, 2001; Katsouyanni *et al.*, 1997).

2.4.6 Nitrogen Dioxide and Effects on Human Health

Nitrogen dioxide (NO_2) is known as a major reactive oxide of nitrogen, it appeared brownish and released into the ambient air through the oxidation of nitric oxide. It contributes to the formation of the photochemical smog and is majorly emitted from most non-point sources. The non-point sources of nitrogen oxides include but not limited to vehicular emissions and emissions from farming/agricultural activities. The release of NO_2 results in acid rain formation. Through the interaction of the factors below:

(1) Emission of related gaseous products,

(2) Interaction with air to form acid rain

(3) Diffusion into the atmosphere,

(4) Residential building,

(5) Release into rivers and stream, and

(6) Vegetation to be likely affected.

Point sources like power plants, sewage treatment plants, and other industrial facilities are known to contribute little amount of nitrogen dioxide (NO_2) emission to the atmosphere (US Environment Protection Agency;, 2013). There are short-term effects and long-term effects of nitrogen dioxide (NO_2) on human health. Short-term effects are increased respiratory illnesses in children while the long-term effects lowering the resistance of respiratory infections. Chiusolo *et al.*, (2011) show the techniques of releasing Nitrogen dioxide into the atmosphere. Their research experimental revealed that nitrogen dioxide exposure increases the permeability of the cell membrane and decreases the auxiliary beat frequency thereby increasing the response of asthmatics to inhaled allergens. The ambient air quality standards for NO_2 are 0.12 ppm averaged over a 1-hour exposure; and 0.03 ppm averaged over a 1- year exposure.

2.5 Geographic Information System Applications in Air Pollution.

Technological improvements are unarguably seen as one of the most lasting remedial measures to manage the increased road transport air pollution risk and reduce health impacts on the human. The arrival of hybrid technology in cars and alternative fuel/energy sources has been proven very useful in reducing the high emission of air pollutants from transportations. Also, the stringent legislation on exhaust emission for all vehicles is highly desired to reduce the hazards on road transportation especially that directly contributing to air pollutions. Improvement of the technology alone may not be sufficient to reduce the effects of transportation system on human health; rather, there is need for integrated planning with the spatial distribution of technological advancements in the form of modeling with the aid of sophisticated technologies (Woodcock, Banister, Edwards, Prentice, and Roberts, 2007). Reducing air pollution and the accompanying health effect is not a minor challenge; rather one of the major problems confronting human health. The air pollution sources are generally multiple not depending upon the geography of the location studies but also the changing meteorological conditions of the locations, and increasingly, climatic variations. The main sources of air pollution in Port Harcourt are power generation, transportation, commercial, residential and industrial activities (Gwilliam, Kojima, and Johnson, 2004). With the increasing vehicles on the Port Harcourt roads with increasing traffics, the situation is becoming grimmer for human health especially in the dry seasons of the year. It is important to note that air pollution occur across boundaries or political zones. In the case of industrial air pollution, transboundary pollution is a common problem when the source is proximal to another city or developed location. The harmful gases, toxins and particulates emitted into the atmosphere during the process of fossil fuel combustion in vehicles adversely affect human health and their welfare and may lead to deaths.

The application of GIS technology is good decision support. It is a tool that can help reduce decision-making time, for example, with transport-related human health problems, by conducting spatial analysis for the evolution of a suitable methodology and modeling. The applications of GIS are divers including in medicine, agriculture, transportation etc. Its application in various transport problems include planning and design of infrastructure, and management, traffic monitoring, transportation safety analysis, control, public transit planning and operations and travel demand analysis, environmental impacts assessment, hazard mitigation, and intelligent transportation systems (Borzacchiello, Casas, Ciuffo, and Nijkamp, 2009; Chowdhury and Sadek, 2003). Recently, there is increasing research on health hazards awareness on air pollution. The increasing demands for visualization of data in spatial forms have provided more details to dynamics of problems or their solutions. According to Knowles and Hillier, (2008), the functions and application of GIS is beyond what maps or databases alone can do; GIS is essentially capable of analyzing descriptive problems of What, Where, When, how much or How big, GIS can tell data patterns in the analysis. In more innovative practice, GIS can resolve conditional queries like "what if" and pose multivariate scenarios. There exist several geospatial tools that can be adopted in GIS models. These tools have been utilized by several researchers to investigate possible exposure and spatial distribution of air pollution in cities and region of study interest. They include;

i. Kriging of Air Quality Parameters

Spatial interpolation tools include Kriging. This tool is an ArcMap tool technique fit into the linear group of squares estimators (Schwartz *et al*., 2008). It is used for spatial analysis of a random field interpolation using values at unobserved locations based on sampled points data acquired. Fundamentally, the tool estimates the weighted averages in a similar way to the Inverse Distance Weighted interpolation except that the weights have been optimized through a least-squares operation. And this is based on the spatial covariance minimizing the variance of the predictive error. The spatial covariance is estimated from the empirical spreading of parameters and requires that the model describing the empirical distribution result in a covariance matrix which is positive semi-definite and symmetric.

ii. Interpolation using Inverse Distance Weighted (IDW)

IDW estimates the spatial distribution of the parameters using the weighted distance values. This is an ArcGIS tool and interpolates a raster surface data from points data of air quality parameters using an inverse distance weighted (IDW) technique (Solvang, 1999; Khare, 2012). The input feature data must contain at least a numerical valid field which the value of the field will be interpolated to the extent of X, Y data. The z data is applied as the concentration value. Barrier structures are input into the ArcMap as polyline features. IDW applies the use longitudes and latitudes (x, y) data coordinates for the linear feature. Consequently, it is not required to provide z-values as the concentration value for the analysis to serve as the barrier. Any z-values provided will be ignored (Schwartz *et al*., 2008).

iii. Existing studies of GIS application

The use of GIS techniques in studies of air quality monitoring has increased recently due to the unique analytical capabilities and best visualization tools for presentation Knowles and Hillier, (2008). In the reviewed studies, there are several studies in which researchers applied Geographic Information System to develop dispersion models which they used in their study to investigate the relationship of the levels of air quality and their environmental issues (Schwartz *et al*., 2008). GIS has a flexible and user-friendly interface with exceptional graphics abilities which most dispersion models do not provide. Gulliver and Briggs, (2011) modeled the dispersion of NOx using GIS tools alone. The emission inventory data for their study area was used to estimate the annual average NOx pollution in the atmosphere. This technique they adopted was useful in identifying long-term air pollution “hotspots”. Though, it did not predict short-term concentrations of the pollutant. But then it could be used to improve the networks of air pollution sitting and to estimate pollutant concentrations in which there is no monitoring data available. Another research study conducted by Jensen *et. al.*, (2001) used ArcGIS to help local authorities in managing air quality in big Danish cities. GIS models integrate administrative databases, digital maps, and an operational street pollution model. It can also be used for mapping traffic emissions and estimates the levels of air quality and human exposures in houses, offices and within streets. The model has shown improvement in assessment of exposure compared with other systems like mathematical models etc.

Jensen *et. al.*, (2001) developed a prototype air pollution model by integrating spatial data with an area pollution data, available digital maps and administrative databases for Danish cities. The model estimates air quality and human exposure at the workplace address and residential area.

Canepari *et al*., (2013) evaluate area using a model. Their study integrated vehicular emission in a model to assess the pollutant dispersion in the study area, backward trajectory model was developed, and relevant attribute data, spatial data and GIS framework were incorporated to develop the techniques. GIS uses the spatial data to describe the urban road network and distribution of atmospheric pollutants. The system is applied in emissions estimation from vehicles to analyse air pollution and its spatial distribution within Taichung City, Taiwan.

The air quality management system for decision support was developed by Elbir, (2004) for the big Turkish cities. The system was developed using ArcMap and was based on a dispersion model and related databases for calculating emissions from various point and non-point sources. The study predicted pollutant concentrations using the dispersion model and comparing the results with observed air quality data from actual monitoring stations. After calibration of the GIS model, air quality mapping and scenario analysis were done.

Danish, (2013) focused on the air quality assessment and visualization and revealing the reactions of long-term pollution exposure of NOx and death rates in Aukland, New Zealand. They developed CALGRID model to simulate the urban air quality of Aukland. CALGRID simulates the transport, diffusion and deposition of O_3 and NOx in the atmosphere. Results of the model were compared with observed air quality concentrations at the monitoring sites around Aukland region. Modeled concentrations were converted from point base grid coverage to polygon grid coverage using GIS. Polygon grid coverage concentrations were then converted to census area unit concentration. Mortality rates were calculated using the no of people exposed to pollution at the census area unit level.

Gulliver and Briggs, (2011) integrated a GIS dispersion model with CALC3QHC, to simulate traffic-related air pollution. This integration improved the actual dispersion model (CAL3QHC) limitations. The system is built as an ArcMap application tool through a customized user interface. GIS visualization functions were used to create a contamination concentration surface, to create a receptor grid with specified intervals and to create a node-line topology for roadway links. A user can prepare maps and images for different planning scenarios.

Theophanides and Anastassopoulou, (2009) conducted research to analyze atmospheric pollution around airports. Emissions from different sources of pollution linked with airport pollution in addition to aircraft were modelled using EDAMS. Emissions determined from EDAMS were entered in ADMS to generate dispersion pattern. GIS platform was used as a means of representing multiple sources of data in different layers. The study concluded that the application of GIS in environmental assessments provides accuracy in handling geographical/topological information.

Studies have shown an integrated approach to predict Ozone (O_3) concentrations, estimate crop damage and assess the magnitude of corresponding economic loss in the Greater Thessaloniki Area, Greece (Akinfolarin *et al*., 2017; Yousefi-Sahzabi, *et. al,* 2011). Ozone (O_3) concentrations for the year 2002 were estimated using the Ozone Fine Structure (OFIS) model. Model results were compared with observed values derived from measured data and were mapped for the area under consideration. Reduction in crop yield, for crops sensitive to O_3, were estimated for reference year in areas where O_3 concentration exceeds the air quality index. Monetary valuation of crop yield loss was carried out and damage cost to agricultural production per cultivated area was spatially allocated in the entire study area. The study found a strong correlation between crop yield loss and O_3 concentrations level (Akinfolarin *et al*., 2017).

(Yousefi-Sahzabi, *et. al*, 2011) also conducted a study that predicted the CO_2 dispersion of in the surrounding of a planned 50 MW geothermal power plant prior to its operation. The US EPA dispersion model ISC3View was used in this study to predict CO_2 concentrations. After optimization of the dispersion, model GIS is used for visualizing model results and better analyses of CO_2 concentration status at a geographical area.

Danish, (2013) in his studies evaluated regional ambient air quality and characterized for SO_2 at a relatively fine geographical scale of $1km^2$. The study also integrates GIS with the AERMOD dispersion model to achieve their research goals. The SO_2 pollution from different sources in Dallas County, Texas was simulated from 1996 to 2002 using the AERMOD model. Concentrations were then analyzed, using GIS spatial analysis tools such as kriging and overlay, to detect their spatial variation over the entire study area.

Gulliver and Briggs, (2011) presented a sample GIS-based air pollution dispersion model for city-wide exposure assessment using STEM-Air (Space-Time Exposure Modeling System-Air pollution) to simulate traffic-related air pollution. The model presented has four components: 1) an emission model, 2) meteorological preprocessor, 3) a GIS-based air dispersion model, and 4) a GIS-based exposure assessment tool. The model operates in two modes, short-term (daily) and long-term (annual). A study on traffic pollution in London, UK applied the same model.

Many researchers (Danish, 2013; Molina, 2010) have assessed much research that applied GIS to study community-level pollutant concentrations and associated health risks. The studies explored the utility of publically available databases, like the U.S EPA‟s National-Scale Air Toxic Assessment, Air Quality System, and National Emission Inventory, for identifying risks of exposure to air pollutants at the community level. Most of these studies provide a stable framework to assist small communities in understanding potential environmental risks and develop mitigating strategies.

Behera and Sharma, (2011) also in their research, applied GIS to develop emission inventory for all sources responsible for PM_{10} pollution in Kanpur, India and then used ISCST3 dispersion model to simulate PM_{10} concentrations to identify pollution hotspots in the city and to evaluate the contribution of each source in PM10 pollution level.

Macit and Gümrükçüoğlu, (2012) calculated SO_2 concentrations from industrial emissions and mapped pollution distribution using GIS. His study was conducted for the city of Sakarya, Turkey. Many researchers have also in the past applied GIS in the assessment of the dispersion of Air pollution in Nigeria and particularly in Port Harcourt (Ukaegbu, Njoku, Iwuji, and Nwuze, 2016; Weli and Adekunle, 2014). The study concluded that it is valuable to calculate pollutant concentrations and analyze dispersion phenomena using an air quality model in conjunction with GIS.

2.6 Air Quality Standards and Monitoring Strategies.

2.6.1 Air Quality in Nigeria.

Air pollution is regulated by three major pieces of a regulation issued by the National Environmental Standards and Regulation Enforcement Agency, these are The National Guidelines and standards for environmental pollution control in Nigeria. National Environmental Protection (pollution abatement in industries and facilities generating wastes) Regulation 1991.

The Management of Solid and Hazardous Wastes Regulations 1991 which gave a comprehensive list of dangerous and hazardous wastes. Industries that have the potential to impact air quality are crude oil production (petrochemical industries) followed by other minor industries like; coal mining, cement manufacture, chemical, fertilizer manufacture, etc.

Generally, according to the final report of the Federal Government's Environmental and Social Management Framework (ESMF) for State Governance Capacity Building Project (SGCBP), the air quality in Nigeria complies with regulatory standards. Although, slight variations are noticed in major industrial cities like Lagos, Ibadan, Aba, Kano, Port Harcourt and Kaduna. Thus, this study is focusing only on Port Harcourt because of increased alarm on the compromised air quality of Port Harcourt since 2014. The Federal Ministry of Environment, Housing and Urban Development (FMEnv. and UD) adopted the WHO standards as the national standards for gaseous emissions against which air quality parameters monitored are compared in order to ascertain its "cleanliness". The Nigerian ambient air quality standard developed by the Federal Ministry of Environment were published in 1991 and covered the emission limits of particulates, SO_2, Non-methane Hydrocarbon, CO, NO_X and Photochemical Oxidant. Their specified limits are 250 ($\mu g/m^3$), 0.1 (ppm), 160 ($\mu g/m^3$), 11-4 ($\mu g/m^3$) or 10 (ppm), 0.04-0.06 (ppm) and 0.06 (ppm) respectively.

2.6.2 Air Quality in Port Harcourt

According to Ogwu *et al.*, (2015), there is stress on the environmental resources in Niger Delta due to the current industrial revolution in the region thus, igniting unfriendly activities in the area. These, their study identified as; aggravated bush burning, combustion, gas flaring, improper disposal of domestic and industrial wastes; pollution through oil spillage; car exhausts, unsanitary and unsafe housing. All these affect human well-being especially the health and socio-economic well-being of the people of the Niger Delta in Nigeria and in the world. The most affected groups are women and children. Their study highlighted the dimensions, nature and characteristics of these phenomena and further examines the implications of air pollution on the health and socio-economic well-being of the people of the Niger Delta. Their study recommended a holistic and integrated approach to air pollution management that will involve all the stakeholders. This was a literary-based study.

2.6.3 Meteorology of air pollution

In City Air Pollution, the meteorological conditions that affect transport and dispersion take place in the planetary boundary layer (Ekman layer), it is approximately lower 1000 m from the atmosphere. Within this layer, wind speed and its direction are influenced by the roughness of the surface and the vertical height of flows (Hung, 2010; Kozáková, *et. al*, 2018). Over the years, the common classification of the atmospheric turbulence was a method developed by Pasquill in 1961. The atmospheric turbulence was categorized into six stability classes named A, B, C, D, E and F with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent class (Kozáková, *et. al*, 2018).

2.6.4 The Role of Climate on the Air Quality

The wind pattern shows that during the day, emission concentrations will be high near the source and low at farther distances. At dawn when soot deposits were very noticeable in Port Harcourt, particulates concentrations will be confined near the source area due to temperature inversion and move downwind of the source below inversion layer due to lateral displacement of air. Lateral displacement of air is always prominent during stable atmospheric conditions(Akinfolarin et al., 2017).

The atmosphere plays a significant role in the dispersion process of air pollutants. Since Nigeria's crude oil/hydrocarbon resources are found beneath the Niger Delta formation, the Niger Delta atmosphere is classified as the primary sink to which the emissions are deposited (Ede and Edokpa, 2015). Regarding local transport emission characteristics, the role of large-scale (synoptic) and local meteorological conditions (including low wind speed), as well as low value of the mixing-layer height, are considered as the key factors that influence the concentration of air quality parameters within the area (Orogade *et al*., 2016; Woody, Arunachalam, and West, 2012). Other studies have also shown that climate contributes a significant amount of increase in soot particulates concentration (Costabile; & Allegrini, 2008).

Furthermore, the occurrence of temperature inversion may cause an additional accumulation of the pollutant near the ground surface of the boundary layer (Guédjé, Houéto, and Houngninnou, 2017; Zhang, Zhong, Wang, Wang, and Liu, 2018). An additional factor that influences changes in particulates concentration is an influx of other air masses pulled by the changing atmospheric circulation (Zhang, Vijayaraghavan, Wen, and Snell, 2009). Concurrently, a change in circulation pattern impacts not only meteorological conditions but also the transport of pollutants (Kozáková et al., 2018; Yousefi-Sahzabi et al., 2011;

Zhang et al., 2018). Trans-boundary airborne intrusions caused by atmospheric circulation are an unavoidable issue for many areas dealing with the problem of air pollution (Canepari et al., 2013).

According to Akinfolarin, *et. al.*, (2017), the results of their assessment of atmospheric particulate matter at the three emerging industrial sites in Port Harcourt in 2017 indicated higher concentrations compared to their control site for both $PM_{2.5}$ and PM_{10}. PM data from their study indicated seasonal variation with the dry season indicating concentrations higher than local acceptable limits of 150 $\mu g/m^3$ and 230 $\mu g/m^3$. The AQI of the three emerging industrial sites of Port Harcourt indicated a category for 'good' to 'moderate' for the wet season while for the dry season, they varied from 'very unhealthy' to 'hazardous' in all the studied areas. Based on their results, they concluded that the activities of some of the industries located at these emerging industrial sites in Port Harcourt may be contributing to the high concentration of particulate matter in the study area (Akinfolarin et al., 2017).

Though, the issue of air quality monitoring in Port Harcourt became alarming in 2015 after carbon soot precipitation in the city and its environs. Okonkwo, *et. al*., (2014) started their air quality monitoring in two locations in Port Harcourt that is noted for heavy traffic congestion in the city. Their monitoring times were chosen to capture traffic congestion. In total, they conducted five (5) morning and evening measurements at each location over the course of two (2) weeks beginning from August 11th – 15th, 2010 for Garrison intersection and August 18th - 22nd 2010, for Slaughter intersection. Concentration measurement for Hydrocarbon (HC), sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and carbon monoxide (CO) were carried out in the morning (6.30 – 8.00 am) and evenings (5.00 – 7.00 pm) peak periods of traffic congestion using the standard gas monitor. In summary a 24 hours mean exposure monitoring was achieved. Their studies revealed that the levels of these gaseous emissions were higher than the permissible level from Wednesday to Saturday at the two junctions in both morning and evening. However, the level of these gases on Sunday at the two junctions in the morning and evening were below the detection limit. Their study revealed that automobile contributes to air pollution in Port Harcourt.

Zagha and Nwaogazie, (2015) surveyed the ambient air quality with respect to Carbon monoxide, Sulphur dioxide, Oxides of nitrogen and Particulate matter (PM_{10}). The study area in Port Harcourt focused on four locations; three junctions (Mile One Junction, Rumuola Junction and Artillery Junction) along the Port-Harcourt Aba Expressway. Their study was purposefully selected because of high traffic density and the presence of roadside vendors while Bodo Street in the New GRA was used as the control. The air pollution measurements were carried out in-situ using automated handheld gas monitors; VRAE Multi-Gas Monitor for SOx and NOx, HAZDUST Particulate Air Monitoring Equipment for PM_{10}, and AEROQUAL Gas Detector for CO. Sampling was carried out for six consecutive days; three days for each location for both the dry and wet season. The results were found to be in the following ranges for hourly readings: CO (0-60.24ppm), NOx (0-1.50ppm), SO_x (0-0.75ppm) and PM_{10} (26-199.00μg/m^3). They modelled the data using Air Quality Index and values in the study varied between 267.17 as the maximum value and 14.71 as a minimum value showing that the health of people who spend long hours along roadsides are at risk. Studies have summarized the effects of the basic pollutants considered fin this study on human health. A current study in Port Harcourt, listed a table basic pollutant discovered. (Abali, Etebu, and Leton, 2018)

The review above covered literature on Port Harcourt air quality with diverse thoughts on air quality and its index, this research, therefore, reveal the Spatiotemporal variation and spatial dispersion of the air quality parameters in the Port Harcourt using geospatial techniques and the result appeared in maps showing concentrations of air quality parameter from dry to wet season in 2018.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Port Harcourt is the capital of Rivers State, Nigeria. It lies along the Bonny River (an eastern distributary of the Niger River) 66km upstream from the Gulf of Guinea. Port Harcourt City due to the current urban expansion has extended and covered both Port Harcourt and Obio/Akpo LGA. The City lies within Latitude $4^0$52’30”N to Longitude $6^0$54’30” and Latitude $4^0$41’30”N to longitude $7^0$5’30”E. The entire city comprising of the two LGA occupies a sum of 472.96 square kilometers.

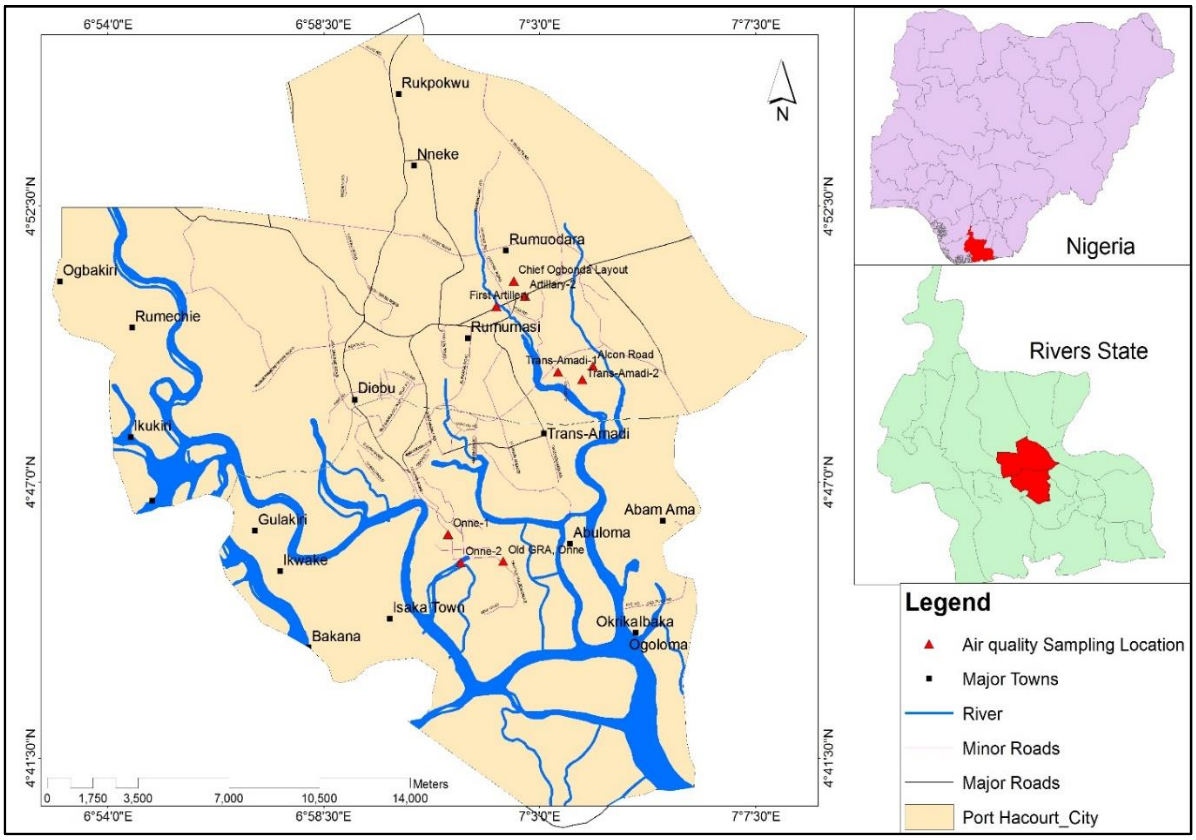

Figure 3.1: Map of the study area showing sampling locations.

Source: Ukaegbu Fieldwork 2018.

Port-Harcourt features a tropical monsoon climate with lengthy and heavy rainy seasons and very short dry seasons. Only the months of December and January truly qualify as dry season months in the city. The harmattan, which climatically influences many cities in West Africa, is less pronounced in Port-Harcourt. Port Harcourt's highest precipitation occurs during September with an average of 367mm of rain. December on average is the driest month of the year, with an average rainfall of 20mm.

Temperatures throughout the city are relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25^0C-28^0 Celsius in the city. A study on the wind energy potentials for a number of Nigerian cities shows that the annual wind speed ranges from 2.32 m/s for Port Harcourt (Ugochukwu, 2008).

The Deltas and estuaries, with their saline wetlands, have a total surface area of 858,000 hectares, while freshwaters cover about 3,221.500 hectares (Nwilo and Badejo, 2005). Other water bodies, including small reservoirs, fishponds and miscellaneous wetlands suitable for rice cultivation cover about 4,108,000 hectares (Kuruk, 2004).

The entire Gulf of Guinea is highly stratified with a thin surface layer of warm fresh tropical water (Ugochukwu, 2008). The stratification of the upper water column along the Gulf of Guinea is generally very strong except in areas subjected to upwelling events. The Nigerian coastal geology is sedimentary and dominated by the geology of the Niger Delta (Nwilo and Badejo, 2005).

3.2 Types and Sources of Data

3.2.1 Types of Data

In-situ air pollutants were measured in the atmosphere within the study area. Carbon monoxide (CO), Nitrogen dioxide (NO_2), Particulate matter ($PM_{2.5}$ and < PM_{10}), Sulphur oxides (SO_2), were collected and compared with National Ambient Air Quality Standards (NAAQS) and World health organization air quality standards. Also, the GPS at the collection point of air quality data in the study area was recorded for further geospatial interpolation analysis using ArcMap 10.0.

3.2.2 Sources of Data

3.2.2.1 Primary Data

The primary data of this study were acquired through field data gathering in the study area, the in-situ measurements of the air quality parameters in the study area. The primary data were acquired at purposefully selected locations using hand-held Gas analyzer; Aerocet-531 Met One Instrument, Drager X-am 5000 and a Handheld Germin-300 Global Positioning System (GPS) device to record the GPS coordinates of the sampling points. The concentrations of selected air quality parameters considered for this study such as $PM_{2.5}$, PM_{10}, and CO, SO_2, NO_2 were measured at the sampling locations using a hand-held Gas analyzer; Aerocet-531 Met One Instrument and Drager X-am 5000 respectively.

3.2.2.2 Secondary Data

The sources of secondary data used are literature and climatic data acquired from published journals, gazettes, brochures, Internet and statistical publications of the Environmental Protection Institutions and Nigerian Metrological Agency, Port Harcourt. The ranges of wind speed and dominant direction data were acquired from the Nigeria Meteorological Agency at the Port Harcourt International Airport station. The assessed literature covers the following parameters such as; CO, SO_2, NO_2, H_2S, O_2, CH_4, NH_2, O_3. Other secondary data assessed was the climatological data covering the study area. This data includes the wind speed and wind direction of the sampling location. This was to enable geospatial processing of the results, incorporating the climatic conditions in the concentration of the parameters measured for both the wet and dry season field data gathering.

3.4 Methods of Data Collection.

Data were collected by *in-situ* measurements of the parameters in Nine purposeful sampling points within the study location. This method involved (real-time) air quality monitoring using a hand-held Gas analyzer, Aerocet-531 Met One Instrument was used to acquire measurements of Particulate Matter 2.5 and 10, Drager X-am 5000 were used to measure the concentration of CO, NO_2, SO_2. A handheld Germin-300 GPS device was used to record the GPS coordinates of the sampling points. The handheld GPS and the handheld air quality meter for the specified parameters, in which air quality was constantly measured and the data was automatically transmitted and saved into the database of the monitoring device. Each air quality monitor was taken at a height of about 2m in the direction of the prevailing wind at each sampling point and readings were taken when the fluctuating sensor of the monitor stabilizes. The readings were measured in parts-per-million. The formula applied in converting gaseous pollutants from ppm to μgm^{-3} is given by:

$$1ppm = \mu g/m \times 0.0224/M.$$

Where M is the molecular weight of the pollutant.

GPS points of all sampling locations were acquired using a Global Positioning System (GPS), the coordinate readings of each sampling point were taken when the sensor of the GPS stabilizes. The monitoring period at each sampling location was for both morning and evening periods. The average values of the two monitoring periods were statistically compared.

3.5 Tools of Data Collection and Analysis

There are two basic categories of tools used for this study, the air quality monitoring devices and the software used for geospatial analysis. The air quality monitoring devices include Garmin X300, a hand-held Global Positioning System. This was used in this study to determine the GPS coordinates and geo-reference each sampling point for both the dry and wet season data acquired at in-situ from the study area. The GPS device is a space-based navigation system that provides location and time information in all weather conditions on or near the Earth. It functions where there is an unobstructed line of sight to four or more

GPS satellites (Solvang, 1999; Kelly and Fussell, 2015). The Global Positioning System (GPS) was initially calibrated for efficiency before use for each monitoring. The Germin 300 GPS, Aerocet-531 device and Drager X-am 5000, handheld devices used for this study were calibrated before use for field measurements. The calibration was for quality assurance purposes under the company's and the manufacturer's calibration standards.

Aerocet-531; is a handheld battery-operated particle counter. It was used in this study to determine the concentration of air-borne suspended particulate matter of the size of up to 1 milligram per cubic meter within the study area. The instrument was set to monitor $PM_{2.5}$ and PM_{10} particle counts with networked data in real-time; data logged values or printed data. All five important mass ranges of size PM_{10}, PM_7, $PM_{2.5}$, and PM_1 is a mass mode on the display along with two frequently used cumulative particle sizes of > 5.0 and > 0.5 microns in the particle mode.

Drager X-am 5000, hand-held air-quality monitoring equipment was used in this study to measure the major gaseous air quality parameters such as Carbon monoxide, Nitrogen Oxides, and Sulphur dioxide. It is a portable gas detector instrument with the capacity of detecting five gases. This gas detector reliably measures combustible gases and vapors as well as oxygen and harmful concentrations of CO, NO_2, SO_2 and other gases which were not included in the scope of this study.

3.5.1 Data Analysis

Microsoft Excel Spreadsheet was used to calculate the mean values of each concentration of air quality parameters for repeated measurements and to ensure the integrity of the values obtained. The Air Quality Index (AQI) was calculated for the study location using the mean daily PM2.5/PM10 by taking the 24-hour concentration average in Local Standard time and converting to AQI. More than 75% of data were considered for valid daily AQI calculation (Fatemeh, *et. al*, 2013). EPA established national air quality standards AQI scaling six categories and a specific colour assigned to each to appreciate at first glance whether air pollutants are reaching unhealthy levels in the area or not as shown in Table 3.1.

Table 3.1; Pollutants exposure limits.

Pollutant	Monitoring Duration	FMEnv Limit	WHO Limit
$PM_{2.5}$	1-hour mean	15 $\mu g/m^3$	
	24-hour mean		25 $\mu g/m^3$
	Annual mean		10 $\mu g/m^3$
PM_{10}	1-hour mean	50 $\mu g/m3$	
	24-hour mean		50 $\mu g/m^3$
	Annual mean		20 $\mu g/m^3$
CO	1-hour mean	5 mg/m^3	
	8-hour mean		55 $\mu g/m^3$
NO_2	1-hour mean	0.5 $\mu g/m^3$	
	24-hour mean		
	Annual mean		40 $\mu g/m^3$
SO_2	1-hour mean	0.83 $\mu g/m^3$	
	10 minutes mean		500 $\mu g/m^3$
	24-hour mean		20 $\mu g/m^3$

Source: (Abali et al., 2018)

EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" pollutants. They are listed below. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m3).

The AQI was computed by using the pollutant concentration data and the linear interpolation equation (Equation 3.1):

$$I_p = \frac{I_H - I_L}{BP_H - BP_L}(C_p - BP_L) + I_L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where: I_p = the index of pollutant, p;

C_p = the rounded concentration of pollutant p;

BP_H= the breakpoint that is greater than or equal to Cp (upper limit);

BP_L= the breakpoint that is less than or equal to Cp (lower limit);

I_H= the AQI value corresponding to BPH; and

I_L= the AQI value corresponding to BPL.

Table 3.2. Air Quality Index Values, Health Colour, and Concerns Codes.

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151-200	Unhealthy	Red
201-300	Very Unhealthy	Purple
301-500	Hazardous	Maroon

Source: www.airnow.gov

3.6 Methods of Results Presentations

The result was displayed using maps, figures, and tables showing the interpolated results in maps for easy understanding of the variation in the concentration of air quality parameters in the study area. Descriptive Statistical analysis of the result was presented in the table and charts to illustrate the correlation and samplings relation between the assessed parameters across the sampling locations. These results revealed the concentration of various air quality parameters in the area and the table of results was displayed in bar charts for more visual interpretation of the results.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The entire analysis and results of the air quality of Port Harcourt and the Spatiotemporal comparison of wet and dry season data of air quality in the study area in 2018 are presented in this chapter (see Table 4.1 and Table 4.2). The result is displayed in maps below.

Table 4.1: Wet Season Results of Air Quality

Location	Latitude	Longitude	NO2 (ppb)	SO2 (ppb)	PM10 (µg/m3)	PM2.5 (µg/m3)	CO (ppb)
Chief Ogbonda Layout	4.844525	7.042735	1.76	28.68	43.12	1.64	0.98
Alcon Road	4.821936	7.068497	1.38	48.15	31.63	28.80	3.95
Old GRA, Onne	4.757149	7.037393	0.85	47.23	37.31	48.50	2.48
First Artillery	4.843698	7.040377	6.48	21.38	87.19	59.22	42.03
Trans-Amadi-2	4.81744	7.064825	8.24	39.12	17.52	52.06	47.21
Onne-2	4.756676	7.022563	9.02	68.51	103.82	41.42	51.02
Artillary-2	4.844179	7.041472	5.89	39.23	96.25	57.42	18.09
Trans-Amadi-1	4.820035	7.056411	9.67	27.68	89.73	74.42	0.05
Onne-1	4.766041	7.018196	28.74	29.85	231.17	80.50	114.29
DPR Limits			0.08	0.04	NS	NS	NS
FMEnv Limits			0.04	0.01	NS	NS	NS

Source: 2018 Fieldwork Wet Season.

Table 4.2: Dry Season Air Quality Parameters.

Location	Latitude	Longitude	NO_2 (ppb)	SO_2 (ppb)	PM_{10} (µg/m3)	$PM_{2.5}$ (µg/m3)	CO (ppb)
Chief Ogbonda Layout	4.844525	7.042735	13.63	71.14	72.09	33.51	1.92
Alcon Road	4.821936	7.068497	15.40	43.59	77.83	35.86	0.99
Old GRA, Onne	4.757149	7.037393	4.70	33.62	101.79	50.36	58.8979
First Artillery	4.843698	7.040377	9.85	48.50	156.44	62.76	7.43
Trans-Amadi-2	4.81744	7.064825	9.34	38.23	159.87	63.76	2.58
Onne-2	4.756676	7.022563	5.45	27.63	175.21	74.72	50.3642
Artillary-2	4.844179	7.041472	7.94	59.80	312.20	134.27	4.20
Trans-Amadi-1	4.820035	7.056411	8.41	36.92	365.26	148.78	2.58
Onne-1	4.766041	7.018196	6.09	34.39	378.68	159.23	50.1285
DPR Limits			0.08	0.04	NS	NS	
FMEnv Limits			0.04	0.01	NS	NS	

Source: 2018 Fieldwork Wet Season.

The mean values of air quality parameters were calculated using the MS Excel Spreadsheet. The results were subjected to Spatiotemporal analysis which was revealed in maps showing the spatial distribution of air quality parameter concentration in maps. Bar charts were developed with the air quality parameter data to compare the variation in the concentrations of wet and dry season air quality data and the different parameters assessed at the different sampling locations in the study area.

4.1.1 Atmospheric Weather Conditions

Average wind speed in Port Harcourt ranges from 1-6m/s and 0.5-2.m/s during the day and night, respectively, and can be higher during occasional periods of storms and squalls. Figure 4.1 and Figure 4.2 revealed the dominant wind directions in Port Harcourt for the most part of the year and the wind speed.

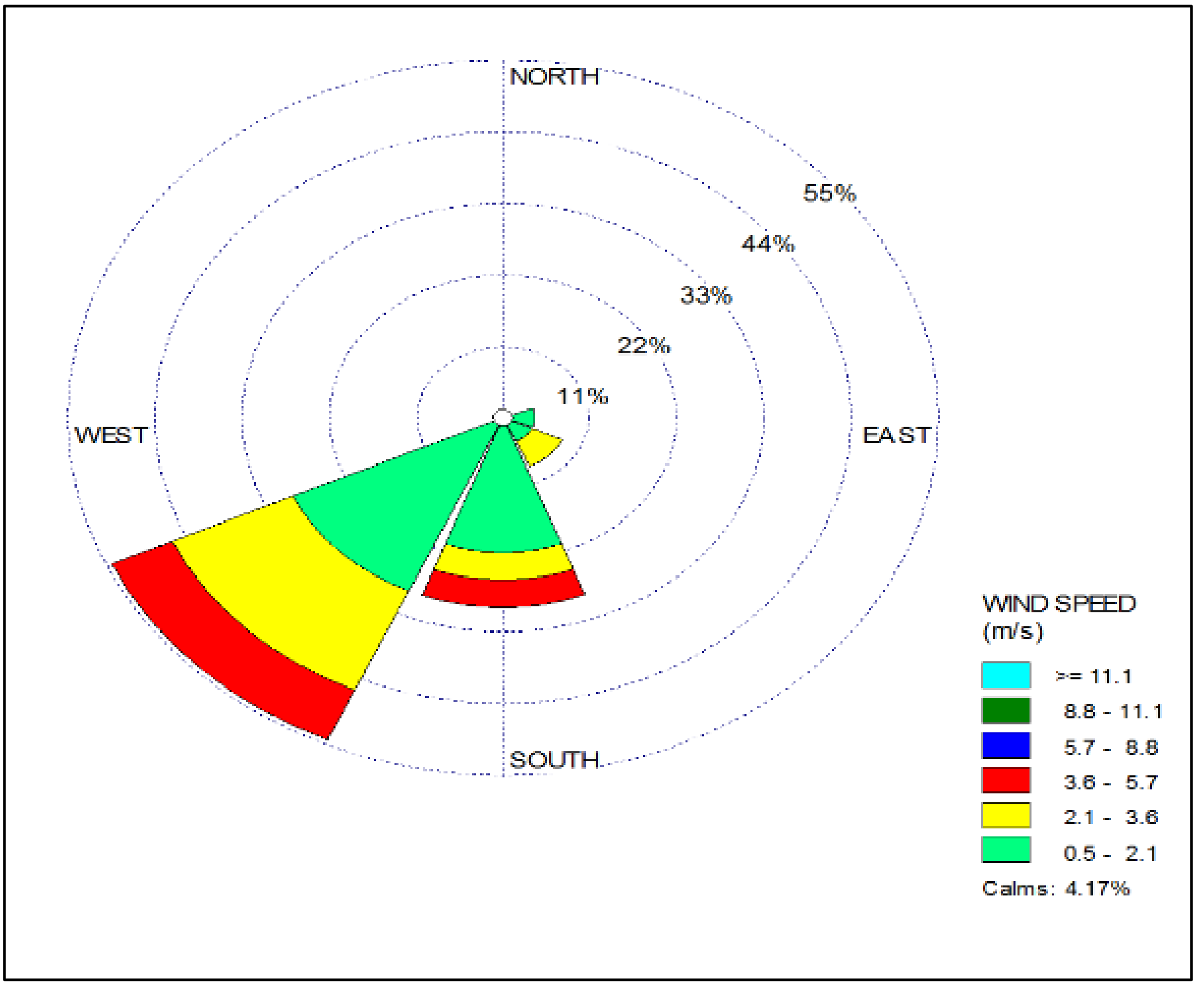

Figure 4.1: Diurnal wind rose pattern in Port Harcourt

Source: (Ede and Edokpa, 2017)

It has been determined that the atmospheric boundary layer stability conditions in Port Harcourt are very stable at night and unstable during the day (Edokpa and Ede, 2013).

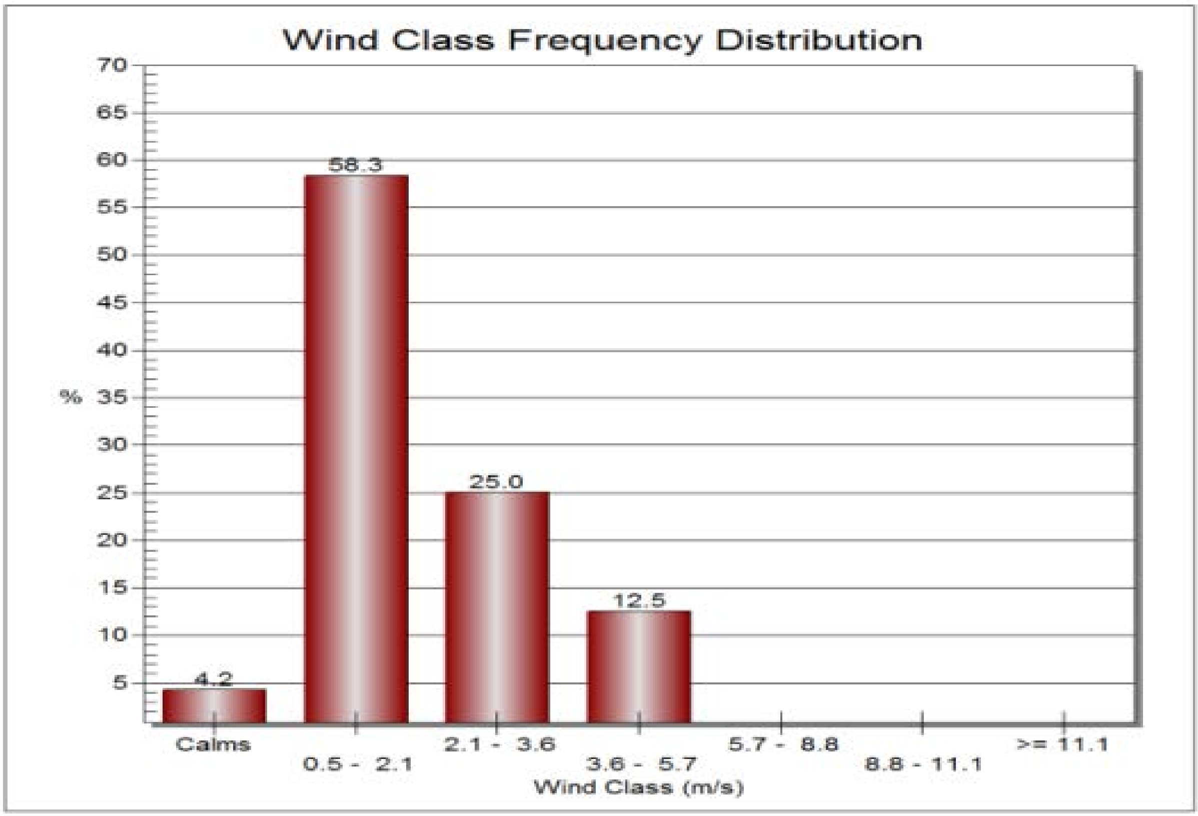

Figure 4.2: Diurnal Wind Speed Pattern in Port Harcourt. Source: Ede and Edokpa, (2017)

The implication of these emissions concentrations around Port Harcourt is that ground-level concentrations will be low for sensitive receptors under unstable atmospheric conditions during the day and severe for sensitive receptors under stable conditions at night (Ede and Edokpa, 2015, 2017; Edokpa and Ede, 2013).

4.1.2 Spatiotemporal Analysis of PM_{10}.

The results obtained from the field monitoring of air quality in the study area in January and September 2018 for both dry and wet seasons respectively, PM_{10} was subjected to spatial interpolation analysis using the Inverse Weighted model

(IDW) tool in ArcGIS. It revealed that the concentration of PM_{10} was high in the city center in both seasons. Lower concentrations considered to be moderate by air quality index were observed in the residential estates within the Trans-Amadi location (Northern/western part) of the city in the wet season. Lower concentration was also noticed towards the southern part of the city. Thus, this could be as a result of the variations in the activities in the area at different study periods (see Figure 4.3). For instance, nearly all industrial processes, as well as the burning of fossil fuels, release particulate matter into the atmosphere (Danish, 2013; Jaffe, 1968).

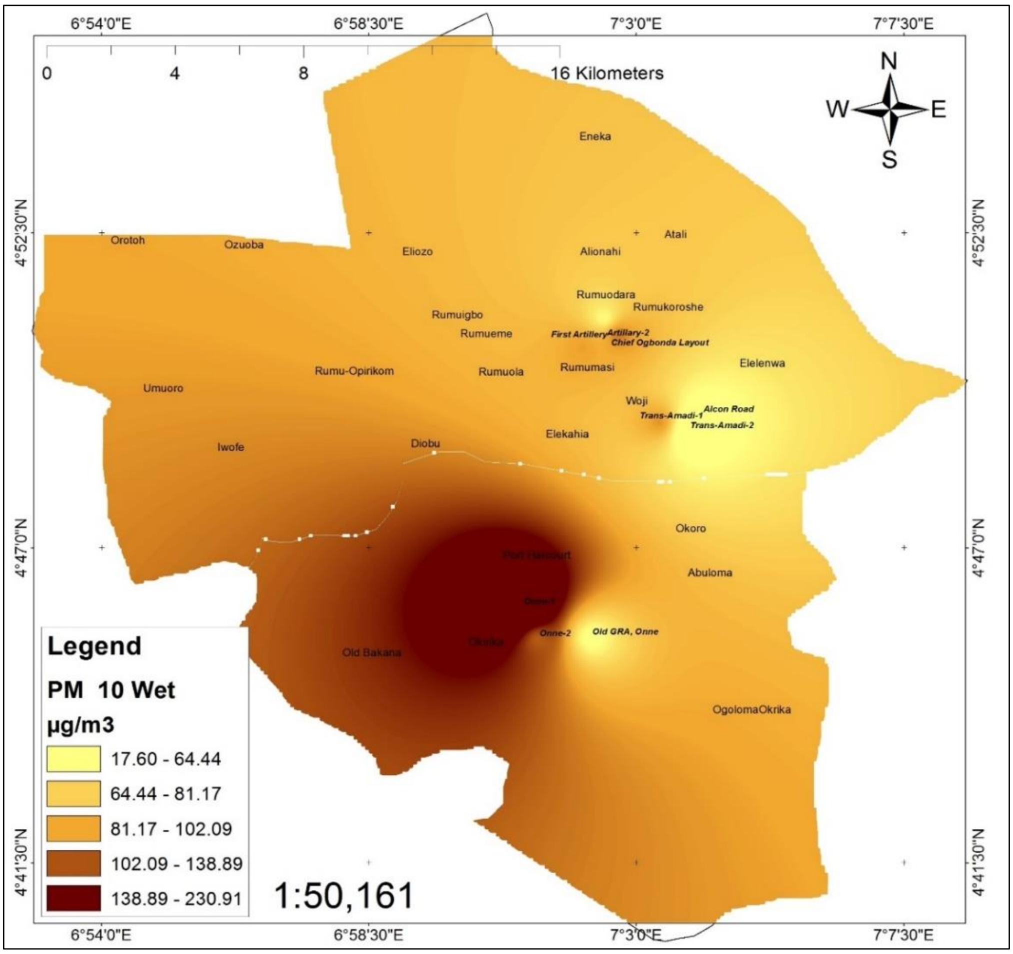

Figure 4.3A: Spatiotemporal Variation of PM_{10} ($\mu g/m^3$) for Wet Season

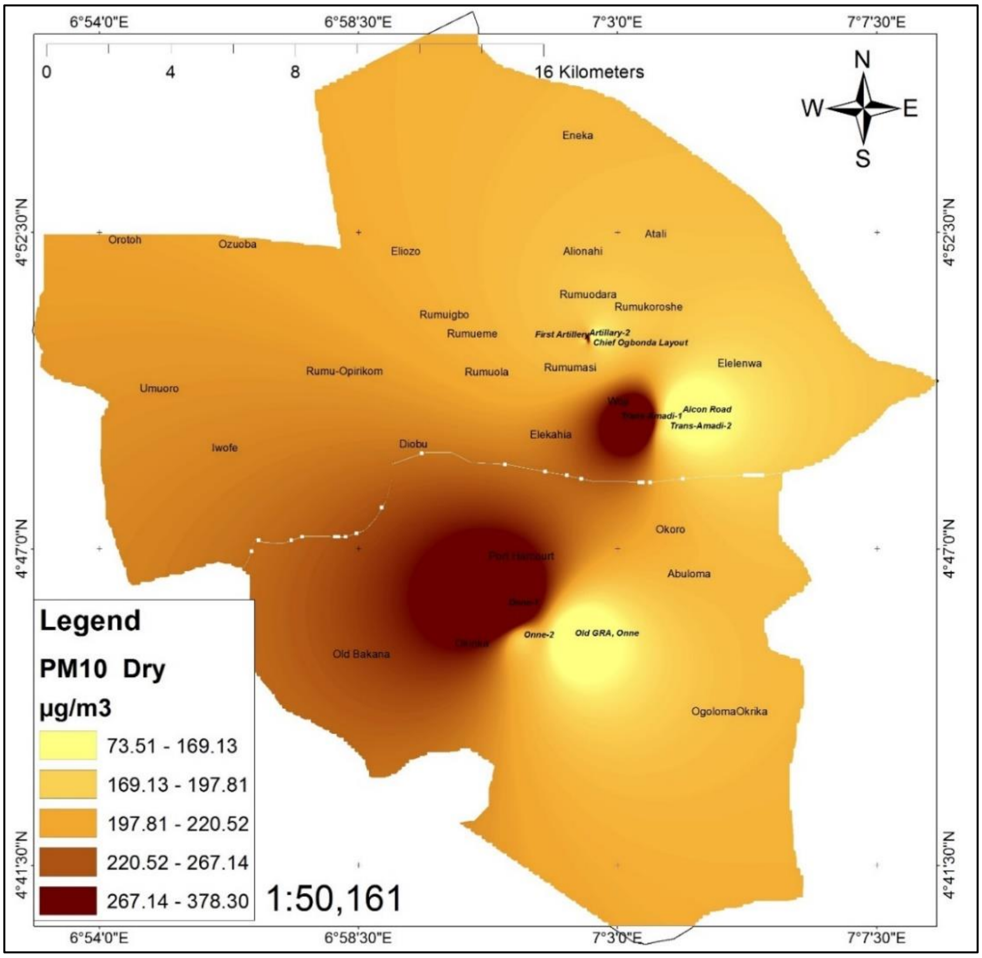

Figure 4.3B: Spatiotemporal Variation of PM_{10} ($\mu g/m^3$) for dry season

In conclusion, the PM_{10} from both Figure 4.3 A and B, wet and dry season respectively revealed that Onne, Trans-Amadi, and Artillery were locations dictated to have a very high concentration above the WHO and FMEnv exposure limits. This concentration followed the same trend in the two seasons. The Spatiotemporal distribution followed the same trend of dispersion and this was further evaluated using a T-test statistical tool. Particulate matter encompasses the small solid or liquid substances that are released into the atmosphere through many activities.

Spatiotemporal Variation of $PM_{2.5}$

From figure 4.4 below, it was revealed that areas around Onne and Trans-Amadi have a very high concentration of $PM_{2.5}$. the range for the dry season was identified as 34.1 µg/m^3 to 159.07 µg/m^3 whereas these values generally reduced in the rainy season. The ranges for the rainy season are from 2.5 µg/m^3 to 80.4 µg/m^3. this shows that pollution is higher in the dry season than the rainy season. This also seen in the seasonal precipitation of soot in the city. See figure 4 below for the spatial distribution in the study area.

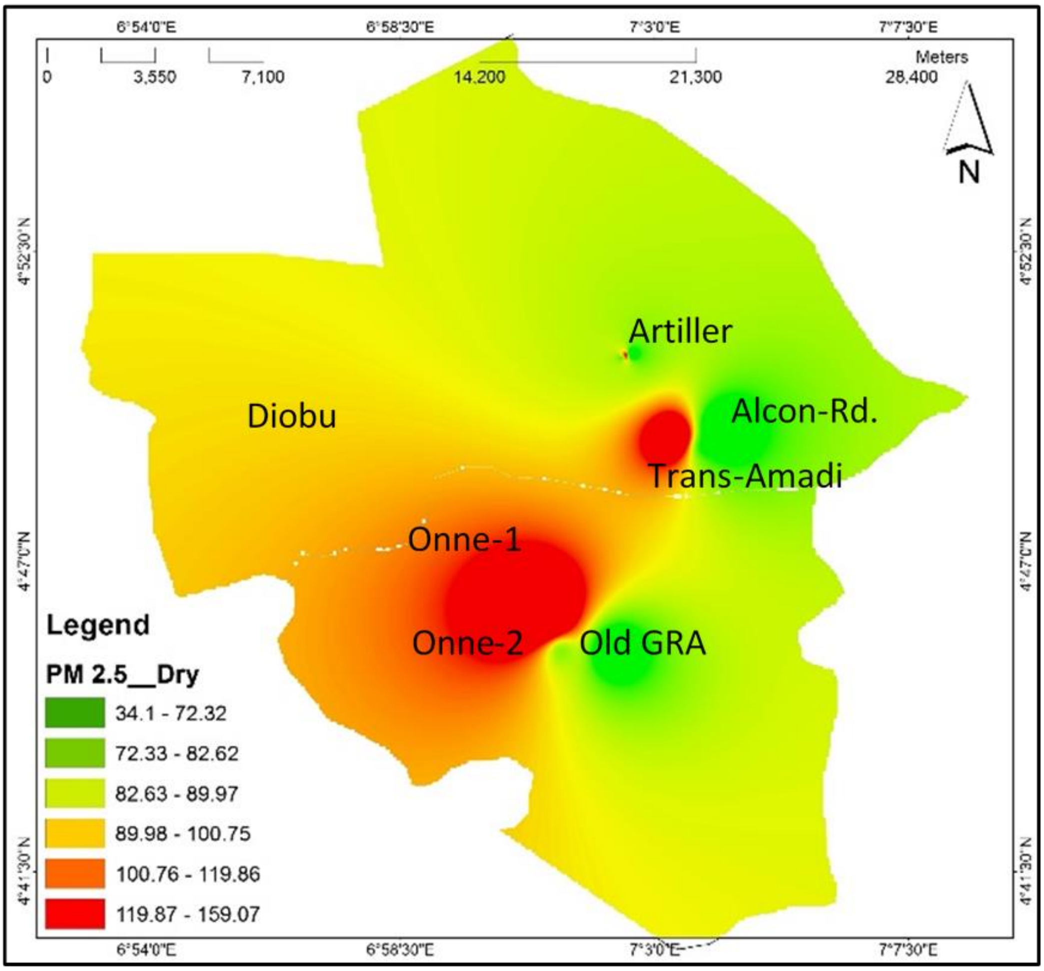

Figure 4.4A: Spatiotemporal Variation of $PM_{2.5}$ (µg/m^3) for Dry Season.

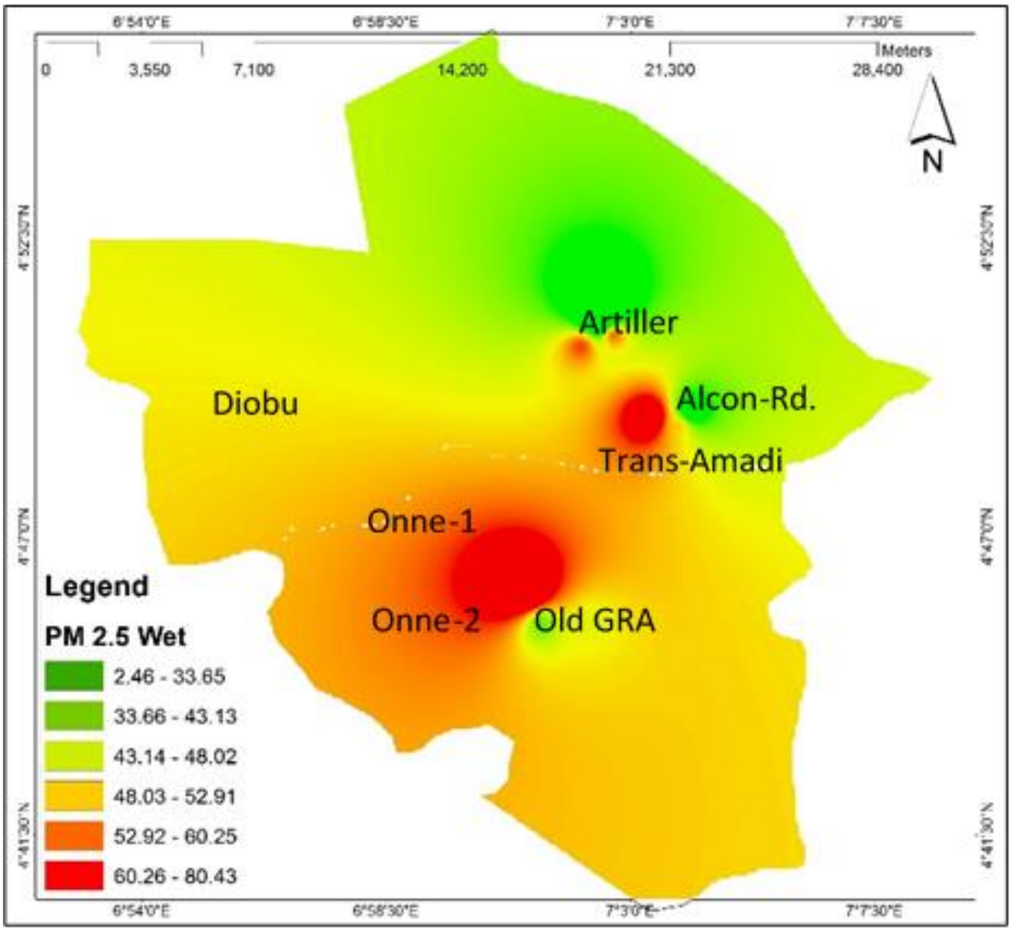

Figure 4.4B: Spatiotemporal Variation of $PM_{2.5}$ ($\mu g/m^3$) for wet season.

Also, on the other hand, the areas that appeared lower in concentration are the second artillery point and the point within Alcon road in Woji and Old GRA. These areas have many vegetative covers as they are well planned with low economic activities.

4.1.3 Spatiotemporal Analysis of Nitrogen Dioxide (NO_2).

Fig. 4.5 shows the Spatiotemporal distribution of nitrogen dioxide concentration in the study location for both dry and wet monitoring seasons. The results of the IDW analysis revealed a high concentration of nitrogen dioxide in the Northern region, but lower concentration at both the city center and southern parts of the study area.

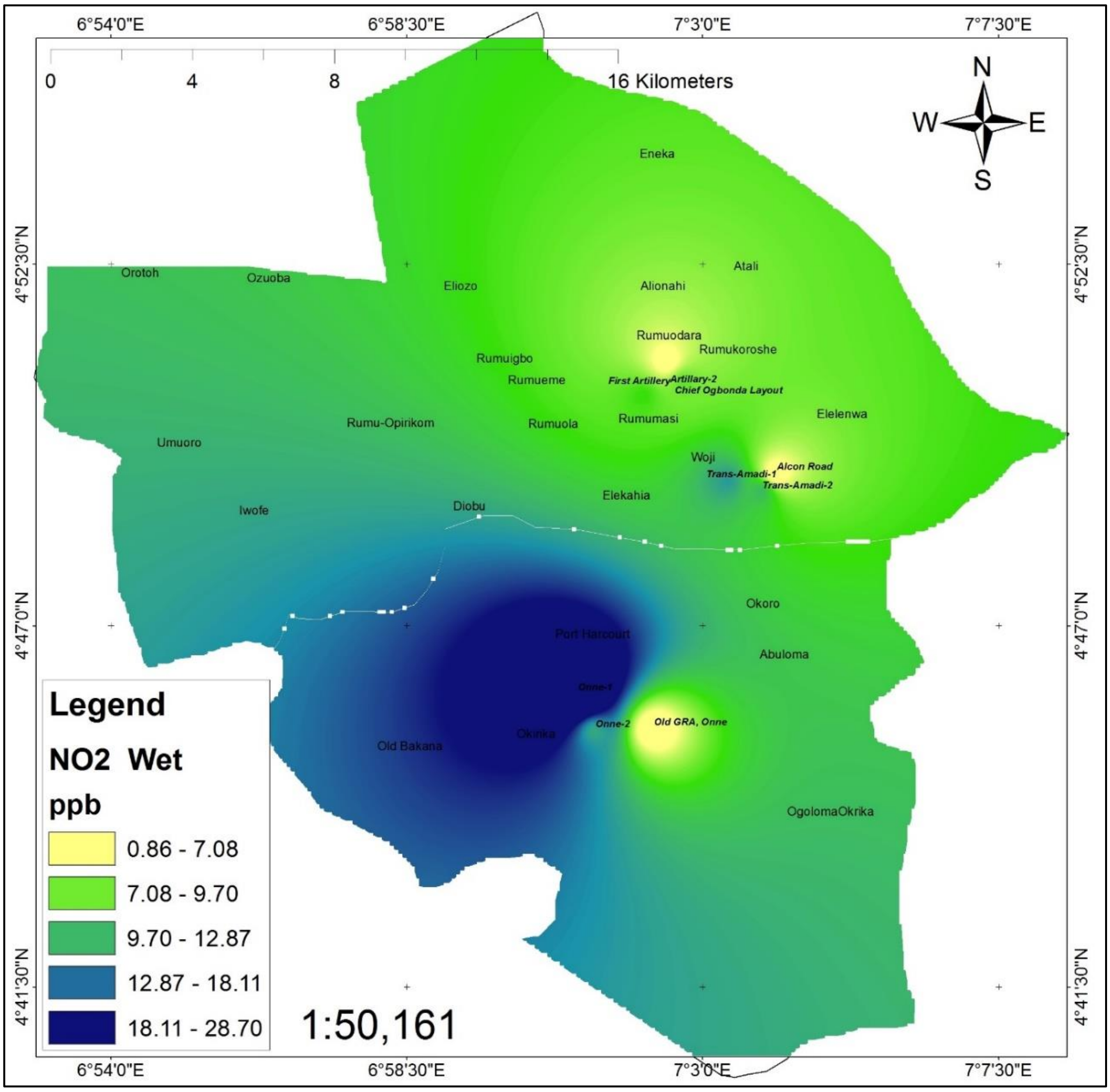

Figure 4.5A: Spatiotemporal Variation of NO_2 (ppb) for wet season

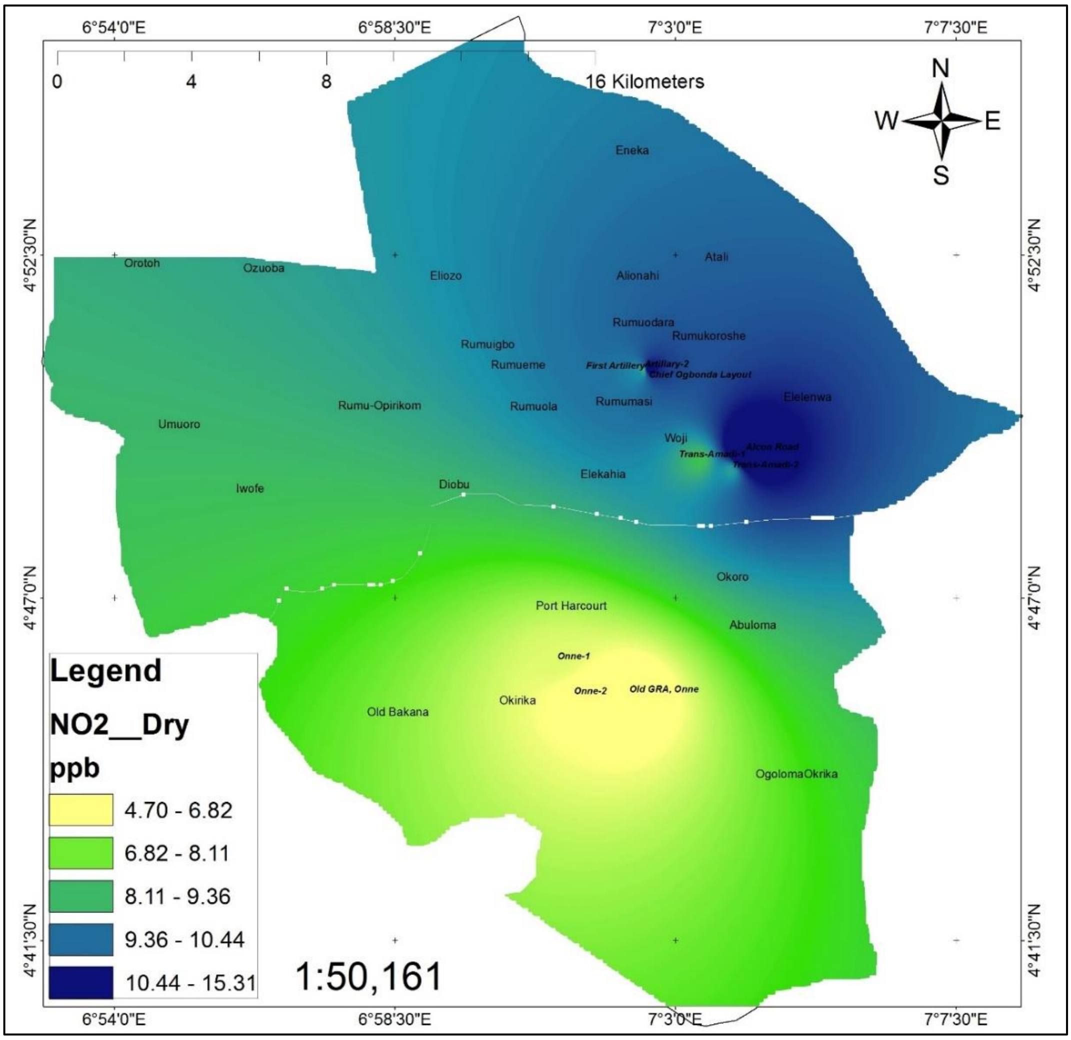

Figure 4.5B: Spatiotemporal Variation of NO_2 (ppb) for dry season

The spatiotemporal distribution of the results revealed that the lowest value was recorded in the Old-GRA of the city for both seasons of the study, whereas in the dry season there are several factors that can possibly contribute to the increasing trend at these points in their study year such as its central location with the junction of major roads and a cluster of minor roads at the North. As regards the Southern part of the city is not the center of the city and thus has fewer local vehicles and major oil and gas flaring as compared to other locations. Also, these areas that are lower in concentration was observed to be above FMEnv and WHO limits of exposure. Moreover, the data levels of nitrogen dioxide are consistently below the DPR and NAAQS air quality goals in the study region.

4.1.4 Spatiotemporal Analysis of Sulphur Dioxide (SO_2).

Figure 4.6 below shows the spatiotemporal distribution of concentration of the sulphur dioxide in the study area at the period of monitoring.

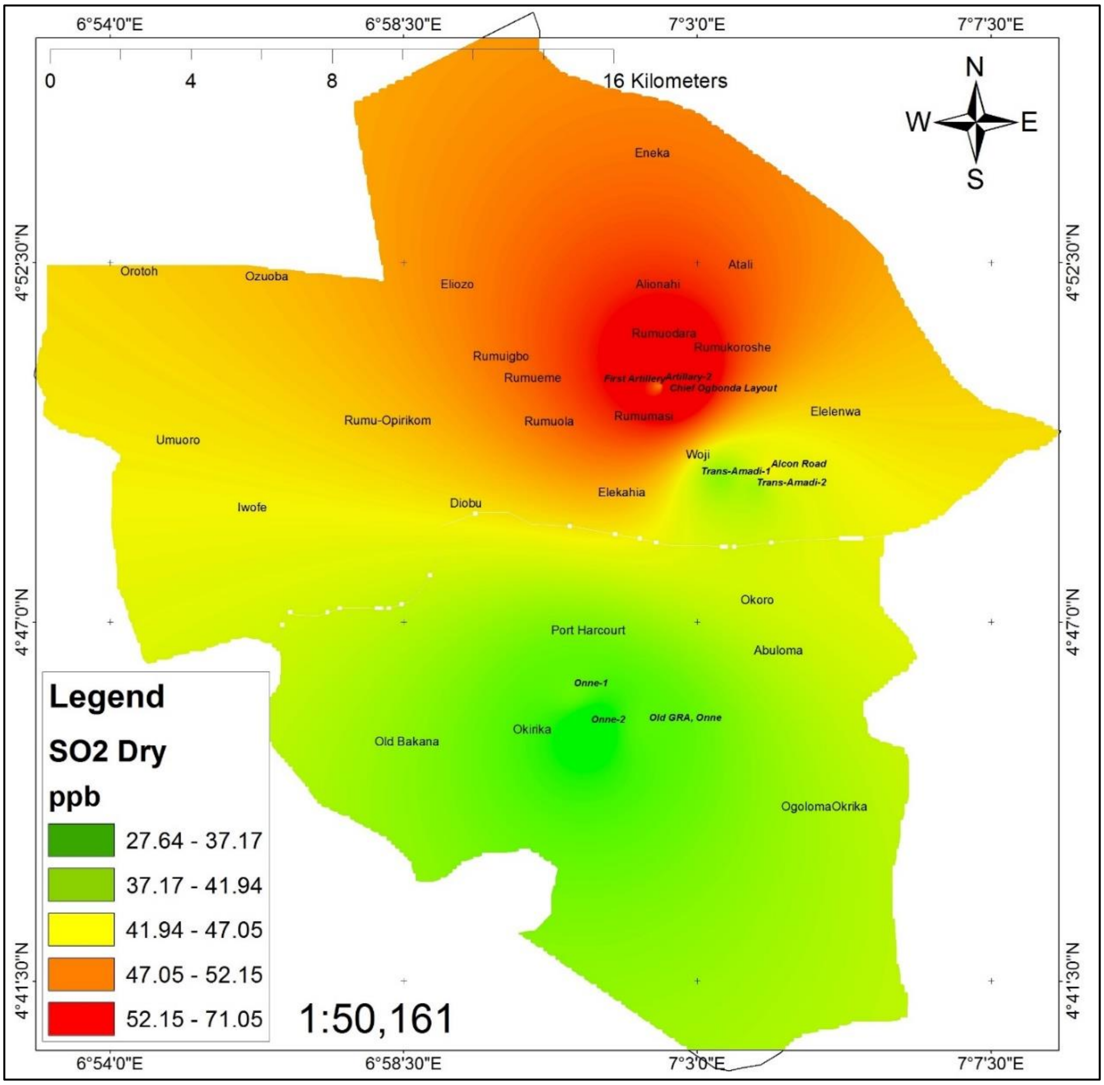

Figure 4.6A: Spatiotemporal variation of SO_2 (ppb) for dry season

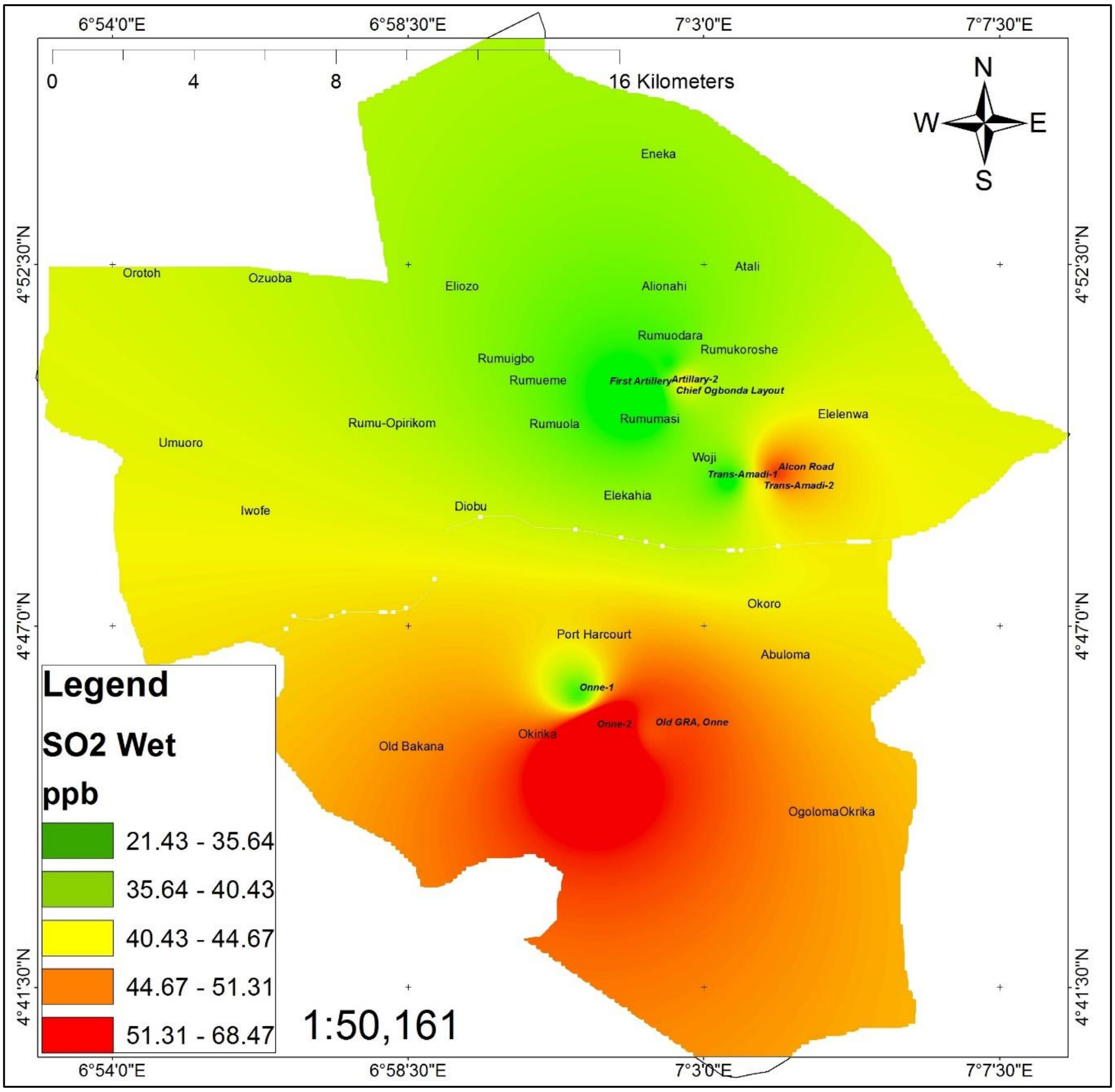

Figure 4.6B: Spatiotemporal variation of SO_2 (ppb) for wet season

The SO_2 concentration observed from the sampling location was in the range of 21.43ppm to 68.47ppm for the wet season. While in the dry season it was discovered that the range was spatially distributed in the area from 27.64ppm to 71.05ppm. The highest concentration of SO_2 was discovered from the city center towards the northern part of the study area. Based on the dry season survey, the reason for the high concentration value could be attributed to the surrounding activities in the neighboring areas like illegal refining and flaring of gases. And traffic congestion was observed at the road intersections, where the long waiting time for vehicles was observed. Thus, the wetness of the area dilutes these gases during the raining season. Hence the concentration is reduced but above WHO and FMEnv exposure limits

4.1.5 Spatiotemporal Analysis of Carbon Monoxide (CO).

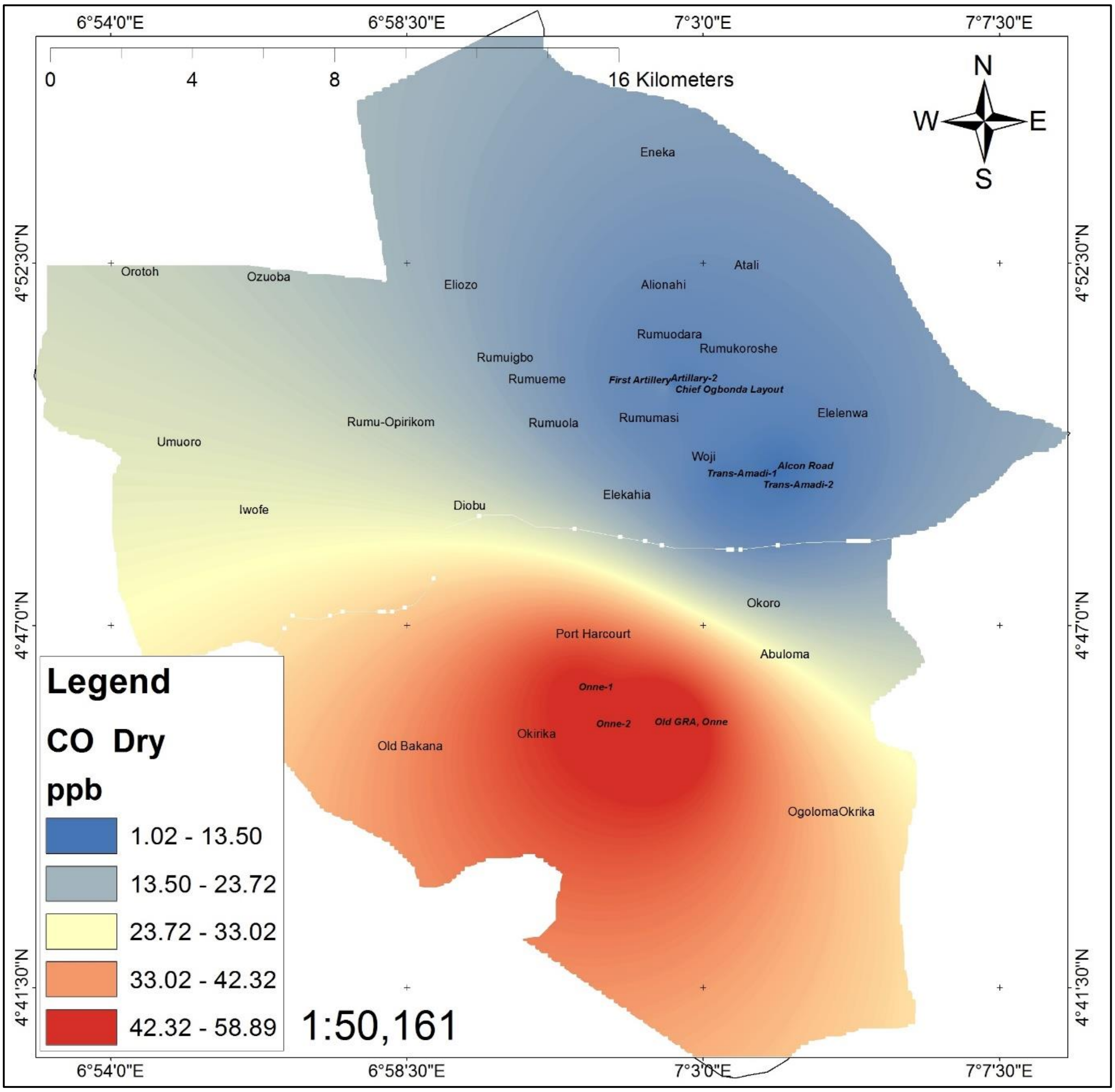

Figure 4.7A: Spatiotemporal Variation of CO (ppb) for dry season

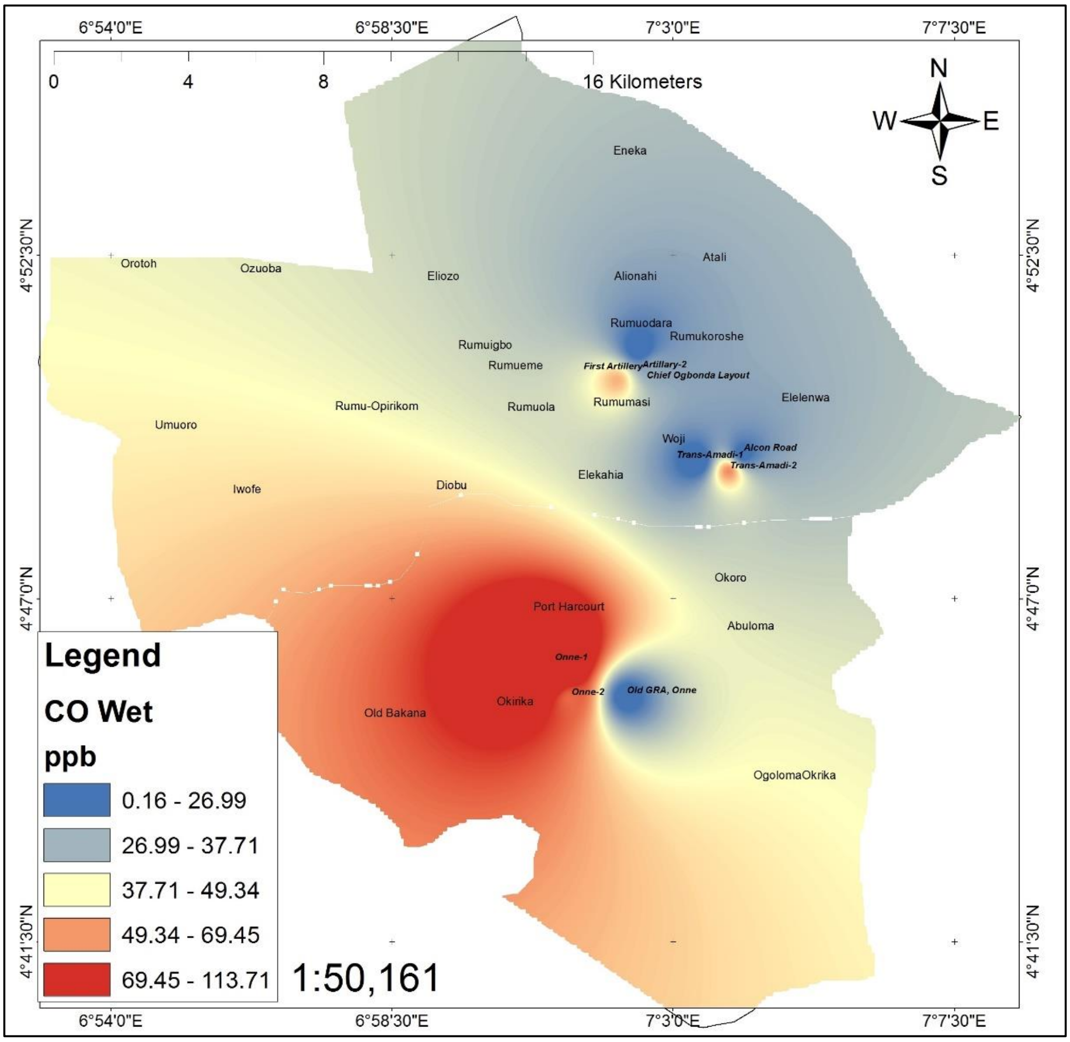

Figure 4.7B: Spatiotemporal Variation of CO (ppb) for wet season

Figure 4.7 revealed the distribution CO in the study area for both dry and wet season in 2018. The result of the spatiotemporal analysis for the two study seasons followed the same trend revealing that the northern part of the city has the highest concentration of CO in the study area. Carbon monoxide was observed to be high in concentration within the Old GRA in the dry season with an average value of 58.89 ppb. This is above normal exposure in the study location. While in the wet season the concentration of CO reduced in comparison with the location with the highest concentration value in dry season result but a higher value was dictated at Onne. According to the field survey, the concentration of CO ranges from 0.98 to 114.3 ppb.

4.1.6 Air Quality Index Mapping of the Study Area

From the AQI model of PM 2.5 of both the rainy and dry season, it was discovered that all sampling locations exhibited unhealthy air quality.

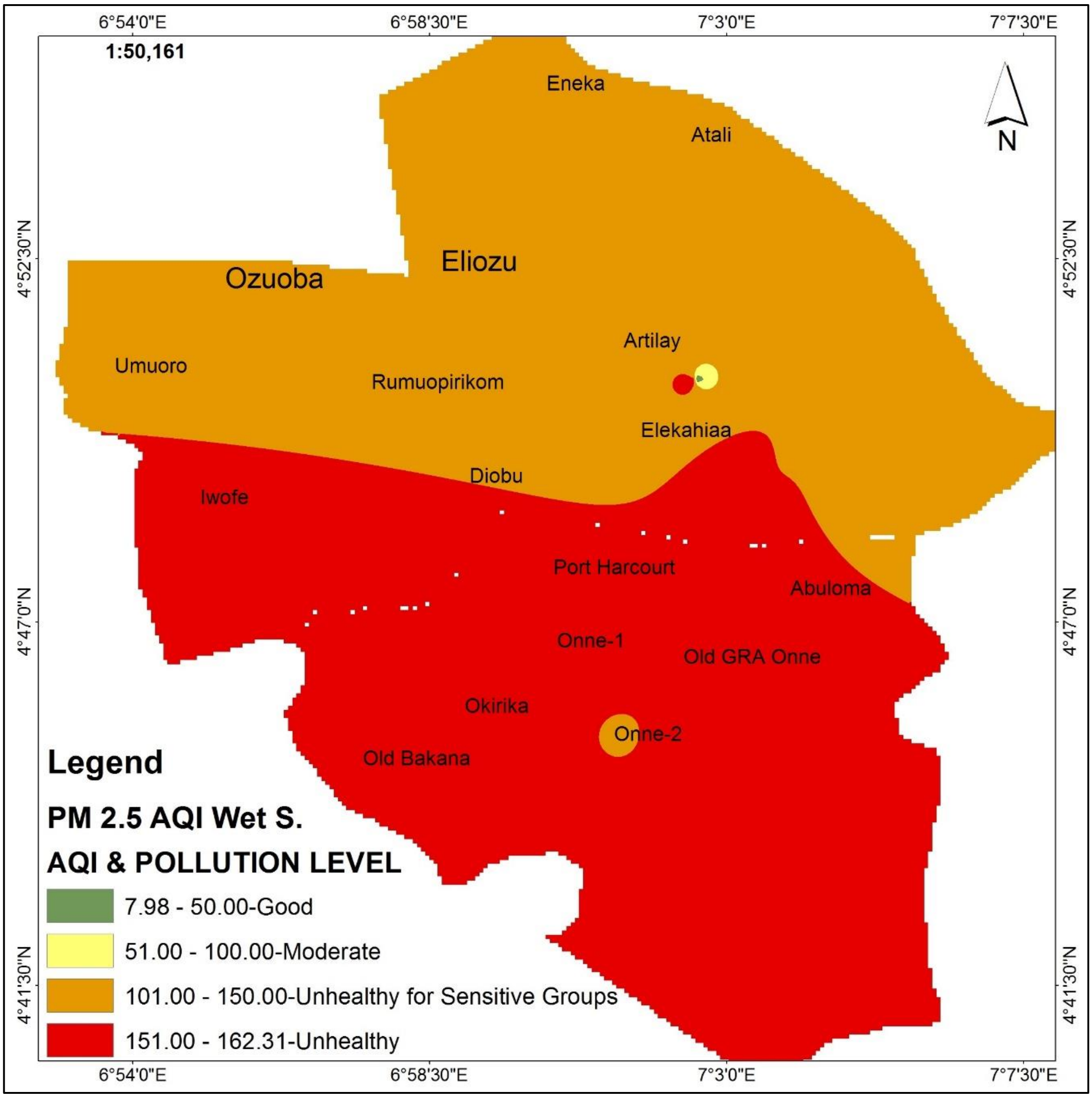

Figure 4.8: AQI Map of $PM_{2.5}$ of the study area for Wet Season.

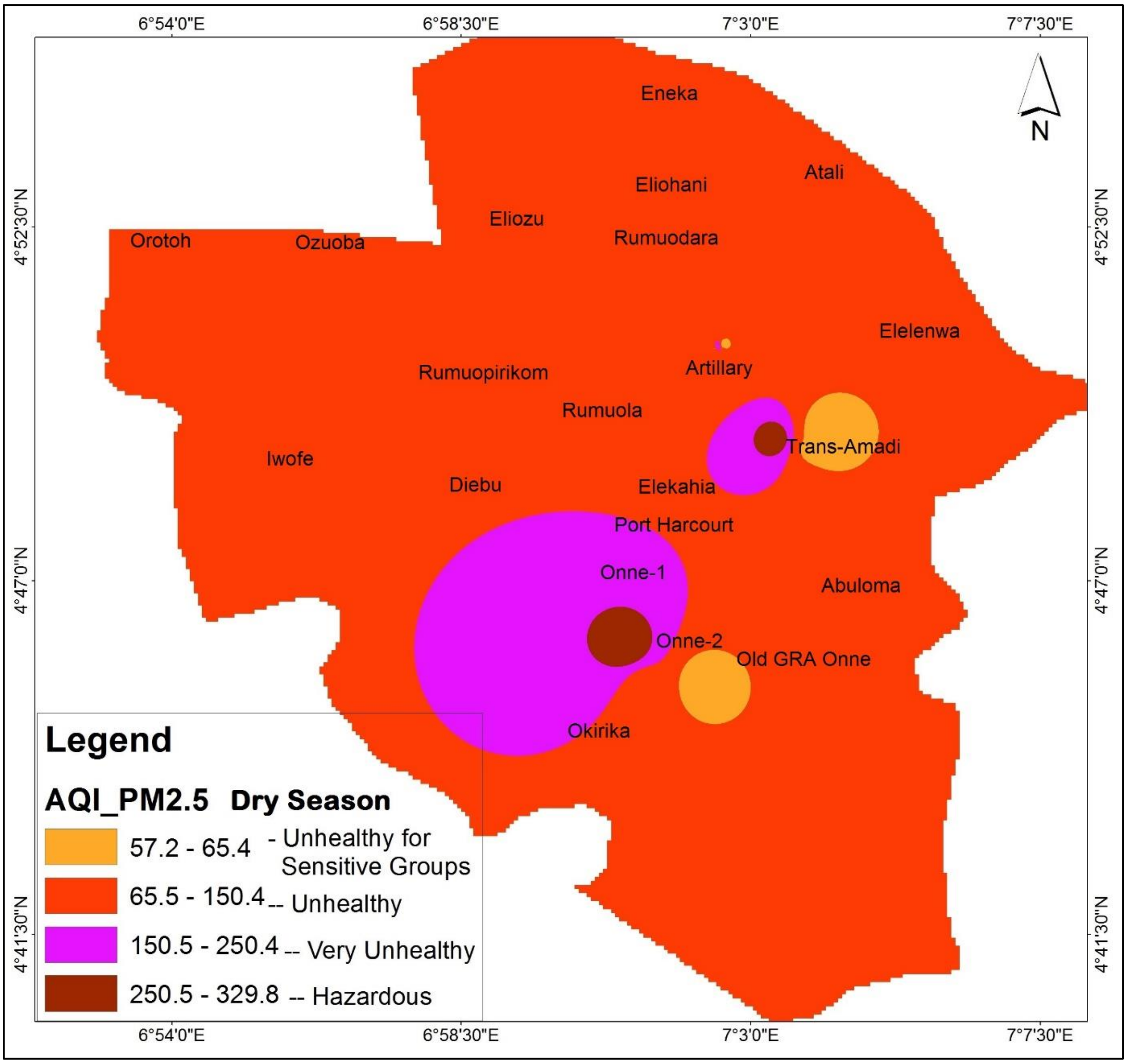

Figure 4.8: AQI Map of $PM_{2.5}$ of the study area for Dry Season.

However, the spatiotemporal AQI model revealed that air pollution in the dry season was hazardous and very unhealthy for sensitive locations in the study area. Locations like Trans-Amadi and Onne, exhibited very hazardous air pollution level with an AQI range of 250.5 to 329.8, while locations like Artillery was recorded to be very unhealthy with AQI range of 150.5 to 250.5.

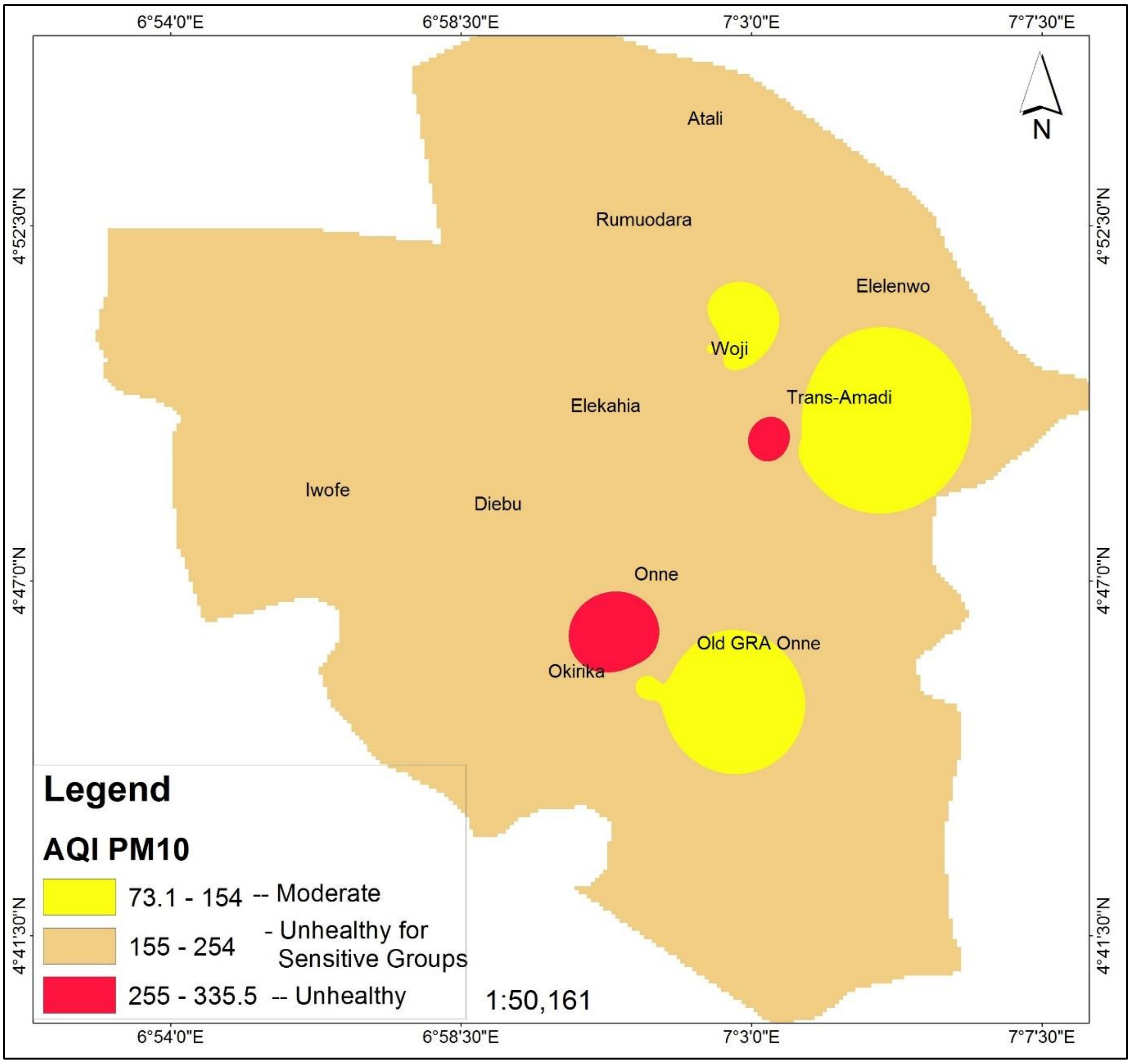

Figure 4.9A: AQI Map of PM_{10} of the study area for Dry Season.

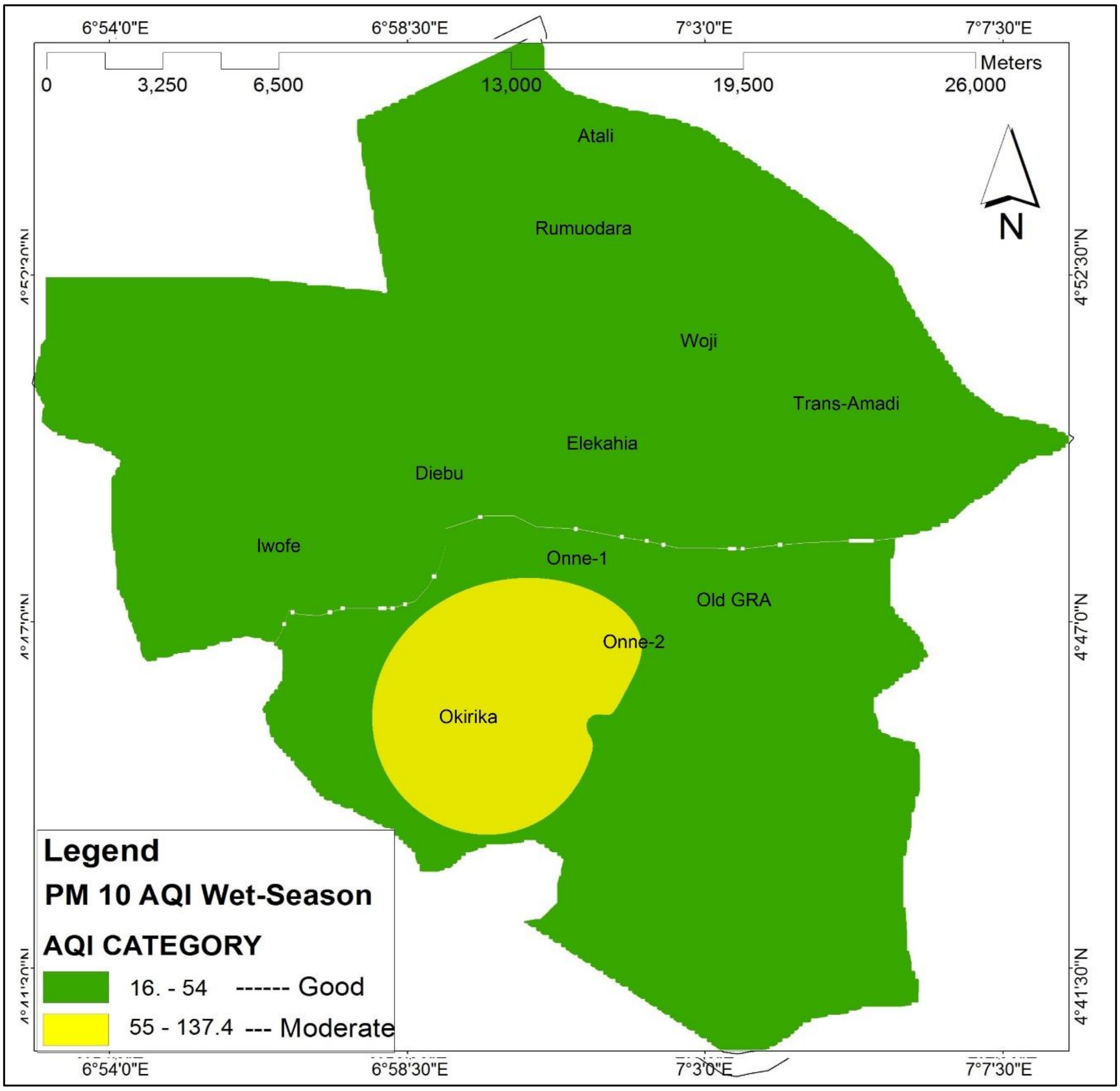

Figure 4.8: AQI Map of PM_{10} of the study area for Wet Season.

There are implications of health concerns for different AQI values obtained from air quality assessment studies which help in the level of the cautionary measure raised for the public health concern in the study area. These health concerns include the following:

1. Good has minimal health impact based on the AQI value and ranges, but from 51 to 100 could cause minor breathing discomfort to sensitive people.

2. Moderate values of Air Quality Index values cause breathing discomfort to the people with lung, heart disease, children and older adults.

3. The rank classified as unhealthy for sensitive groups appears in the AQI category of 201 to 300 and it could cause breathing discomfort to people on prolonged exposure.

4. Very poor AQI values of 301 to 400 are classified unhealthy and could cause respiratory illness to the people on prolonged exposure.

4001 AQI values are classified as severe and are of hazardous effects. This could cause respiratory effects even on healthy people.

4.1.7 Statistical Analysis of Air Quality.

Table 4.3 displayed the correlation between all air quality parameters sampled in the study area.

Table 4.3: Correlation of air quality parameters sampled in the study area

	NO2 (ppb) W	*SO2 (ppb)W*	*PM10 (µg/m3) W*	*PM2.5 (µg/m3) W*	*CO (ppb) W*
NO2 (ppb) D	1				
SO2 (ppb) D	0.602864	1			
PM10 (µg/m3) D	-0.47255	-0.22787	1		
PM2.5 (µg/m3) D	-0.49246	-0.22122	0.997397	1	
CO (ppb) D	-0.76917	-0.62634	0.084088	0.121793	1

Direction for interpretation

* Significance @ 10% i.e ≤ 0.1

** Significance @ 5% i.e ≤ 0.05

*** Significance @ 1% i.e ≤ 0.01

Each parameter with "d" is for dry season

Each parameter with "w" is for wet season

Table 4.4: Correlation between PM_{10} of Dry and Wet season

	PM10 (µg/m3) Wet	***PM10 (µg/m3) Dry***
PM10 (µg/m3) Wet	1	
PM10 (µg/m3) Dry	0.520148	1

There was a significant correlation between the PM_{10} of data acquired in Wet season and that of Dry Season with the correlation coefficient (R) of 0.5 at 0.05 level of confidence.

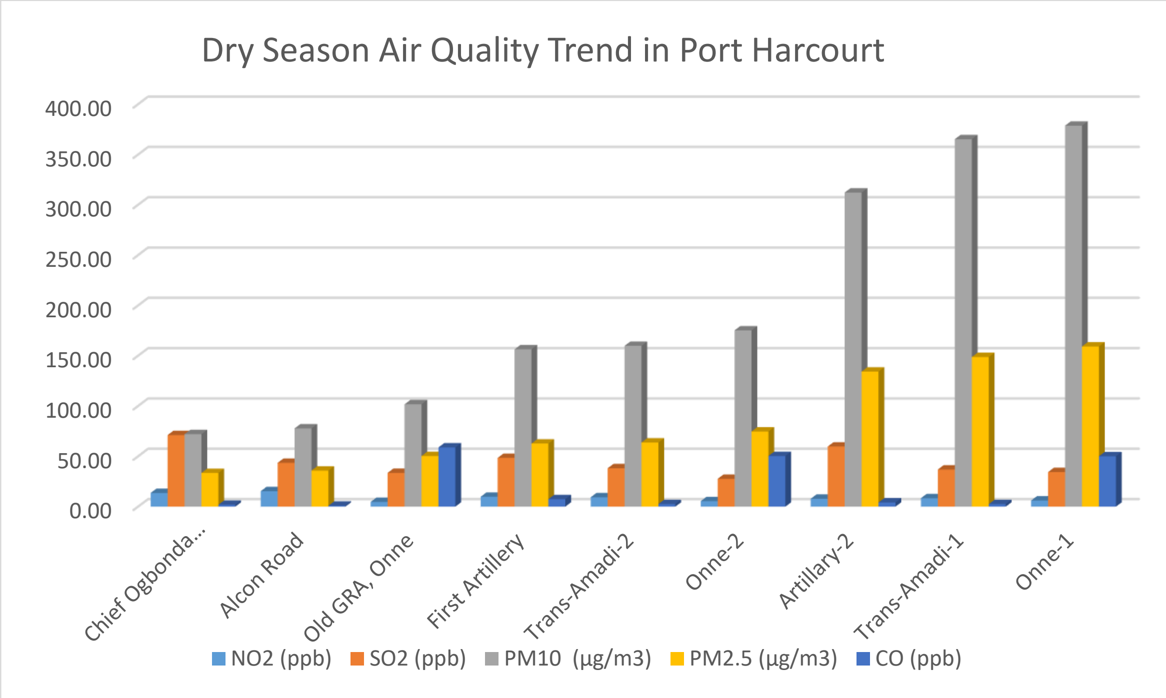

Figure 4.10A: Variation of Air Quality parameters in Dry Season.

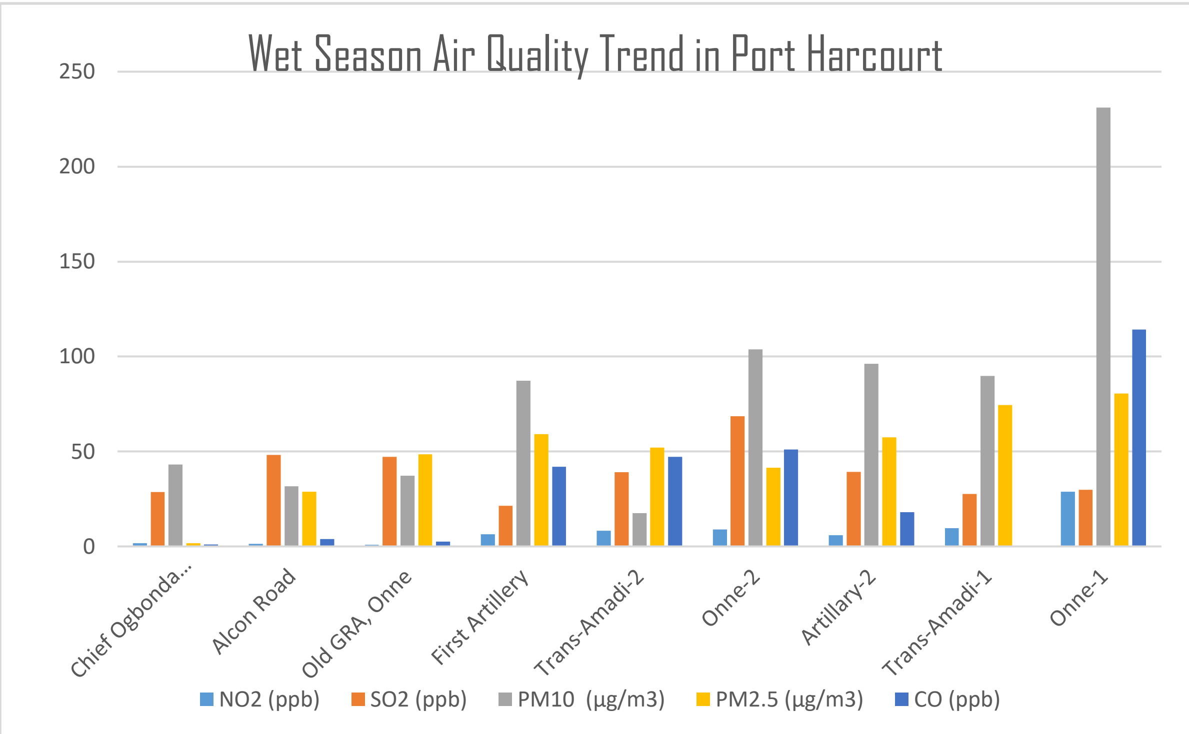

Figure 4.10B: Variation of Air Quality parameters in the Wet Season.

Figure 4.10A and Figure 4.10B revealed that air pollution exists in high concentrations in a busy location and lower in the location of low movement and fewer activities.

4.2 Discussion of Results

This conclusion was drawn from the variations observed from the bar charts where areas of high commercial activities are noted to be very high in concentration and are above WHO and FMEnv standards. This is similar to the study done in 2015 on Roadside Air Pollution Assessment in Port Harcourt and the two results followed the same trend of variation in Concentration. The results of these two studies confirmed that Rumuola, Artillery and Mile One Junctions were exposed to high levels of air pollutants (Zagha & Nwaogazie, 2015). This study's addition to knowledge was that it went further to reveal the spatial dynamics of air pollution which suggests possible sources and directions of activities that increase pollutant concentration. Generally, all the results of Air quality parameters are above the WHO and FMEnv Air Quality Standards. $PM_{2.5}$ and PM_{10} have a maximum value of 159.23 and 378.39 respectively which are higher than the WHO and FMEnv. Standard limits for 24hours exposure. Also, SO_2, NO_2, and CO recorded values higher than FMEnv. And WHO standards in most locations sampled and their spatiotemporal analysis showed a similar trend of the spatial and temporal distribution of Air Quality parameters.

The statistical analysis revealed that NO_2 was significantly correlated with SO_2 with correlation coefficient (r) = 0.6 at p = 0.05 (2-tailed). This implies that the independent variable can predict the dependent variable with 60% accuracy. But the relationship was directly proportional. Although there was a negative correlation between NO_2 and PM_{10}, $PM_{2.5}$, and CO. there was a positive significant correlation between PM_{10} and $PM_{2.5}$ with the correlation coefficient of 0.99 at P equal to 0.05. PM_{10} was significantly correlated with CO with a correlation coefficient (R) = 0.084 at a 5 percent level of confidence. $PM_{2.5}$ was observed to have a significant correlation with CO with a correlation coefficient of 0.121 at a 5 percent level of confidence. This study is also in agreement with the results from other studies in Port Harcourt on air pollution.

It is noted that some parts of Onne have an Artisanal refinery which is usually set ablaze by police and this burning or explosion of hydrocarbon material from illegal or Artisanal refinery, gas flaring and excessive vehicular emission in and within the city surrounding causes the heavy carbon soot pollution in Port Harcourt.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of Research Findings

The following are a summary of findings of the study;

i. A greater percentage of the areas mapped for $PM_{2.5}$ revealed unhealthy values.

ii. The recorded exceedance is 68.5ppb, 28.7ppb and 113.7ppb for SO_2, NO_2, and CO respectively, in the wet season. Also, 71.1ppb, 15.31ppb and 58.9 ppb for SO_2, NO_2, and CO respectively in the dry season.

iii. The exceedance in the result revealed that there are still remote unhealthy activities going on within or at the surrounding towns to the study area. As an oil-producing city, there could be cases of illegal refinery activities and flaring of gases which could lead to such level of air pollution (see Figure 4.5). This calls for urgent attention in the city. Special attention is to be paid to areas that appeared within the categories of hazardous as this could cause serious health damage to the public within these areas.

iv. Figure 4.5 PM_{10} revealed that a greater percentage of the area is unhealthy for sensitive people. However, there is still a minor portion of the study area that appeared unhealthy which could cause great health implications at long exposures. The AQI provides an indication of the quality of the air and it's health effects as revealed in the results. Concentrations of some of the pollutants were higher than the FMEnv and WHO Air Quality Standards and were also higher within industrial areas and along traffic zones than in residential areas. The monitored pollution values varied with time and space in the study area.

However, this study has effectively answered the research questions and contributed to a better understanding of the air quality situation in Port Harcourt. The values of air quality measurements from this study were all majorly higher above limits in the dry season and the wet season values are slightly lower than levels measured in the dry season. The artisanal refinery, Land, water transportation and power generating plants are known to produce obnoxious gases that could lead to atmospheric pollution. Some of these air pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM), and sulphur dioxide (SO_2). Greenhouse gases including carbon dioxide (CO_2) were also be dictated.

5.2 Conclusions

In summary, the high emission values of Carbon monoxide and Suspended particulate matter was because of the regular explosion and vandalization of oil facilities in Port Harcourt and greatly from artisanal refinery operations within the city periphery. A greater percentage of the areas mapped for $PM_{2.5}$ revealed unhealthy values see the breakpoint in Appendix 1. This implies that there are still remote unhealthy activities going on within or at the surrounding towns to the study area. Hence, according to the health cautionary measures; everyone in the city should avoid all outdoor exertion. As an oil-producing city, there could be cases of illegal refining activities and flaring of gases which could lead to such levels of air pollution (see Figure 4.5). This calls for urgent attention in the city. Special attention is to be paid to areas that appeared within the categories of hazardous as this could pose serious public health challenges within these areas.

There is an immediate need for a response to the emission of high air pollutants in Port Harcourt, this implies prompt environmental monitoring (monitoring the source of the pollution and conducting evacuation or sanction of facilities causing heavy air quality degradation); environmental risk publication using the electronic and social media, to keep the public informed. There is a need to set up an Environmental surveillance team from the regulatory agencies in terms of environmental monitoring and develop a strategic method of concealing the artisanal refinery equipment for oil and gas reservoirs to avoid explosion which will lead to heavy pollution. The sampling and analyzing air samples and generating scientific quantitative data is the major objective of this study, however, the geospatial models were revealing about the spatial distribution of the parameters measured within the strategic sampled locations. Major views of precious literature suggested that information dissemination thereby communicating up-to-date results to the public is a key strategy. The International Oil Companies in Port Harcourt has stepped up in the game of supporting Rivers State Government in its successful long-term air quality monitoring within the city. They are developing prevention techniques and are incorporating other stakeholders in the form of multiagency concerted intervention. Addressing the current environmental health emergency would benefit from a pool of resources by the River State Ministry of Environment Port Harcourt, River State Environmental Sanitation Authority Port Harcourt, and River State Environmental Protection Agency Okhumode 2017. Efforts from academia and non-profit organizations will also benefit intervention efforts. Additionally, population health risk has probably increased by way of exposure to particle pollution. Epidemiologic evaluation of this risk and its overall health effect on the exposed population in terms of morbidity and mortality is necessary to enable the government to make informed decisions and to take further action. Academia and the Rivers State Ministry of Health have significant roles to play in terms of conducting intensive research including prospective and retrospective epidemiological studies.

Figure 4.6 PM_{10} revealed that a greater percentage of the area is unhealthy for sensitive people. However, there is still a minor portion of the study area that appeared unhealthy which could cause great health implications at long exposures.

Based on the Spatiotemporal distribution of the discussed results (see Figure 4.3 to 4.9), the major high pollutants are from the explosion of artisanal refinery operations in Port Harcourt. These activities occur within the creeks surrounding the city metropolis.

5.3 Recommendations

Port Harcourt being rated as one of the fastest-growing economic city, in Nigeria. It has also been recently rated by AirVisual as the 9th most polluted city of the world in 2018 and as one of the economic base of the nation. Nigeria as a developing is experiencing increased demand for energy and other environmental resources, the prevention of air degradation by means of controlling atmospheric emissions has become a necessary responsibility.

Following the results discussed in the previous chapter and conclusions drawn from this study, the following recommendations are to ensure that Port Harcourt has clean air quality:

i. The should have improved the mass transportation system, like very low emission buses in the Port-Harcourt city.
ii. The public should be encouraged to use energy-saving vehicles or low emission vehicles or consider using metro bus services to encourage private vehicle users to switch to mass transportation.
iii. Reforestation of trees is encouraged to trap a significant number of particulates from the atmosphere as part of their normal functioning. Vegetation increases the air quality of an area and its surroundings. It should be considered an integral part of any urban planning for sustainability.
iv. There should be awareness campaigns to sensitize the general public on preventive measures for air pollution in the city.

v. Federal Road Safety Commission should effective procedure for checking of vehicle roadworthiness and exhaust emission should be considered as fitness criteria and this should be strictly implemented and enforcement for all vehicles on the roads.

vi. Practice the use of clean fuels as energy sources for a friendly environment.

vii. There should be strict compliance with the set regulations to help reduce ambient air pollution in Port-Harcourt.

viii. Air pollution monitoring stations should be put in place in Port-Harcourt city.

In general, there should be regulatory platform *vis-à-vis* air quality and climate change, be strengthened, including implementation, monitoring and improvement of standards to effectively check operational as well as illegal activities that have the potential for adverse environmental outcomes.

Industrial operators should adopt a more pragmatic approach towards technological and procedural improvements aimed at environmental sustainability.

In addition, there should also be a regular power supply to help reduce the rate of using generating set for power supply by the public in their neighborhood. This will, in summary, reduce the emission of carbon and other unfriendly gasses that pollute the atmosphere. Also, adequate preventive measures like air purifiers may be installed inhabitable spaces like homes and offices.

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Appendix 1: Breakpoints for the AQI

Breakpoints for the AQI

Category	Good	Moderate	Unhealthy for sensitive groups	Unhealthy	Very Unhealthy	Hazardous	
AQI	**0-50**	**51-100**	**101-150**	**151-200**	**201-300**	**301-400**	**401-500**
Pollutant	0-4.4	4.5-9.4	9.5-12.4	12.5-15.4	15.5-30.4	30.5-40.4	40-50.4
CO (ppm)			0.125-0.164	0.165-0.204	0.65-1.24	1.25-1.64	1.65-2.04
NO2 (ppm)	0-15.4	15.5-40.4	40.5-65.4	65.5-150.4	0.205-0.404	0.405-0.504	0.505-0.604
O3 1-hour (ppm) PM 2.5		55-154	155-254	255-354	150.5-250.4	250.5-350.4	350.5-500.4
PM 10	0-54	0.035-0.144	0.145-0.224	0.225-0.304	355-424	425-504	505-604
SO2 (ppm)	0-0.034				0.305-0.604	0.605-0.804	0.805-1.004

Source: (Fernando, 2012).

Appendix 2: The Correlation of Air quality Parameter for Wet and Dry Season

Correlations											
Control Variables		NO2 (ppb)d	SO2 (ppb)d	PM10 (µg/m3)d	PM2.5 (µg/m3)d	CO (ppb)d	NO2 (ppb)w	SO2 (ppb)w	PM10 (µg/m3)w	PM2.5 (µg/m3)w	CO (ppb)w
NO2 (ppb)d	Correlation	1.000	.603*	-.473	-.493	-.769**	-.427	-.268	-.462	-.619*	-.420
	Significance (2-tailed)	.	.086	.199	.178	.015	.252	.485	.211	.076	.260
	Df	0	7	7	7	7	7	7	7	7	7
SO2 (ppb)d	Correlation	.603*	1.000	-.228	-.221	-.626*	-.382	-.474	-.250	-.553	-.397
	Significance (2-tailed)	.086	.	.555	.567	.071	.310	.197	.517	.123	.290
	Df	7	0	7	7	7	7	7	7	7	7
PM10 (µg/m3)d	Correlation	-.473	-.228	1.000	.997***	.084	.743**	-.292	.752**	.824***	.458
	Significance (2-tailed)	.199	.555	.	.000	.830	.022	.446	.019	.006	.215
	Df	7	7	0	7	7	7	7	7	7	7
PM2.5 (µg/m3)d	Correlation	-.493	-.221	.997***	1.000	.122	.737**	-.267	.763**	.813***	.450
	Significance (2-tailed)	.178	.567	.000	.	.755	.024	.488	.017	.008	.225
	Df	7	7	7	0	7	7	7	7	7	7
CO (ppb)d	Correlation	-.769**	-.626**	.084	.122	1.000	.373	.473	.446	.247	.449
	Significance (2-tailed)	.015	.071	.830	.755	.	.322	.198	.229	.521	.226
	Df	7	7	7	7	0	7	7	7	7	7
NO2 (ppb)w	Correlation	-.427	-.382	.743**	.737**	.373	1.000	-.213	.909***	.674**	.895***
	Significance (2-tailed)	.252	.310	.022	.024	.322	.	.583	.001	.046	.001
	Df	7	7	7	7	7	0	7	7	7	7
SO2 (ppb)w	Correlation	-.268	-.474	-.292	-.267	.473	-.213	1.000	-.180	-.248	-.044
	Significance (2-tailed)	.485	.197	.446	.488	.198	.583	.	.643	.521	.911
	Df	7	7	7	7	7	7	0	7	7	7
PM10 (µg/m3)w	Correlation	-.462	-.250	.752**	.763**	.446	.909***	-.180	1.000	.618*	.788**
	Significance (2-tailed)	.211	.517	.019	.017	.229	.001	.643	.	.076	.012
	Df	7	7	7	7	7	7	7	0	7	7
PM2.5 (µg/m3)w	Correlation	-.619*	-.553	.824***	.813***	.247	.674**	-.248	.618*	1.000	.520
	Significance (2-tailed)	.076	.123	.006	.008	.521	.046	.521	.076	.	.151
	Df	7	7	7	7	7	7	7	7	0	7
CO (ppb)w	Correlation	-.420	-.397	.458	.450	.449	.895***	-.044	.788**	.520	1.000
	Significance (2-tailed)	.260	.290	.215	.225	.226	.001	.911	.012	.151	.
	Df	7	7	7	7	7	7	7	7	7	0