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Particle (Soot) Pollution in Port Harcourt Rivers State, Nigeria—Double Air Pollution Burden? Understanding and Tackling Potential Environmental Public Health Impacts

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Abstract: Residents of Port Harcourt in Rivers State, Nigeria, and its environs have since the last quarter of 2016 been experiencing adverse environmental impacts of particle (soot) pollution. This “double air pollution burden”—the unresolved prevailing widespread air pollution and the “added” emergence of particle pollution considered an environmental health threat, led to protests against government inaction in some parts of the state. In February 2017, several months following the onset of the pollution, the government declared an Emergency, and set up a Task Force to investigate and find a solution to the problem. Global research suggests that particle pollution correlates positively with a range of morbidities and an increased risk of mortality among exposed populations. This underscores the need for rigorous implementation of existing environmental legislations established to protect the environment and public health. Nigeria’s rapid response to the 2014–2015 Ebola Virus Disease (EVD) and successful prevention of its spread provides some lessons for addressing such environmental health emergencies—strategic action, including effective environmental risk communication, environmental audit, and monitoring is key. Epidemiological studies of the affected population is imperative. A concerted effort by the Rivers State Ministries of Environment and Health, as well as academia and private organizations is required. Public service campaign in terms of government providing up to date information on the existing situation is required.

Keywords: air pollution; criteria air pollutants; double air pollution burden; environmental impact assessment (EIA); environmental management system (EMS) environmental monitoring; environmental policy; epidemiological studies; morbidity; mortality; particulate matter (PM); PM_{2.5}; PM₁₀; particle pollution; soot; toxicological studies

1. Introduction

According to the World Health organization (WHO) [1], air pollution constitutes the largest among all of the environmental risks: 3 million annual deaths are associated with outdoor air pollution exposure. In 2012 alone, 11.6 percent of global deaths equivalent to 6.5 million deaths were outdoor air pollution-related. 94% of the approximately 90% of air pollution-related deaths occurring in low- and middle-income countries are as a result of non-communicable diseases, including cardiovascular diseases (CVDs), chronic obstructive pulmonary disease (COPD), and lung cancer. Industrial activities constitute a principal source of air pollution [1]. Data for Nigeria’s air quality status contained in the Little Green Data Book 2015 [2] puts the population exposed to air pollution at PM_{2.5} levels, and exceeding WHO guidelines, at 94%. This number is above the 72% Sub-Saharan Africa average [2]. The poor are further disproportionately affected [3,4].

Several studies have not only emphasized the poor air quality in the Niger Delta, including Port Harcourt, but also the above national and international regulatory-recommended levels of ambient air pollutants [5–8].

In recent years, studies carried out to assess the levels of criteria air pollutants in cities of Rivers State, including Port Harcourt, and their probable association with air borne diseases, provide evidence of correlation. Adoki [9] carried out air quality survey in four different locations in Rivers state at varying distances (60, 100, and 500 m) from emission source. According to his findings, almost all the samples complied with (Department of Petroleum Resources (DPR)) guidelines for annual average apart from SO_x and NO_x whose annual means exceeded specification at only one location. Non-conformity occurred mostly in the dry season. During that season, levels of the pollutants tended to be higher in the evenings and sustained through the early hours of the morning. In all four locations, suspended particulate matter (SPM) conformed to specification of $230 \mu\text{g}/\text{m}^3$; with the highest annual mean being $129 \mu\text{g}/\text{m}^3$. Like with NO_x and SO_x , season significantly influenced their concentrations [9].

Nwachukwu et al. [7] in their survey of a 5-year (2003–2007) epidemiological data discovered that the levels of all the criteria air pollutants in Rivers State was significantly higher than the WHO specification. They determined that air pollution was associated with air related morbidities and mortalities in the state. Amongst the air-related morbidity assessed, including cerebrospinal meningitis (CSM), chronic bronchitis, measles, pertussis, pulmonary tuberculosis, pneumonia, and upper respiratory tract infection (URTI), pneumonia was the most prevalent for all of the years that were studied, and was responsible for the highest number (7) of deaths in 2005.

In a study to ascertain the disease prevalence associated with industrial-related air pollution in specified Niger Delta communities, Godson et al. [10] established strong relationships between air pollutants, including PM with morbidities, such as respiratory diseases, traumatic skin outgrowth, and child deformities. Their study compared health effects in Eleme, a highly industrialized community with those observed in Ahoada East, a less industrialized community. Particularly, air pollution significantly correlated with painful outgrowths ($p = 0.027$), as well as respiratory health conditions ($p = 0.044$). Analysis of data to determine the probable relationship of the use of firewood as domestic cooking fuel with health outcomes, detected significant association with child deformities ($p < 0.0001$). Findings from a different study indicate that adverse health conditions, such as eye and skin disorders, occurred amongst workers who spent eight hours per day working at facilities with poor air quality due to ineffective control. For these workers, strong association ($p = 0.000$) of health disorders with occupational exposures was established. Additionally, statistical analysis indicated a strong association ($p = 0.000$) of number of hours of residence in homes with cancers, deformed children, health effects that are related to air pollutants, miscarriages or still births, and respiratory diseases [5]. A separate study conducted in 2010 further substantiates the health consequences of air pollution in Port Harcourt—prevalence of lung and skin cancers were found to be higher in Port Harcourt than in Ibadan [11].

In the recent past months, plumes of soot in the air have affected the residents of Port-Harcourt, and its environs. According to sources, the first observation was in November 2016 [12]. Some affected residents complained that the government delayed in responding, and only acted when people began expressing their concerns on social media, and publicly challenging their inaction. [12–14].

This paper highlights the severe consequences of human exposure to particle pollution, and the need for the implementation and enforcement of existing national environmental regulations. It proposes translating the lessons learned from positive governmental action in preventing the spread of the 2014–2015 Ebola Virus Disease (EVD) into air quality issues. The discussion section highlights the potential health risks of exposed residents by way of the nature, geography, and socioeconomics of Port-Harcourt. It also suggests the significance of epidemiological studies to determine the health effects of the pollution to exposed residents.

1.1. The Niger Delta

The oil-rich Nigeria’s Niger Delta is located in the south of the nation and on the delta of “River Niger”. Niger Delta comprises of nine oil-bearing states namely Abia, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers (Figure 1), whose lands and waters provide all of Nigeria’s crude oil supply. Coastal Barrier islands, fresh water swamp forests, lowland rain forests, and mangrove forests comprise its main ecological zones [15,16]. considered as one of the most heavily populated regions in Africa [17,18], the Niger Delta occupies 70,000 square kilometers of southern Nigeria, and constitutes the flood plain through which rivers Benue and Niger discharge into the Atlantic Ocean. Essentially, a network of creeks connecting rivers, rivulets, and streams, including rivers Benin, Bonny, Brass, Cross, and Nun [16], it serves as a repository of national resource of significant economic value [19].

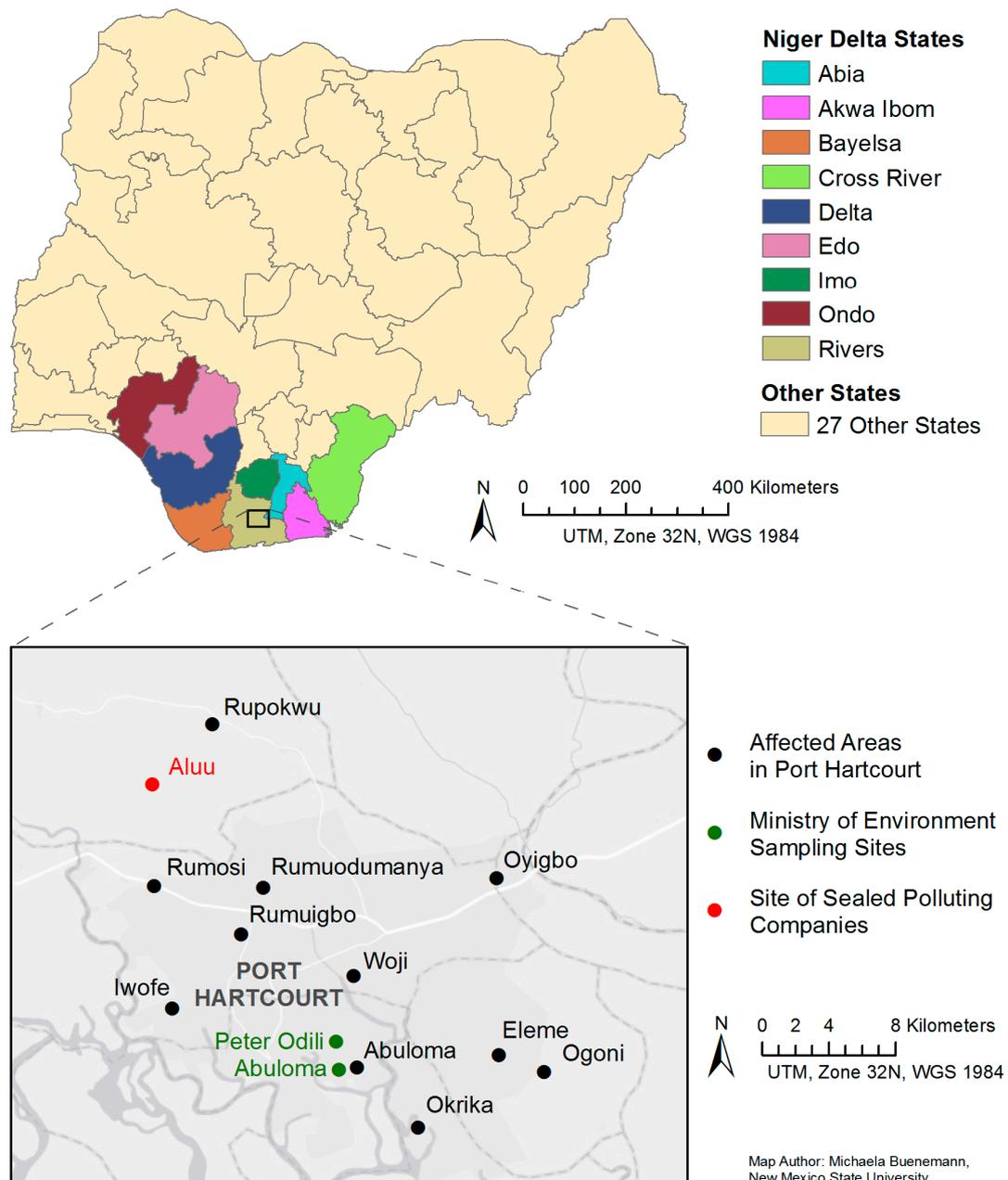


Figure 1. Map showing soot-polluted areas, Ministry of environment sampling sites, and the location of sealed companies in Aluu.

The Niger Delta sustains Africa's largest, and the World's third mangrove forest, bearing not only Nigeria's most abundant petroleum resources, but also diversified ecosystems, and numerous aquatic and terrestrial organisms [20–22]. However, over the decades, environmental degradation has severely affected the people of the region, constituting an issue of contention among stakeholders. Despite the accrued wealth from petroleum, access and condition of social services are low—educational and healthcare facilities are dilapidated and lacking in basic amenities, with no qualified personnel to administer minimum basic services. Large numbers of clay-constructed buildings predominate [22,23], particularly in the rural areas. Environmental degradation has significantly contributed to the increase in unavailability of safe drinking water—76–80% in rural areas, and 50–55% in urban areas lack access to safe drinking water. These conditions explain why indigenes feel marginalized and disadvantaged in many aspects [22,23].

Customarily, fishing and farming have been the main source of employment, and until date, account for more than half of the region's occupation. However, widespread pollution that accumulated over the years devastated their environment, and consequently their livelihoods [16]. GDP per capita is set at 2400 USD, and poverty is extensive, with an estimated 50% of the 32 million people (22% of the nation's total population) living on less than \$1.25 per day [16]. Thirty percent of the region's population is age 30 and younger. Moreover, the region's characteristic tough geographical terrain makes the costs of infrastructure rise. Impoverishment is thus not the only issue, underdevelopment adds to the various problems of the region [22,23].

Furthermore, different communities and ethnic groups have for many years engaged in prolonged conflicts with one another, the oil companies, law enforcement, and the government, particularly over their rights including land acquisition and ownership, settlements in form of monetary compensation, environmental degradation, and deprivation. Although, the number of people that are living in poverty falls below the national average, in comparison with the rest of the country, on socioeconomic indicators such as education, environmental quality, and health, its performance is largely lower [22,23]. Additionally, having one of the highest levels in infant mortality rate, a very vital indicator for general welfare, it performs poorly. Among youths, levels of underemployment and unemployment are the highest, set at approximately 40 percent. Youth unrest in the region is attributable to problems arising from the prevailing substandard environmental, and attendant socioeconomic conditions [22–24].

Despite the serious environmental, economic, socio-political challenges posing significant threat to the region for over five decades, its oil and gas sector accounts for 95 percent of the country's export earnings, and 80 percent of the federal government's revenue [19,25].

Port Harcourt

Port Harcourt is a metropolitan city [26] and capital of Rivers state, occupying approximately 1811.6 km² area [27], with a population of about 1.5 million [28,29]. It constitutes the state's main city and has one of the largest seaports in the Niger Delta region, thus being the center of administration, commerce, and industrial activities [27]. It is situated between Latitude 4°45' N and 4°55' N, and Longitude 6°55' E and 7°05' E in the state, occupying the entrance of the Bonny river. The city is bounded in the north by Abia and Imo states; east by Akwa-Ibom state; west by Bayelsa state; and, south by the Atlantic Ocean. Its estimated mean altitude is 12 km above average sea level, lying between the Dockyard creek/Bonny River and the Amadi creek [27].

Climatically, Port Harcourt undergoes two distinct seasons viz dry and rainy; nonetheless, the atmosphere sustains adequate moisture throughout the year. The city's proximity to the South Atlantic explains this trend—nearness of inlands to the Atlantic increases annual relative precipitation, thus this characteristic assures heavy and persistent rainfall, owing to the strong south-west wind. Wind force reduces as it approaches inland. Mean maximum and minimum temperatures are approximately 34 °C and 21 °C, respectively—the months of April through October having the highest temperatures. Like other Nigerian States, the interaction between two major pressures and wind systems drives the entire weather system in Port Harcourt. They include the two actively produced sub-tropical

high-pressure cells (anticyclones) that are centered over Azores Archipelago (off the west coast of North Africa) and St. Hellena Islands (off the coast of Namibia). These permanent high-pressure centers create and run the Northeast trade winds and the South-West winds, respectively, which are the northward extension of the re-curved Southeast trade winds of the South Atlantic Ocean.

Geographical location and topography of Port Harcourt is such that air borne pollutants travel fast and the farthest, as high lands are practically absent. Studies suggest that periodic plumes of pollutants from industrial discharges, a principal source of air pollution, constitutes a frequent occurrence in the city. Furthermore, occurrence of land breeze, as well as Harmattan, facilitate emission transfer into the city [27,30–32].

1.2. Double Air Pollution Burden

The current situation suggests a step backward from progress made in the reduction of emissions by 29%, between 2005 and 2010 [33]. The Niger Delta residents have for many decades suffered the severe exposures of pollution due to various industrial and non-industrial operations and processes [9,34]. To date, they have had to suffer environmental, health, and socioeconomic costs of the various forms of pollution, including air contamination [22,23]. Additionally, the current poor air quality due to soot emission further aggravates the existing poor air quality situation of the region, suggesting a “double air pollution burden” on population health.

1.3. Prevailing Air Quality Problems

The petroleum industry constitutes a major source of air pollution in the Niger Delta. Within this industry, production operations, such as oil and condensate spills, gas flaring and venting, as well as transportation, constitute main sources of pollutants [35]. Other sources include power plants, heavy industry equipment, including boilers, burners, coolants, and separators. Industries such as foundries, chemical and solvent, automobile, construction, and agriculture also contribute to air quality impairment in the Niger Delta [36,37].

Gas flaring constitutes a major environmental public health issue in Port Harcourt and other Niger Delta states. The human health consequences are diverse and include various morbidities and mortalities [38]. Health conditions associated with pollutants discharged in flares include asthma, cancer of the lungs, difficulties in breathing, miscarriages among pregnant women [38–40], and premature deaths [39,40]. Some gases released from gas flares and other petroleum production-related activities, and their health consequences are well documented [10,34,38–41]. Yakubu [41] and Ede [37] document some other pollutants detected in the Niger Delta region and their various health effects.

In their assessment of pollutants originating from automobile in heavy traffic urban areas in Port-Harcourt, Okonkwo et al. [42] demonstrated not only the prevalence of gaseous pollutants, but also their occurrence at levels exceeding the Federal Ministry of Environment’s I-hour guidelines. Average concentrations obtained for carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen oxide (NO₂), and hydrocarbons (HC) were above the Federal Environmental Protection Agency (FEPA) (now FME) standards. Additionally, their study included a comparative analysis of the quantities obtained at peak periods both in the mornings and in the evenings of each sampling day. Their findings suggest that the ambient concentration of pollutants at the two sampling sites were in most cases higher in the mornings between the hours of 8 a.m. and 9 a.m. than in the evenings between 4:30 p.m. and 5:30 p.m. Although, the differences for the sampling times were not so significant, readings obtained for Monday through Saturday were much higher than those that were obtained for Sunday, during which time less industrial activities and traffic occur.

Ede et al. [37] analyzed air samples obtained from 16 communities in the Niger Delta including Port-Harcourt for their CO, SO₂, NO₂, HC, and suspended particulate matter (SPM) composition. In most cases, the quantities of pollutants exceeded the WHO Air Quality Guidelines. In particular, the particulate load was above the WHO specification for both PM_{2.5} and PM₁₀ annual mean and 24-h mean (PM_{2.5}: 10 µg/m³ annual mean, 25 µg/m³ 24-h mean; PM₁₀: 20 µg/m³ annual mean, 50 µg/m³

24-h mean). Although, the value range obtained for each pollutant was dependent on the time of the day and year or season; nearness to point source; and extent of anthropological engagement. Amongst the 16 locations, Port-Harcourt had the highest mean SPM load. Association of high SPM loads with such factors as high numbers of oil fields and gas flare sources; ongoing construction activities, location on or proximity to highly engaged roads, and industrial facilities occurred [37].

In 2014, Weli [43] conducted an extensive research involving in-depth quantitative analysis of the spatial and seasonal atmospheric levels of PM₁₀ in Port Harcourt, and the environmental health implication of their occurrence at measured concentrations. Relative quantities of the pollutant in various areas based on land use, and the time of the year were compared with land use, including commercial, high-density residential, low-density residential, industrial, and rural. PM₁₀ sampling and analysis was conducted in the dry, transition, and wet seasons. Findings suggest that land use and season influenced atmospheric concentrations of PM₁₀. For all land use type, the trend in the seasonal levels of PM₁₀ was dry > transition > wet. In terms of land use, the commercial and industrial areas had the highest values in the dry season. The Low-density residential areas had the lowest PM₁₀ value. The seasonal total atmospheric loading for the wet, transition, and dry seasons were 3436.1 µg/m³, 8573.12 µg/m³, and 16,148.87 µg/m³. The study also suggests a statistical significant difference in the seasonal PM₁₀ concentration amongst the land use types. People who live and work around the areas with a high concentration of PM are susceptible to respiratory disease infection. This includes high-density residential areas.

In its five years period (2008–2013), assessment of air levels of particle pollution (PM_{2.5} and PM₁₀), the WHO selected 765 cities from 67 countries. Results from this assessment suggest that among cities with a population exceeding 100,000 inhabitants, four major Nigerian cities, namely Aba, Kaduna, Onitsha, and Umuahia constitute 20 of the most polluted cities in the world, in terms of annual mean concentration of PM₁₀ (Air pollution levels rising in many of the world’s poorest cities) (Figure 2). Among these, Onitsha ranks the worst polluted with a record 30 times higher than the WHO stipulations. The WHO specifies a 20 µg/m³ annual mean. Aba and Onitsha form part of Nigeria’s manufacturing center [4,44,45], and are states in the Nigeria’s Niger Delta. Kaduna, Aba, and Umuahia showed a 21, 19, and 18 times more annual mean average of PM₁₀ than WHO limits, respectively.

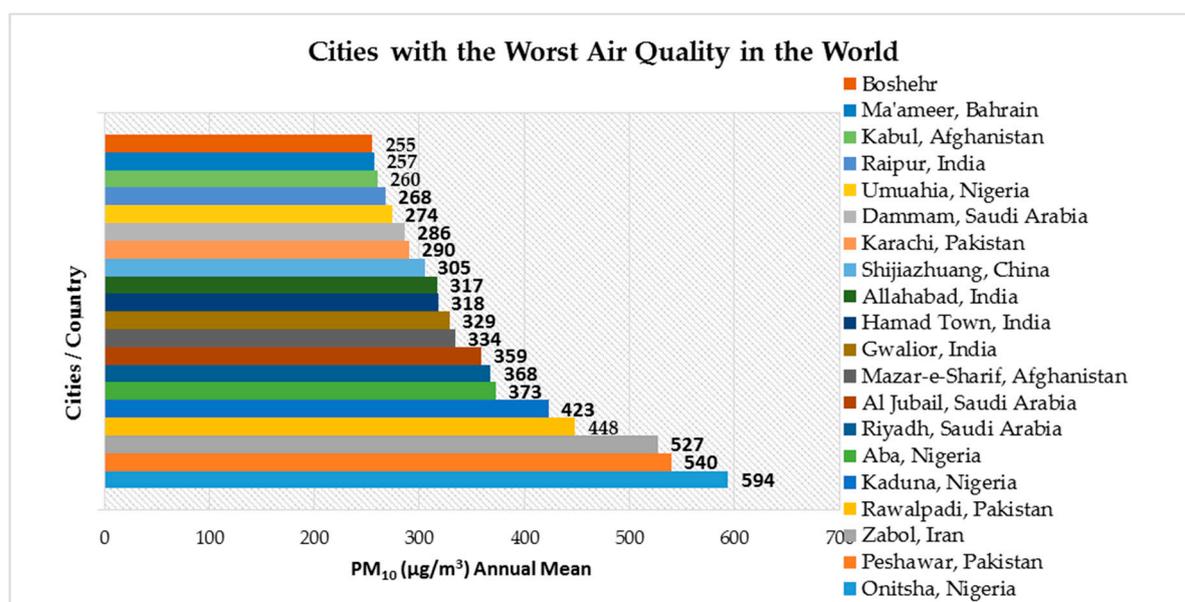


Figure 2. World Health organization (WHO) Urban Ambient Air Pollution Data Base 2016 Update (data only).

2. Criteria Air Pollutants—The United States Environmental Protection Agency (EPA)

The criteria air pollutants are those commonly present in outdoor air, originate from multiple sources, and are harmful to environmental public health. They can also result in property damage. They include carbon monoxide (CO), ground level ozone (O₃), lead (Pb), nitrogen dioxide (NO₂), particulate matter (PM), and sulphur dioxide (SO₂) [46]. The US Federal Clean Air Act (CAA) institutes the regulatory structure for the control of air contaminants. Section 108 of the CAA mandates the EPA to set up National Ambient Air Quality Standards (NAAQS) for criteria air pollutants for the protection of the environment and public health. Provisions of the CAA include the monitoring of their ambient concentrations [46].

3. Seriousness of the Problem

3.1. Public Health Impacts

The EPA defines PM₁₀ as inhalable tiny fragments, with diameters that are commonly 10 micrometers and less (aerodynamic diameter $\leq 10 \mu\text{m}$ (PM₁₀)) or the thoracic fraction; and PM_{2.5} as fine inhalable tiny flecks, with diameters that are mostly 2.5 micrometers and tinier (aerodynamic diameter $\leq 2.5 \mu\text{m}$ (PM_{2.5})). Coarse PM fraction (aerodynamic diameter between 10 μm and 2.5 μm (PM_{10-2.5})) or only one size fraction also exists. The particle size of soot is approximately 2.5 microns, a type of particle pollution that is associated with deep lung penetration [47,48]. Fine particulate fraction is the leading cause of global pollution-related mortality [49,50]. Particles that are approximately 10 microns (PM₁₀) or larger are usually trapped in the upper respiratory tract, and prevented from penetrating deep into the respiratory tract. Particles 5 microns or smaller can make it down to the lower lung where the gas exchange occurs in the alveoli. The largest PM_{2.5} fragment is 30 times smaller than the average human hair, which is approximately 70 micrometers in diameter [51]. Soot penetrates deep down in the lungs, imparting a wide range of serious health outcomes, including acute bronchitis and aggravated asthma among children, heart attacks, and strokes, as well as premature death [52]. Further, the American Lung Association [53] suggests that inhaling soot can potentially cause “cancer as well as developmental and reproductive disorders”.

3.2. Carcinogenicity of Soot and Other Particle Pollution

The routes of entry into the human body include ambient and indoor air inhalation, ingestion of contaminated food, and dermal contact. Based on sufficient evidence from human carcinogenicity studies, soot causes cancers in humans [54]. In 1775, British surgeon Percivall Pott established a correlation between scrotal cancer and exposed chimney sweeps. In subsequent years, substantial amounts of epidemiological studies have since confirmed the elevated risk of scrotal and other skin cancers among chimney sweeps [55]. Similarly, research establishes strong association between occupational exposure (chimney sweeps) and increased mortality from lung cancer, in a number of European countries. In a separate study, leukemia and cancer of the esophagus, as well as risks of liver cancer correlated with exposure to soot [47,56]. Correspondingly, follow-up studies among Swedish chimney sweeps revealed that risks for esophageal, hematopoietic, prostate, urinary bladder, and total lymphatic cancer were elevated [57].

3.3. High Risk Populations

Soot can have adverse health consequences on population health, however, babies and children (particularly due to their premature respiratory organs [3]), the elderly, and people with preexisting health conditions, including heart or lung diseases (such as asthma) are more vulnerable [56]. Like other particle pollution, soot is associated with difficulty in breathing; eye, lung, and throat irritation; birth related problems, such as low birth weight; and, heart disease [56].

3.3.1. Preexisting Diseases

According to the EPA [46], preexisting health conditions including cardiopulmonary diseases and diabetes may increase susceptibility to PM health effects among exposed human populations. Recent epidemiological and experimental studies demonstrating association between PM exposures and morbidity and mortality among human populations, substantiates this argument [58–63].

Cardiovascular Disease (CVD)

Peel et al. [58] discovered that patients with preexisting hypertension when exposed to PM₁₀ experienced an increased risk of emergency department visits for dysrhythmias and congestive heart failure (CHF). Toxicological studies carried out on rat models of hypertension by Sun et al. [59] provide support for results obtained by Peel et al. [58]—PM_{2.5} concentrated ambient particle (CAP) exposure led to increased mean arterial pressure when compared with air controls. This outcome establishes the association between exacerbation of hypertension-related CVD and PM_{2.5}.

Coronary Artery Disease (CAD)

Park et al. [60] conducted a panel study in Boston to examine preexisting cardiovascular-related CAD on PM-related cardiovascular effects. Their findings suggest that patients with preexisting ischemic heart disease (IHD) suffered more significant heart rate variability (HRV) than those without IHD on exposure to PM_{2.5}. Several animal studies carried out following this finding suggest similar outcomes [61,62].

Congestive Heart Failure (CHF)

A number of epidemiological studies examined the probable alteration in PM-related cardiovascular effects by comparing two groups (with and without preexisting CHF) of individuals at different locations. One study discovered that short-term exposure to PM_{2.5} correlated with increased risk of hospital admissions for events related to acute IHD among individuals with preexisting CHF [63]. Similarly, a different study carried out in Cook County, Illinois, indicated a greater risk of mortality associated with PM exposure among those with preexisting CHF than individuals without [64].

3.3.2. Respiratory Disease

Chronic Obstructive Pulmonary Disease (COPD)

Epidemiological studies on the effect of PM on lung function demonstrated that in response to PM_{2.5} exposures, higher declines in pressured expiratory volume per second and forced vital capacity were recorded for patients with, than for those without COPD [65,66]. Other studies [67,68] also suggest that COPD increases the potential risk of PM-related health effects.

Asthma

Several epidemiological studies have established the association of PM exposure with exacerbated asthma symptoms. Short-term PM_{2.5} exposure among children with asthma had a correlation with breathing symptoms, such as cough, gasping, and tightness in chest [69], as well as increased medication use [70]. Although, limited evidence exists on the health effects of PM exposure in adults with preexisting asthma, Desqueyroux et al. [71] observed an association of short-term PM₁₀ exposure with asthma attacks. Additionally, when compared with nonasthmatics, in a controlled human exposure study, asthmatics showed acute responses in the cardiovascular system and systemic circulation following PM_{2.5} CAPs exposure [72].

3.3.3. Children and Older Adults

Among children, elevated PM dose per unit surface area of the lungs, and the consequent adverse effects on growing lungs, are a result of greater activity levels, outdoor duration, as well as volume per unit body weight. Epidemiological studies of short-term PM exposure suggest increased respiratory health effects, including cough, respiratory hospital admissions, and wheeze among children less than 18 years of age when compared with adults [73,74]. A collection of toxicological studies demonstrates that exposure to PM during the critical stages of development may hamper the maturation of the respiratory system in terms of structure and function [75,76].

According to Sacks et al. [77], when compared with children and younger adults, older adults constitute a probable vulnerable population to the health effects of air pollutants, including PM due to the higher prevalence of preexisting cardiovascular and respiratory conditions, which may aggravate susceptibility to PM. Several epidemiological studies on PM_{2.5} [78], PM_{10-2.5} [73], and PM₁₀ [79] exposures indicate increased risk of cardiovascular disease (CVD) hospital admissions among older adults when compared to all ages below 65. Correspondingly, some studies [80] indicate correlation between PM exposures with respiratory diseases in older adults. Controlled epidemiological studies of human exposures to PM_{2.5} concentrated ambience among older adults indicated decreased heart rate variability (HRV) with or without accompanying COPD [81,82]. Furthermore, some epidemiological studies have shown an association of short-term PM_{2.5} [83] and PM₁₀ [84,85] exposure among older adults ≥ 75 years, with the progression of health effects from early stages to cardiovascular-related hospitalization or respiratory-related hospitalization and eventual non-accidental death. These studies show that this age group are more susceptible when compared with younger ages that is ≤ 75 years. Naess et al. [85] made similar observations for long-term PM_{2.5} exposures.

3.3.4. Socioeconomic Status (SES)

Research suggests that low SES correlates with higher prevalence of preexisting health conditions. A study by Dutton and Levine [86] revealed that socioeconomic status (SES), including income level, social status estimated by educational attainment, and work status evaluated based on type of occupation, could have an influence on susceptibility of a population to PM-related health effects. According to Kan et al. [87], restricted medical care and access to healthy foods are directly proportional to increased susceptibility of the health effects of PM.

Franklin et al. [83] in their epidemiological studies estimated low SES based on median household income (i.e., those living below poverty level) and found a correlation with an increased risk of mortality for short-term exposure to PM_{2.5}. Likewise, Jerrett et al. [88] established a correlation of residential environment with a greater mortality rate for exposure to PM_{2.5} on a short-term basis. Other studies established a coherent trend of increased mortality correlation with human exposures to PM_{2.5}, and PM_{10-2.5} for low educational attainment groups (\leq high school diploma) [89–91]. Additionally, several studies demonstrate that residential location or environment significantly correlates with greater mortality risks for short-term PM_{2.5} exposures, based on studies carried out in Hamilton Canada and in Phoenix, Arizona [92].

3.4. Environmental Consequences

Haze of soot has since covered most parts of Port Harcourt city [93]. Visibility impairment by PM_{2.5}, soil, and water deposition, resulting in a change of chemical composition of the affected media and staining of materials, are some of the environmental consequences. The overall result includes more acidic lakes and streams; alterations in nutrient equilibrium in rivers and coastal waters; soil nutrient depletion; and, disruption in ecosystem diversity. Particle pollution also contributes significantly to the impact of acid rain [52].

3.5. Socioeconomic Costs

In consideration of the serious environmental conditions, some parents out of fear restrained their children from playing outside [94]. Residents spend most of their time indoors rather than outdoors. According to The Guardian [94], some residents in various cities, such as Rumosi and Rumuodumanya (Figure 1), both in Obio/Akpor Council abandoned their homes to other cities that they considered safe. The effect of this movement is a decline in business activities with an anticipated cost on the economy of Rivers State as whole.

4. Stakeholders' Reaction

4.1. Public Response

Port-Harcourt residents, including prominent Nigerians, in February 2017, protested the increased deterioration of ambient air quality. Complaints that were made included black soot settling on cars, floors, roofs, and household furniture surfaces. Furthermore, frequent cleaning off a mass of soot from nostrils occurred on a regular basis. Residents also complained about drinking and domestic water turning black. In specific instances, families and household members complained about windows, bathtubs, bathroom, and kitchen sinks being completely covered with soot. Mopping of floors and other household surfaces takes place at least three times a day. Residents compulsorily rewashed and cleaned again, already washed and dried dishes before each use [12,95]. Those who depend on rainwater, having no alternatives, use the soot-contaminated water. Having to face the effects not only outside, but also inside their homes indicates the severity of the situation. Homes are no longer a place of refuge, as soot find its way through unlocked doors and open windows. Deposits clog the protective nets of such doors and windows [93]. Protesters used the opportunity to call on both the federal and state governments to aim for a more permanent solution to the problem [96]. Although, reports suggest that Abuloma, Iwofe, Rupokwu, Okrika, and Woji constitute the most impacted areas [96], affected areas also include Rumuigbo, Eleme, and Oyibo Local Government Councils, as well as Ogoni [96].

4.2. Government Action

In February 2017, the Ministry of Environment declared the air pollution an “Emergency situation”. This declaration was made “in an effort to immediately address the problem” [97]. In the same month, the Governor Nyesom Wike-led administration set up a Task Force comprising of a three-man committee, namely, Commissioners for Environment, Professor Roseline Konya; Special Duties, Mr. Emeka Onowu; and, Information, Dr. Austin Tam-George. The principal duty of the committee was to investigate the source of the pollution and find a resolution [97]. The government also advised that residents should take such protective measures as “refrain from eating foods prepared outdoors, including roasted plantain and suya; avoid drinking rain or exposed water; ensure all foods are covered; keep doors and windows closed; ensure children are indoors and kept away from the floor; and, adopt use of face masks. Asthma patients were advised to take extra care” [96,97]. Although some residents expressed satisfaction in Rivers State government reaction to the problem, describing it as “prompt, rising to the occasion and handling the problem headlong” [94,98]. Others claimed government was slow in taking urgent necessary action [12,14,99]—it took the government more than four months to respond to such an “environmental emergency” that put the lives of approximately 6 million citizens at risk [12,14,99].

4.3. Task Force Findings

According to reports, the Ministry of Environment results obtained from air samples collected and analyzed in late December 2016 at various sites in the city, suggest an 11 times higher than WHO specification for PM_{2.5}. Collection of samples occurred between 12 a.m. and 6 a.m., implying that the activities of the polluter(s) occurred at night. The minimum result obtained was 62 µg/m³ [96,100]. According to the Commissioner of Environment, the report of analysis for samples obtained on

23 December, 2016, exceeded WHO specification for both PM_{2.5} and PM₁₀ [100]. The Ministry of Environment analyzed samples obtained at two different periods: 12 a.m. to 6 a.m. and 6 a.m. to 8 a.m., and from two locations in Port Harcourt, namely Abuloma Road and Peter Odili Road. For both locations, they obtained 270 µg/m³ for the 12 a.m. to 6 a.m. and for the 6 a.m. to 8 a.m. period, 125 µg/m³ and 62 µg/m³ for the two locations, respectively. This non-compliance suggest an 11-, 5- and 2.5- times higher values than the WHO standard for 24-hours mean PM_{2.5}, respectively [96,100].

In an effort to address the situation, the special Task Force identified and shut down Chinese Government Company (CGC), H&H Engineering Company, and AUC Asphalt Company. All three located in Aluu community, were found to be discharging high volumes of emissions, therefore contravening environmental regulations [100,101]. According to the Commissioner for Environment, other suspected sources of the soot include activities of Illegal refineries, burning of tires, gas flaring, liquefied natural gas (LNG) operations and processes, petro-chemical companies, and refineries [100].

4.4. Other Sources of Particle Pollution

Some schools of thought suggest that there is an association between the emission of soot and artisanal refining, as well as the burning of illegal refineries within the region [96,99,100]. Recent reports indicate that the law enforcement agents have been seizing and burning illegal refineries. Furthermore, equipment of operations and storage worth 3b naira from an accumulation of 40 illicit refineries were destroyed in the “sanitizing mission”. According to reports, some residents considered the action unethical, arguing that it amounts to a pollution equivalent of 10 to 20 incinerated tanker load of crude [96,99].

4.5. Lessons from Nigeria's 2014–2015 Ebola Virus Disease (EVD) Prevention

World leaders and experts, international organizations, professionals, and the academia acknowledged Nigeria for preventing the spread of the EVD [102]. Various authors described the 2014–2015 EVD, declared as Public Health Emergency of International Concern (PHEIC), [103] an outbreak with high pandemic potential of serious consequences. However, owing to the prompt measures that the federal and state ministries of health embarked upon, EVD was significantly controlled [102]. Lagos, Africa's largest city, has a high population of 21 million [104], presents a fertile ground for the spread of any epidemic such as EVD. That is, there was a high potential for transmission given the dense population of Lagos, and being the nation's business and travel center [102].

Research suggests that Nigeria's success is attributable to the strategic action plan, rapid response by the government to declare an emergency, easy communication flow, as well as inter-agency collaboration [102,105]. The action plan that may serve as lesson learned for addressing the recent Port-Harcourt air quality deterioration, both in the present and in the future, include, but not limited to, strategic approach including immediate response, information dissemination; intergovernmental partnership, and surveillance. Citizens engagement is also required.

5. The Role of Environmental Policy and Regulation

Nigeria's environmental policy provides structural elements that encourage responsible environmental behavior by individuals and industries. Formulation, enactment, implementation, and enforcement of legislations that serve to offer environmental protection through effective action towards environmental planning, as well as pollution prevention and control, help to achieve environmental goals. Section 20 of the 1999 Constitution of the Federal Republic of Nigeria [106], which makes provision for environmental preservation and upgrade, establishes the fundamental idea of environmental policy in the country. Consequently, it is mandatory that the Nigerian State enforces the protection of air, land, and water, as well as ecosystems, including forests and wildlife [106]. The Federal Environmental Protection Agency (FEPA), established by the FEPA Act in 1988, was responsible for national environmental management and protection. However, in 1999, it was replaced,

and subsequently its functions taken over by the Federal Ministry of Environment (FME), the central administrator and regulator of environmental laws in Nigeria [107].

5.1. Environmental Impact Assessment (EIA) Act 1992

EIA is a key legislation in Nigeria. It demands that prior to embarking on projects, private and public organizations are obligated to carry out an EIA. This is to ascertain projects' likely significant impacts (positive or negative) and suggest potential mitigation measures where necessary. Section 13 of the EIA Act [107] highlights situations or projects requiring an EIA. While, Section 2(1) emphasizes the requirement of an EIA for private and public projects having a potential of significantly affecting the environment, Section 2(4) [107] demands that written application by project proponents to the agency precedes project commencement. This suggests that the approval of such applications and their EIAs must undergo review by the ministry [107,108].

5.2. National Environmental Standards and Regulation Enforcement Agency (NESREA) Act 2007

NESREA Act [109] replaced the FEPA Act and the FME administers it. Relevant provisions of NESREA Act include section 7, [109] which issues authority for conformity with statutory environmental regulations on sanitation, pollution prevention, and control, through monitory and regulatory standards. Section 8(1) (K) [109] mandates the agency to create and revise air and water quality legislations; limitations of effluents; and, control of various harmful substances [107,109].

Some Regulations under NESREA

Relevant NESREA regulations include the following:

National Effluent Limitation Regulations

Section 1(1) [109] mandates industrial facilities to make provisions for pollution abatement equipment that ensures effluent treatment. Similarly, Section 3(2) [109] requires that they present a report of their treated effluent composition to the agency [107,109].

National Environmental Protection (Pollution Abatement in Industries and Facilities producing Waste) Regulations (1991)

In addition to the requirement of Section 1 [109], which proscribes hazardous substances discharge into the air, land, or water of Nigeria, Sections 4 and 5 [109] stipulate that should any discharges occur, the industries must inform the agency and submit a comprehensive list of chemicals that are used for production [107,109].

Federal Solid and Hazardous Waste Management Regulations (1991)

Section 1 [109] of this regulation, makes compulsory the identification by industries, of dangerous solid hazardous wastes that constitute a threat to public health and the environment. Industries are also obligated to research the potential of recycling such wastes. Similar to Section 3(2) [109] of the National Effluent Limitation Regulations requirement, Section 20 [109] of this regulation demands that operators formally inform the agency of the occurrence of any discharge [107,109].

Harmful Wastes (Special Criminal Provisions) Act of 1988

This Act bans transporting, depositing, and discarding of harmful waste in air, land, or water, void of preapproved legal authorization, within the Nigerian state [107,109].

5.3. Factories Act, CAP F1, LFN 2004

The Nigerian federal government in an attempt to foster worker health and safety established the Factories Act. Section 13 [108] of the Act authorizes a regulator or inspector decide that emergency

measures be taken by qualified person in the event of pollution. Section 30 [108] of the Act recommends precaution for factory operations involving emission of explosive or inflammable dust, gas, vapor, or other substances. Specifically, Section 45 [108] prescribes adoption of all practicable action to enhance worker protection from inhaling dust or fume or other impurity. It also recommends the prevention of any buildup of such pollutants in the work area [108].

5.4. Infringements and Penalties

The foregoing regulations make provisions for sanctioning offending individuals or businesses for contravening established legislations under the various Acts. For instance, Section 27 of the NESREA Act [109] stipulates a prohibition on unauthorized disposal of hazardous substances into the environment. Contravention of this regulation attracts a maximum fine of one million naira, including a five-year prison term. Furthermore, an additional fifty thousand naira fine is accruable for each passing day the infringement continues. Violation of any provisions of the EIA Act incurs acts punishable by law (Section 60) [109]. Section 108 [109] of the Federal Solid and Hazardous Waste Management Regulations 1991 specifies disciplinary action against offenders for violating any regulations, including the discharge of hazardous substances into the environment, and the failure to notify the agency of such discharges. The Harmful Wastes (Special Criminal Provisions) Act explicitly makes a provision for forfeiture of land or any equipment or other facility employed in perpetrating the infraction; as well as life imprisonment. Commensurate penalties are enforceable on any negligent company staff who plots, colludes, and assents to commit an offence. Additionally, persons afflicted either by way of being injured or by way of becoming ill become a liability to the offending individual. These are stipulations of Sections 6, 7, and 12, respectively [107–109].

6. Discussion

6.1. Implications for Public Health

Port Harcourt is observing a “double air pollution burden”—the unresolved prevailing widespread air pollution and the “added” emergence of particle pollution [20,37]. Global research highlights the significant public health threat posed by human exposure to air pollutants including PM. A plethora of health conditions, including life-threatening morbidities, as well as mortalities, implicates the different fractions of PM as direct causative agents [5,7,10,11,43,58–92].

Although epidemiological studies investigating PM exposures’ relationship with morbidities and mortalities in Nigeria is limited, a significant amount of epidemiological and toxicological studies in Asia, Europe, the United States (US), and elsewhere in the world establish a strong association between PM exposure and various diseases and deaths [58–92]. Studies also provide evidence showing the potential susceptibility of specific at-risk population namely children, and older adults [73–85].

In a study to assess the effects of industrial air pollutants on the respiratory health of children, Nwokocho et al. [110], in their 18-month prospective study, provide a strong correlation between exposures to four criteria air pollutants, namely CO, NO₂, SO₂, and PM, and the incidence of bronchitis, cold, cough, phlegm and sinusitis. Children less than two years of age, living in the populated area, were 3.5 times more susceptible to the pollutants than were those in the less polluted zone. Likewise, Onwuchekwa et al. [111] in a geriatric admission survey discovered that chronic diseases accounted for a larger percentage of morbidities and mortalities among patients 60 years and above.

Correspondingly, growing evidence suggests correlation of PM exposure among people of low SES with various health conditions and mortality [86–92]. Port Harcourt is a city in the Niger Delta, a region where 50% of the population are living on less than \$1.25. Moreover, it performs lower than other parts of the country in terms of SES indicators: ambient air quality, availability of safe drinking water, food safety, chemical exposures, residential environments, educational attainment, availability of educational services and healthcare facilities, and household income based on number of people living below poverty level.

Underdevelopment further compounds this problem. These are critical public health issues—in Nigeria, children aged ≤ 14 years constitute the largest population group (42.79% of 186 million) as of 2016 [112]. Addressing these public health issues to protect for the most part, the at-risk population is important. The double air pollution burden thus presents a health concern. It should serve as a reminder and further call to action to address not only the recent situation, but also the prevailing pollution problem in Port Harcourt, and indeed, the entire Niger Delta.

Some of the health effects of the poor air quality occasioned by the emissions that lasted for months may not be immediate, however, given the duration and the “above limits” concentrations recorded by the Ministry of Environment, a rise in the prevalence of airborne-related diseases in the affected areas is probable. It is noteworthy that research suggests that short-term (hours to days) exposure to $PM_{2.5}$ is correlated with an increased risk of hospital admissions for aggravated acute IHD [63], and aggravated asthma in children [69]. Low SES, particularly living below poverty level, is associated with increased risk of mortality among population exposed to short-term $PM_{2.5}$ exposure [83]. In a similar manner, residential environment significantly correlates with higher mortality risks for short-term $PM_{2.5}$ exposures [92].

Evidence of preexisting health problems from research study by Weli et al. [113] provides support to the probable near future morbidities and perhaps, mortality rise. The researchers evaluated the relationship of spatial incidence of CVDs with the air quality of four selected abattoirs in Port Harcourt. They limited their investigations to the roasting section, which generated large quantities of smoke. The pollutants sampled and analyzed comprised CH_4 , CO, H_2S , NO_2 , SO_2 , $PM_{2.5}$, and PM_{10} . Findings indicate that pollutant concentration, age, job duration, as well as exposure duration, correlated with the incidence of CVDs amongst workers. This may imply that such PM-related disease as CVDs, CADs, CHF, and respiratory diseases, such as COPDs and asthma, may further rise above currently reported rates due to the soot pollution.

6.2. Violations of Environmental Regulations

The root cause of companies emitting pollutants above stipulated standards is fundamentally inadequate enforcement of existing environmental regulations and/or faulty/unedited environmental policy framework. The current soot pollution adds to the existing violation of environmental policy by the oil and gas industry that has for decades left the Niger Delta in widespread pollution [20]. However, the current particle pollution event comes as “unexpected”, because the three Ministry of Environment-sealed factories do not fall under the “more difficult to regulate” oil and gas sector.

Considering the relevant environmental legislations highlighted in Section 5, it is obvious that violations of national environmental regulations occurred—not so much so that polluting companies failed to implement rudimentary environmental legislations, but that there was probable negligence on the part of the regulating agencies to either enforce them or ensure adequate monitoring of implementation by businesses. The EIA Act (Decree No. 86 of 1992) [107] makes provisions for all of the categories of industry to implement fundamental environmental laws. These provisions emphasize environmental management (EM) as their target. Included within the scope of EM is the environmental management system (EMS). Both of these concepts are “products” of EIA and assure that the overall goal (EM and its goals) of EIA is achieved not only prior project commissioning, but also post-commissioning. It also assures that attaining the ultimate goal of pollution prevention is continuous, and is sufficiently maintained throughout the life of the project. The overarching goal of EM is environmental public health safety [41].

The fact that Nigeria has a plethora of unimplemented environmental laws and a growing occurrence of industry infractions of environmental legislations cannot be overemphasized [114]. One major issue that arose in the event of the soot pollution episode is the fact that responsible regulating agencies should have prevented the event from occurring in the first place [14]. Some school of thought expressed their concern and raised such pertinent questions as: “Who cleared the Chinese company to start operations? Who is the Environmental Health Officer at the local government where it

operates?" They further expressed concern about how the responsible agencies were uncertain what to do at the onset of the pollution, describing setting up of the special Task Force as "inessential" because even a "blind man could perceive the very palpable pollution" [14]. Additionally, they considered it "inexcusable" that the Ministry of Environment would allow such big companies discharge high levels of factory emissions into the environment without executing urgent necessary action. They emphasized the indispensability of the Environmental Impact Assessment (EIA) requirement, asserting that enforcement at all levels of business operations is mandatory [14].

Indeed, an EIA would have determined the kind, and possibly, quantities of effluents of the Asphalt and other polluting companies would be discharging prior project commissioning. It also would have proffered mitigative solutions; otherwise, project approval should not have occurred in the first place. Aside from the issue of EIA, another very vital question that requires attention is "what about routine (monthly or quarterly) inspections by the regulating agencies, such as the Ministry of Environment and Environmental Protection Agency (EPA)?" Under normal circumstances, execution of appropriate environmental laws detects such nonconformities and prevents escalation of the problem.

In expressing his concerns about the environmental health problems in Ogoniland, Yakubu [41] recommended an environmental management/environmental management system (EM/EMS) model. This encompasses all the necessary tools, procedures, and processes required for pollution prevention for businesses. The model makes room for an independent environmental consultant accredited by the responsible environmental agencies to provide professional services to businesses and serve as a liaison between companies and the agencies. This adds to the strategies of pollution prevention.

Environmental consultants facilitate compliance with statutory environmental legislations and help businesses realize their environmental goals. Among other things, the EM/EMS model underscores the vital role company environmental policy plays in achieving environmental goals, including pollution prevention. The extent of EMS adoption determines what the outcome for pollution prevention is [41]. Nevertheless, a major requirement for achieving company environmental goals through the implementation of EM/EMS is in conformance with environmental regulations. This is where environmental monitoring and/or periodic environmental inspection by state or federal agencies plays a significant role.

Regarding the seizure and destruction of equipment, properties, and oil products from artisanal refineries by the Military, a more responsible approach is required. Statutory environmental legislations require that it is incumbent upon the federal and state Ministries of Environment or the designated regulating agency to take charge of the disposal of confiscated materials [107].

6.3. Current Situation

The website of the Ministry of Environment does not provide any current information about the situation, so the public lacks access to up-to-date information for them to make informed decisions if and where necessary. There is inadequate information as to if investigations are still ongoing as declared by the ministry.

7. Conclusions

Governmental rapid response to the 2014–2015 EVD in Nigeria provides a good template for addressing environmental health emergencies. It is commendable that the government declared an Emergency Situation in February 2017, and requested that residents take protective measures to enhance health and safety. However, residents may have appreciated immediate action more, and considered it timelier, particularly at the onset of the event. Immediate response may have prevented public protest. Although EVD is a very serious disease and action taken by the government to prevent its spread was commensurate to its virulence and pathogenicity, nevertheless, to a certain extent, the application of some of the strategies to the soot pollution may have reduced its impacts. Some opinions may suggest that there is no basis for comparing the EVD outbreak with soot pollution in terms of

severity, it is, however, important to mention that epidemiologic evidence suggests that short-term exposures (i.e., hours to days) to PM_{2.5} fraction correlates positively with mortality among exposed humans. Therefore, particle pollution is also a serious environmental health issue.

Immediate response to the PM emission implies prompt environmental investigations (finding out the source of the pollution and conducting environmental audit); environmental risk communication using the electronic and social media, to keep the public informed; surveillance in terms of environmental monitoring (sampling and analyzing air samples and generating scientific quantitative data), and information dissemination (communicating up-to-date results to the public). Another step that was taken by the Nigerian government in its successful prevention of the spread of EVD was the cooperation among stakeholders in 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. 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. An 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 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.

Following EIA, routine environmental inspection and monitoring by regulatory agencies is required to forestall future reoccurrences. The various environmental laws require implementation. Disposal of seized materials from artisanal refineries require more environmental responsible approach to assure environmentally friendly measures that prevent pollution. Responsible environmental agencies should be involved. Citizens involvement in terms of possession of affordable and portable air monitoring devices to record and report above limits ambient criteria air pollutants would be beneficial. However, education of the public, as well as easy access to the ministry, is required for such efforts to be successful.

Additionally, it is important that the Ministry provide answers to such questions: what is the recent concentration of ambient PM? What ongoing efforts are in place to put an end to reoccurrence, including action taken against the offenders, and what probable proportion of the pollution is attributable to the indicted sources?

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