Spatial Analyses of Air Pollutants Concentration around the Warri Refining and Petrochemical Company (WRPC), Delta State, Nigeria

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Abstract

This study investigates air pollution from the Warri Refining and Petrochemical Company (WRPC) of Delta Sate, Nigeria with the intent of determining the variations in pollution levels associated with increasing distance from the refinery. The following pollutant gases: Carbon monoxide (CO), Volatile organic compounds (VOC), Hydrogen sulphide (H2S), Nitrogen dioxide (NO2), Sulphur dioxide (SO2) and Particulate Matter (PM2.5 and PM10), were monitored intermittently with the use of digital hand-held probes, at sampling points located between 1,500 meters to 16,000 meters from WRPC. Air sampling was carried out on a weekly basis, for a duration of one (1) year. The average annual concentration of CO, VOC, H2S, NO2, SO2, PM2.5 and PM10 measured were 0.2543 ppm, 4.4922 mg/m3, 0.0004 ppm, 0.0063 ppm, 0.5263 ppm, 36.3825 µg/m3, 91.7346 µg/m3 respectively. The results of the spatial analyses of air pollutants show that concentrations of VOC, NO2, PM2.5, and PM10 shared a significant inverse relationship with distance (p values 0.00 ≤0.05). The study suggests a minimum of 10,250 meters radial extent of buffers around WRPC, as a long-term strategy in reducing exposure of residents to air pollution. Short-term strategies include enforcement of legislation reducing/banning emissions from industries and bush fires, use of alternative eco-friendly technologies and energy sources, tree planting, revamp of the hydroelectricity power sector and general sanitization of the environment.

Keywords: Air Pollution, Buffers, Distance, Exposure, Refinery, Spatial

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Received on January 15th, 2021/ Accepted on March 15th, 2022

Ghana Journal of Geography Vol. 14 (2), 2022 pages 50-81

Doi: https://dx.doi.org/10.4314/gjg.v14i2.3

Introduction

The World Health Organisation (WHO, 2017) defines air pollution as the "contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere". The refining and use of fossil fuel has been a major factor contributing immensely to air pollution around the world (Alhaddad et al., 2015; Nelson, 2012; Ragothaman and Anderson, 2017). As such, a lot of effort and legislations are being made towards protecting man and the environment from emissions, either by reduction of emissions, or isolation of emission sources.

The environmental agencies of developed countries such as the United States Environmental Protection Agency (USEPA) regularly monitors and releases policies and guidelines protecting the environment and people from the impacts of pollution from refineries (Nelson, 2012). This has been successful to an extent, as there has been considerable reduction in air pollution levels in Western Europe and North America (Khanfar, 2015; Ragothaman and Anderson, 2017; Turnock *et al*., 2016; Lurmann *et al*., 2015; Mackie *et al*., 2016). In Africa, air quality monitoring is restricted in terms of scope, area coverage and frequency and many countries within the continent are not well equipped with air quality standards to guide and control emissions (Petkova *et al*., 2013). Without such controls in place, most of the population in Africa are exposed to air quality conditions that exacerbate much health problems (Pope and Dockery 2006; Pearson et al., 2010).

In Nigeria, air pollution problem seems to go unchecked, even though environmental policies and air quality standards are available. Uncontrolled air pollution problems have been attributed to legislations, which are obsolete, fragmented and lack implementation in most cases (Eneh and Agbazue, 2011). Therefore, to manage deterioration in air quality effectively, continuous air quality monitoring programs should be undertaken to assess the present state of air quality, provide feedback required for pollution prevention and control systems; and to guide the necessary corrective plan of action or strategy for areas suffering from the devastating effects of air pollution (Center for Pollution Control Board CPCB, India, 2003). It must also be ensured that residential units are not located too close to refineries, as this can reduce the risk of exposure of people to air pollutants. For this reason, the Federal Government of Nigeria had deemed it necessary to promulgate legislation and policies addressing the issue of reducing industrial emissions as well as isolating air-polluting industries, which include the refineries.

Concerning isolation of industries using separation distances and/or buffer zones, the Nigeria National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) Regulations, contained in the FEPA Act of 1991 (S.1. 9 of 1991., under section 37, No. 12) states that "each State of the Federation shall designate industrial layouts, which shall be separate from residential areas; and provide buffer zones between industrial layouts and residential areas". It further states that "buffer zones shall be rigidly kept away from developers and be monitored to prevent development encroachment by developers". Nevertheless, it is worthy of note that the Act does not specify the numerical extent of buffers around industries.

Separation distances in form of buffer strips or setbacks are necessary to cushion the effects of pollution from industries. Buffer strips are quite different from setbacks. In the context of environmental quality, buffer zones are green belts (i.e. man-made strips of vegetation) located and designed around industries to reduce or cushion the impact of severe damage due to explosions, fires, heat and toxic releases from industries, while setbacks are described as the linear distance between the pollutant source and an ecosystem that needs protection (Aruninta, 2012).

Only if a setback is subject to management or natural preservation can it be considered a buffer. Nevertheless, to achieve a desired ecosystem function or goal, it is advised that setbacks in disturbed and built-out systems be actively managed to function as buffers, as setbacks alone may not likely provide the desired ecosystem function of preventing agricultural and residential encroachment (National Research Council, Washington DC, 2000).

For buffer specifications to be objectively defined in the Nigerian legislation, it is important that measurements of extensive emission rates around industrial locations be studied to obtain a clear picture of the pollution pattern and dispersion, thereby necessitating changes in the residential arrangements around industries. An effective approach in delineating buffers around industries is the use of atmospheric dispersion models (Macdonald, 2003; Goyal, and Kumar, 2011; Dubey, 2014). According to Musalaiah *et al*. (2013), atmospheric dispersion models are used to predict concentration of pollutants downwind of a source. Input data required include ambient or background concentrations of the pollutant at the source, contaminant emission rate (velocity and temperature of the gas being emitted), characteristics of the emission source (such as the stack height and stack diameter), meteorology of the area (such as the wind-velocity, wind direction, ambient temperature, atmospheric stability and mixing height) and the nature of the local topography (Collet and Oduyemi, 1997).

Previous studies by De Santis et al., (2004), Odjugo (2004), Odjugo, (2011); Abdulkareem (2005); Grigoras et al., (2012); Tawari and Abowei (2012); Mbaneme et al., (2014) and Ighile et al. (2015) have revealed that pollutants are more concentrated in areas closer to their emission sources, and that industries, including refineries, contribute immensely to air pollution in the areas in which they are situated. The results of studies by Tawari and Abowei (2012); Al-Haddad et al., (2012); Odigure and Abdulkareem (2005) reveal that concentration of air pollutants around industrial areas investigated, exceeded regulatory limits, Studies by Jacobson, (2005); Odat (2009) and Radaideh, (2017) identify other factors apart from distance, capable of influencing variability in air pollution, which include meteorological and topographic factors. Abdel-rahman (2008) has used the Gaussian Plume Dispersion Model to illustrate concentration of pollutants from a source as spreading outwards, along horizontal and vertical directions from the centerline of the plume, following a normal statistical distribution. His study determined that the point of maximum concentration, which is the point of plume descent is influenced by factors such as atmospheric turbulence, stack height, exit velocity, wind speed, ambient temperature and gas exit temperature. The findings from previous air quality studies have shown that air quality monitoring is necessary to ensure that the environment and human lives are not put at risk. For instance, ascertaining the point of plume descent can be useful in delineating air polluting industries from residential areas. For this reason, continuous air quality monitoring is necessary, especially around industrial areas (Center for Pollution Control Board CPCB, India, 2003). The study aims at answering the research question, which is 'how significant distance is, in relation to the concentration of air pollutants from a point source? This is with a view to determining the minimum safe distance recommendable from a refinery. The objectives of study were to spatially analyze the pattern of air pollutants concentration around WRPC, and to compare measured values of pollutants with their regulatory limits. This study also serves as an update of previous studies, since air quality is very dynamic and subject to quick changes within a short period. The results provide the basis for delineating an appropriate buffer limit for WRPC, even as specified setbacks alone may not be sufficient to cushion the impact of pollution emanating from the refinery.

Study Area

Ubeji, Ifie-kporo, Jeddo, and Ekpan communities, which play host to WRPC, are located in three L.G.As in Delta State. Ubeji and Ifie-Kporo communities are located in Warri-South L.G.A., Jeddo community is located in Okpe L.G.A., while Ekpan Community is located in Uvwie L.G.A. (Figure 1). The population size of these four communities is projected at 48,118, using 3.2% growth rate, according to the National Population Commission, (NPC, 2010). The host communities of WRPC engage in some other small-scale economic activities, which include aquaculture, local gin brewing, furniture making, trading, lumbering/ logging and tourism (Okoye and Iteyere, 2014). Some residents are also public servants and private firm employees.

WRPC covers a total land area of 1,104,014 hectares (www.wrpcnnpc.com.ng). Its boundaries are located on the coordinates 5^{o}34'18" N and 5^{o}42'33" E (North Western boundary), 5^{o}34'19" N and 5^{o}43'19" E (North Eastern boundary), 5^{o}33'36" N and 5^{o}42'33" E (South Western boundary), and 5^{o}33'35" N and 5^{o}43'25" E (South Eastern boundary), as shown in Figure 2. The refinery is located in Ubeji community, in Warri-South L.G.A. of Delta State. Delta State is one of the 36 states in Nigeria, located in the oil-producing region of Niger-Delta. It is also in the South-South geo-political region of the country, with a population of 4,112,445 (National Bureau of Statistics, 2009).

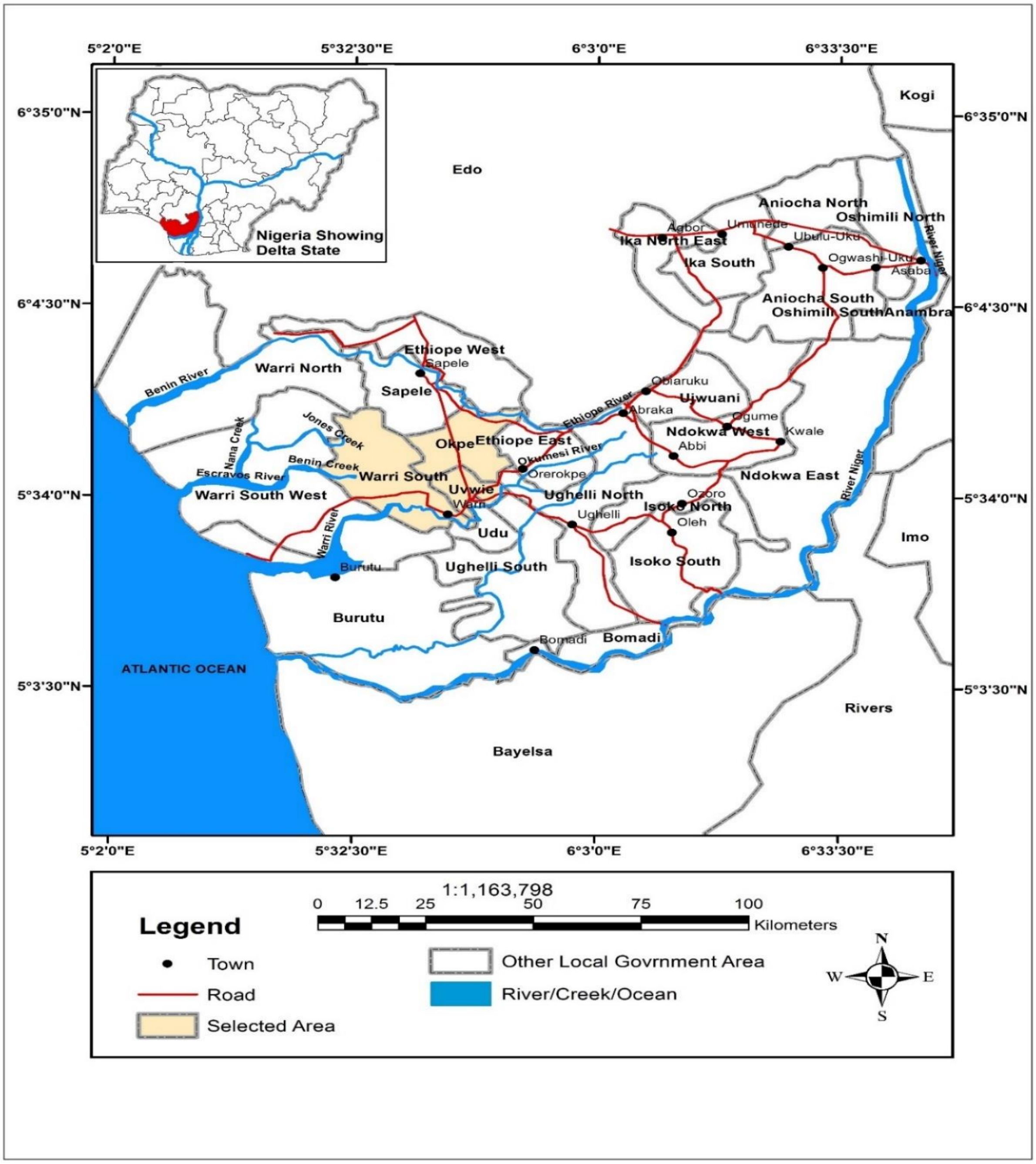

Figure 1. Delta State (Inset Nigeria).

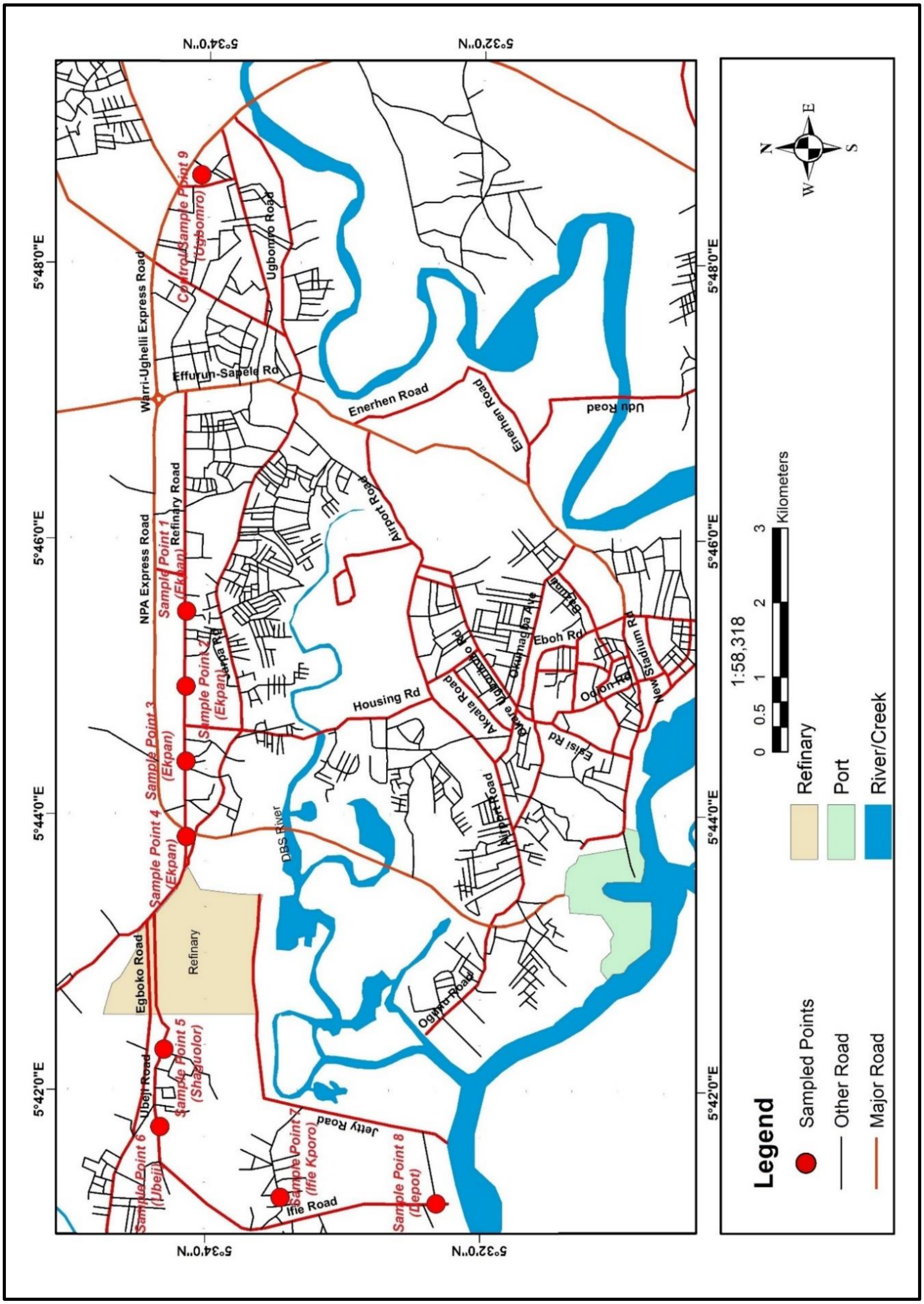

Figure 2. Study Area: Warri Refinery and Petrochemical Company of Nigeria and Environs

WRPC constitutes one of the 11 affiliates of the Nigerian National Petroleum Corporation (NNPC), and was created in 1988 (with the merger of the Warri Refinery and the Ekpan Petrochemical plant), at the onset of the NNPC commercialization exercise (www.wrpcnnpc.com.ng). The company functions both as a fuel plant refinery and petrochemical prefinery - polypropylene and carbon black (Department of Petroleum Resources, 2017).

The vegetation of the study area located within the wetlands of the Niger Delta region of sub-Saharan Africa can be described as flat low-lying forest swamps. These swamps are intercepted by meandering streams, rivers and creeks (Ana, 2011). The topography is generally flat, with an average relief height of about 13meters above sea level (Mode et al., 2010). Its climate is classified as the wet equatorial climate type (Koppen's Af. climate). The area is tropical humid of the semi-hot equatorial type. It has a mean annual rainfall ranging from 2,000mm to 4,500 mm (Odjugo, 2004). The wet season, extends from April to October annually, although there is intermittent precipitation during the dry season. (November –March). There are two major prevailing wind systems in the region. The South-West Trade wind is associated with the rainy season, while the North-East trade wind is associated with the dry season (Ojeh, 2012). Mean annual temperature ranges from 26^0C-28^0C (Odjugo, 2004).

Materials and Methods

For this study, primary and secondary data with spatial and non-spatial attributes were utilized. The primary data included air quality parameters ($PM_{2.5\mu m,}$ and $_{10\mu m}$), Volatile Organic Compounds (VOC) and Carbon Monoxide (CO). $PM_{2.5\mu m,10\mu m}$ was measured using a digital hand-held probe (HoldPeak Laser PM meter – HP 5800D, Zhuhai Jida Huapu Instrument Company Limited, China). CO concentrations was measured using the GM8805 Carbon dioxide meter, Lancol

Corporation, China. VOC, temperature and relative humidity were measured with the UNI-T meter; model UT338C, Uni-Trend Technology Limited, China. H_2S, SO_2 and NO_2 were measured with the BH-90a single gas monitor, Bosean Electronic Technology Company Limited, China.

Sampling points were located off the major roads, at 1500, 2500, 3500 and 4500 meters from the centroid of the refinery, in the North East and South West direction of the prevailing winds as shown in Figure 2. The control point (16,000 meters from the centroid of WRPC) was located at Ugbomro Community, Effurun, Delta state. This served as a control measure for the study. This was an appropriate choice as there are least concerns for significant sources of pollution in a community having an educational institution as one of its major land uses (Balogun and Orimoogunje, 2015). The coordinates of all sampling stations were captured with the use of GPS (Global Positioning System) device.

The Australian Standard AS2922, (1987) provided the necessary basis for siting sampling units for the study. Sampling points for the study were selected to satisfy the category of peak stations, which were stations located at areas likely to produce maximum ground concentration levels of pollutants. Maximum concentrations of pollutants were expected to be at distances within the range of 1,500 meters and 4,500 meters from WRPC, which were considered relatively close to the pollutant source. Although interference in the readings of air quality parameters by other natural and anthropogenic pollutant sources may have been unavoidable, interfering emissions from anthropogenic sources were reduced by siting sampling stations away from unsealed roads, vegetation and dumpsites. This was in accordance with the guidelines in Australian Standard AS2922.

Sampling for all air quality parameters was carried out once in a week for a one-year period (December 2017 to November 2018), producing a total of 52 sample counts per sampling station.

This satisfied the requirements of the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria - EGASPIN (Department of Petroleum Resources - DPR, 2002, Section 4.4.4), which stipulates monitoring of air emissions on a monthly basis. Sampling duration covered the wet season months from April to October and dry season months from November to March, in line with the guidelines by the UK Environment Agency (2011).

Intermittent or batch sampling procedure was applied in sampling ground concentration of air pollutants in selected communities around the refinery. A sampling day was selected within each week (Mondays to Saturdays) on a sequential basis. This ensured that every weekday, apart from Sunday (based on religious concerns) was incorporated in the sampling process. Sampling was carried out twice at each sampling point, for one hour. Sampling period for the selected days spanned from 9am to 6pm. Air quality monitoring height was between 1 and 2 meters from the ground level. Ethical clearance for the study was obtained from the Delta State Ministry of Environment, Asaba and the Department of Petroleum Resources, Warri, Delta State.

Results

Spatial Analysis of Air Pollutant Concentration around WRPC

Results of measured mean values of air pollutants obtained from December 2017 to November 2018 from nine (9) sampling points located at the communities around WRPC are shown in Table 1. The highest value for CO (1.50 ppm), VOC (5.63 mg/m^3), H_2S (0.002 ppm), SO_2 (0.02 ppm), NO_2 (0.60 ppm), $PM_{2.5}$ (42.97 µg/m^3) and PM_{10} (123.90 µg/m^3) were recorded at sampling points 8, 1, (1 & 7), 6, 1, 8 and 5 respectively. Lowest values for CO (0 ppm), VOC (2.41 mg/m^3), H_2S (0 ppm), SO_2 (0 ppm), NO_2 (0.11 ppm), $PM_{2.5}$ (12.91 µg/m^3) and PM_{10} (20.28 µg/m^3) were recorded at sampling points (1, 6 & 9) for CO, sampling point 9 for VOC, sampling points (2 ,3 ,4

,5 ,6 ,8 & 9) for H_2S, sampling points (1 & 3) for SO_2 and sampling point 9 for NO_2, $PM_{2.5}$ and PM_{10}. Generally, the results show that there were higher concentrations of pollutants at the sampling points 1 and 8, and minimal concentrations of pollutants at sampling point 9, which is the control point.

Table 1. Mean Concentration Values of Air Pollutants at Sampling Points around WRPC

Sampling Points	Communities / Description of Sampling Points	CO (ppm)	VOC (mg/m^3)	H_2S (ppm)	SO_2 (ppm)	NO2 (ppm)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
1	Ekpan, by Kayriot Hotel (4,500 m N.E of WRPC)	0.00	5.64	0.002	0.00	0.60	42.45	101.2 8
2	Ekpan, by Alenos Petrol Station (3,500 m N.E of WRPC)	0.19	4.70	0.00	0.01	0.58	39.52	94.66
3	Ekpan by Chicken Republic Eatery (2,500 m N.E of WRPC)	0.13	4.42	0.00	0.00	0.59	36.86	89.94
`4	Ekpan, by Shaguolo Flyover (1,500 m N.E of WRPC)	0.1 3	4.25	0.00	0.004	0.58	37.40	96.09
5	Ubeji, by Isaiah Junction (1,500 m S.W of WRPC)	0.0 4	4.80	0.00	0.01	0.58	37.78	123.9 0
6	Ubeji, by RCCG Worship Center (2,500 m S.W of WRPC)	0.0 0	5.12	0.00	0.02	0.57	37.62	96.28
7	Ifie-Kporo, by Desopadec Junction (3,500m S.W of WRPC)	0.3 1	4.50	0.002	0.003	0.57	39.93	96.50
8	Ifie-Kporo, by Matrix Depot (4,500m S.W of WRPC)	1.5 0	4.59	0.00	0.01	0.57	42.97	106.6 7
9	(Ugbomro Community) Control Point (16,000 m N.E of WRPC)	0.0 0	2.41	0.00	0.001	0.11	12.91	20.28
	Annual Average	0.2 5	4.49	0.0004	0.006	0.53	36.38	91.73

The annual mean concentrations of air pollutants recorded at nine (9) sampling points located at the North East (N.E.) and South West (S.W.) orientations from WRPC were re-grouped according to their distances from WRPC and represented in Table 2. The highest annual mean values for CO (0.75 ppm), VOC (5.11 mg/m^3), H_2S (0.001 ppm), NO_2 (0.58 ppm) and $PM_{2.5}$ (42.71µg/m^3) were the aggregates for the sampling points (1 and 8) located 4,500 meters from WRPC. The highest annual mean values for SO_2 (0.01 ppm) and PM_{10} (109.99 µg/m^3) were the aggregates for sampling points close to WRPC (2,500 meters for SO_2 and 1,500 meters for PM_{10}). The lowest mean values for CO (0.00 ppm), VOC (2.41 mg/m^3), SO_2 (0.001 ppm), NO_2 (0.11 ppm), $PM_{2.5}$ (12.91 µg/m^3) and PM_{10} (20.28 µg/m^3) were the aggregates for sampling point 9, located 16,000 meters from WRPC. Mean concentration values for H_2S were constant across all sampling points, except for a slight rise (0.001ppm) between 3,500 meters and 4,500 meters from the refinery.

Table 2. Mean Annual Concentrations of Air Pollutants According to Distance from WRPC

Air Pollutants	Mean Concentration Values of Air Pollutants				
	1,500 meters (Sampling Points 4 & 5)	2,500 meters (Sampling Points 3 & 6)	3,500 meters (Sampling Points 2 & 7)	4,500 meters (Sampling Points 1 & 8)	16,000 meters (Sampling Point 9)
CO (ppm)	0.0817	0.0625	0.2500	0.7500	0.0000
VOC (mg/m^3)	4.5240	4.7731	4.5990	5.1139	2.4092
H_2S (ppm)	0.0000	0.0000	0.0010	0.0010	0.0000
SO_2 (ppm)	0.0058	0.0096	0.0087	0.0038	0.0010
NO_2 (ppm)	0.5788	0.5784	0.5731	0.5841	0.1077
$PM_{2.5}$ (µg/m^3)	37.5899	37.2418	39.7245	42.7106	12.9087
PM_{10} (µg/m^3)	109.9962	93.1120	95.5784	103.9784	20.2817

The results as of the study generally indicate that the highest concentrations for most of the pollutants were measured at 4,500 meters from WRPC, diminishing at 16,000 meters from WRPC. Peak aggregate values for SO_2 and PM_{10} were recorded at 2,500 and 1,500 metres respectively before diminishing at 16,000 meters from WRPC. The highest aggregate values for PM_{10} and SO_2, which were measured at the sampling points located 1,500 and 2,500 meters respectively from WRPC, indicate that mean concentrations of PM_{10} and SO_2 tend to decrease with increasing distance from the refinery. On the other hand, CO, VOC, NO_2 and $PM_{2.5}$ tend to increase with distance, up to 4,500 meters from WRPC, and then diminished at 16,000 meters from the refinery. Concentration values of H_2S also increased slightly at 3500 and 4500 meters, after which it decreased at 16000meters from WRPC.

High values of pollutants recorded at 4,500 meters, which is relatively farther (compared to sampling points located 1500, 2500 and 3500 metrers) from WRPC, may be as a result of lengthy stacks used by WRPC to expel air pollutants into the upper atmosphere, above ground level. A stable atmosphere would result in the descent of pollutant plumes to ground level at a point farther from the base of the stack. Higher concentrations of pollutants at ground levels relatively far from the stack height signifies the point of plume descent.

Abdel-rahman (2008) explains that the height of the stack emitting air pollutants and the level of turbulence of an atmosphere determines the time and distance it takes for plumes having maximum concentration of pollutants to reach ground level. Turbulence in an unstable atmosphere brings the plume to the ground very quickly, resulting in high peaks near the stack, with concentrations decreasing downwind. On the other hand, a stable atmosphere has a lower concentration peak close to the stack, but begins to appreciate downwind. In the communities around WRPC, the high altitude of pollutant gas emitting stacks at the refinery and stable atmospheric conditions may have been responsible for maximum concentration of pollutants at distances further downwind from the source of pollutant. In addition the Matrix Depot, which is a secondary pollutant source in the area, could also be accountable for the high values of pollutants recorded at 4,500 meters from the refinery. The combination of pollutants from WRPC and the Matrix Depot could have resulted in peak values recorded at same point.

Pollutant concentrations were also categorized on community basis in Table 3, which shows aggregates of mean concentration of air pollutants across the communities (Ekpan, Ubeji, Ifie-Kporo and Matrix Depot) surrounding WRPC as well as the control point located at Ugbomro Community. The highest annual mean aggregate values for VOC, SO_2 and PM_{10} (4.9596 mg/m^3, 0.013 ppm and 110.09 µg/m^3 respectively) as well as the highest standard deviation value for PM_{10} (162.772 ug/m^3) were the aggregates for Ubeji community. This is not unexpected even as WRPC is located within same community. Highest annual mean and standard deviation value for H_2S (0.0019 ppm and 0.14 ppm respectively) were the aggregates for Ifie-kporo community, which shares border with Ubeji community.

Table 3. Annual Mean Concentration and Standard Deviation Values of Air Pollutants across Selected Communities

Air Pollutants		Mean Values/ Standard Deviation				
		Ekpan	Ubeji	Ifie	Matrix Depot	Ugbomro (Control Point)
CO (ppm)	Mean	0.11	0.02	0.31	1.50	0.00
	Standard Deviation	0.85	0.20	1.85	13.67	0.00
VOC (mg/m^3)	Mean	4.75	4.95	4.50	4.59	2.41
	Standard Deviation	1.64	1.24	1.22	1.46	1.00
H_2S (ppm)	Mean	0.0005	0.0000	0.0019	0.000	0.0000
	Standard Deviation	0.007	0.0000	0.014	0.000	0.0000
SO_2 (ppm)	Mean	0.0043	0.0135	0.0038	0.0077	0.0010
	Standard Deviation	0.040	0.0736	0.028	0.036	0.0098
NO_2 (ppm)	Mean	0.59	0.5736	0.57	0.57	0.1077
	Standard Deviation	0.098	0.1003	0.078	0.102	0.2538
$PM_{2.5}$ ($\mu g/m^3$)	Mean	39.06	37.70	39.93	42.97	12.91
	Standard Deviation	32.09	34.24	43.01	45.30	4.72
PM_{10} ($\mu g/m^3$)	Mean	95.49	110.09	96.50	106.67	20.28
	Standard Deviation	146.74	162.77	147.40	151.76	9.28

The highest annual mean aggregate for NO_2 was recorded at Ekpan community. This could be the result of high vehicular traffic plying the popular Refinery road axis, which transverses Ekpan community. Vehicles which release fumes are secondary sources of pollutants besides the WRPC.

Matrix Depot recorded the highest mean aggregates for CO (1.5 ppm) and $PM_{2.5}$ (42.9683 µg/m^3), as well as the highest standard deviation values for same pollutants (13.67ppm and 45.3 µg/m^3 respectively). The depot is located relatively farther from the refinery, at the outskirts of Ifie-Kporo. Such high annual mean concentration and standard deviation values for CO and $PM_{2.5}$ could be attributed to shipping activities which take place at the depot. During the course of field study, commercial activities such as transportation and lifting activities were observed at the depot. Sighting of heavy duty trucks, emitting smokes and noxious gases was the usual occurrence. Generally, variations in mean concentrations of air pollutants across the selected communities within which the sampling points were located indicate that Ubeji had the highest readings for PM_{10} and VOC, Ekpan had the highest readings for NO_2, while the Matrix Depot had the highest reading for CO and $PM_{2.5}$. Readings for H_2S and SO_2 show minimal variations across all communities.

The relationship between distance from WRPC and concentration of air pollutants was investigated using Pearson product-moment correlation coefficient. The results of the analysis in Table 4 indicate significant relationships between the concentration values of air pollutants (VOC, NO_2, $PM_{2.5}$ and PM_{10}) and distance from WRPC, having all same p value of 0.000 (at 0.05 level of significance). Values for CO, H_2S and SO_2, which had non-significant p values could be attributed to the fact that these lightweight gases are dispersed much quickly compared to the rate at which they are emitted. Readings for these gases were generally low throughout the course of field sampling.

Correlation coefficients (r) of -0.42, -0.74, -0.22, -0.17 for VOC, NO_2, $PM_{2.5}$ and PM_{10} respectively are as indicated in Table 4. Negative (r)s imply negative relationships between these air pollutants and distance from WRPC. In other words, concentration values of VOC, NO_2, $PM_{2.5}$ and PM_{10}

tend to decrease with increasing distance from the refinery. Coefficients of Determination of 17.31, 54.76, 4.71 and 2.96 for VOC, NO_2, $PM_{2.5}$ and PM_{10} respectively are also indicated in Table 4. These imply that 17.31%, 54.76%, 4.71% and 2.96% concentration of VOC, NO_2, $PM_{2.5}$ and PM_{10} respectively could be explained based on distance from WRPC.

Table 4. Correlation of Air Pollutant Concentration and Distance

S/N	Air Pollutants	Number of Samples	p value	Correlation Coefficients (r)	Coefficient of Determination (r^2 x 100)%
1	CO	936	0.847	-0.006	0.0036
2	VOC	936	0.000	-0.416	17.3056
3	H_2S	936	0.833	-0.007	0.0049
4	SO_2	936	0.186	-0.043	3.4596
5	NO_2	936	0.000	-0.740	54.76
6	$PM_{2.5}$	936	0.000	-0.217	4.7089

Air Pollutant Concentration at WRPC and WHO Regulatory Limits

This section compares measured annual values of air pollutants (NO_2, $PM_{2.5}$ and PM_{10}) at varying distances from WRPC with their corresponding WHO annual regulatory limits. The annual values of these pollutants were considered for comparison, because annual limits for same pollutants have been specified by WHO, as against the other pollutants which have only daily and hourly (one hour or more) limits specified by WHO due to their highly toxic nature.

The annual mean values of NO_2, $PM_{2.5}$ and PM_{10} at sampling points located 1500 (sampling points 4 & 5), 2500 (sampling points 3 & 6), 3500 (sampling points 2 & 7), 4500 (sampling points 1 & 8) and 16000 (sampling points 4 & 5) meters from WRPC were plotted against their regulatory limits as shown in Table 5. The results reveal that measured annual mean values of NO_2, $PM_{2.5}$ and PM_{10} at all distances were above WHO regulatory limits. While WHO annual regulatory limit for NO_2, $PM_{2.5}$ and PM_{10} stood at 0.02 ppm, 10 µg/m^3 and 20 µg/m^3 respectively, measured annual mean values ranged from 0.11 ppm (16,000 meters from WRPC) to 0.58 ppm (4,500 meters from WRPC) for NO_2; 12.91 µg/m^3 (16,000 meters from WRPC) to 42.71 µg/m^3 (4,5000 meters from WRPC) for $PM_{2.5}$ and 20.28 µg/m^3 (16,000 meters from WRPC) to 109.99 µg/m^3 (1,500 meters from WRPC) for PM_{10}.

Table 5. Comparison of Measured Annual Values of Air Pollutants and WHO (2005) Annual Limits

Air Pollutant	Distance from WRPC (meters)				
	1500	2500	3500	4500	16000
NO_2 (ppm)					
Annual Mean Values	0.58	0.58	0.57	0.58	0.11
WHO Annual Limits	0.021	0.021	0.021	0.021	0.02
$PM_{2.5}$ (µg/m^3)					
Annual Mean Values	37.59	37.24	39.72	42.71	12.91
WHO Annual Limits	10	10	10	10	10
PM_{10} (µg/m^3)					
Annual Mean Values	109.99	93.11	95.58	103.98	20.28
WHO Annual Limits	20	20	20	20	20

The results indicated that measured annual values of NO_2, $PM_{2.5}$ and PM_{10} exceeded WHO annual regulatory limits up to 16,000 meters from WRPC. Nevertheless, being that measured values of NO_2, $PM_{2.5}$ and PM_{10} at 16,000 meters from WRPC (0.11 ppm, 12.9087 µg/m^3 and 20.2817 µg/m^3 respectively) were slightly above the WHO maximum limit (0.021 ppm, 10 µg/m^3 and 20 µg/m^3

respectively, it would therefore not be out of place to recommend an extent of isolation for WRPC to be mid-way between 4,500meters and 16,000 meters from WRPC.

This was calculated to be 10,250meters from WRPC centroid.

(16,000 – 4,500) meters = 11,500 meters
½ of 11,500 meters = 5,750 meters
½ way between 4,500 meters and 16,000 meters from WRPC = (4,500 + 5,750) meters
= 10,250 meters from WRPC

Measured values of air pollutants were also compared with their WHO regulatory limits using the paired-sampled T-test. The paired-samples T-test was applicable because it is a statistical tool which is used for a particular group of data comprising two sets, collected at two different occasions (Pallant, 2011). The first set of air quality data consisted of measured values of air pollutants derived from the nine sampling points located in Ugbomro, Ekpan, Ubeji and Ifie-Kporo communities, while the second set of data consisted of daily and hourly permissible limits of air pollutants as stated by WHO air quality standards and guidelines (WHO, 2000; WHO, 2005). WHO specifies daily permissible limits for H_2S, SO_2, $PM_{2.5}$ and PM_{10}, as 0.15 mg/m^3 (0.12 ppm), 20 $\mu g/m^3$ (0.008 ppm), 25 $\mu g/m^3$ and 50 $\mu g/m^3$ respectively. It also specifies hourly permissible limits for CO and NO_2 as 25ppm and 200 $\mu g/m^3$ (0.1 ppm) respectively.

The results of the t – test analysis in Table 6 show that measured values of CO (M = 0.2543, SD = 4.64) and H_2S (M = 0.0004, SD = 0.0065) were significantly less [at t (935) = -163.295 and -537.062 respectively, $p \leq 0.05$] than their corresponding WHO limits; (M = 25, SD = 0.00) for CO and (M = 0.115, SD = 0.00) for H_2S. On the other hand, measured values of NO_2 (M = 0.5263, SD = 0.19329), $PM_{2.5}$ (M = 36.3825, SD = 34.928) and PM_{10} (M = 91.735, SD = 145.051) were significantly higher (at t (935) = 67.471, 9.970 and 8.803 respectively, $p \leq 0.05$) than their corresponding WHO limits; (M = 0.1, SD = 0.00) for NO_2, (M = 25, SD = 0.00) for $PM_{2.5}$ and (M

= 50, SD = 0.00) for PM_{10}. Measured values for SO_2 (M = 0.0063, SD = 0.0464) were not significantly less (at t (935) = -0.783, $p \leq 0.05$) than its corresponding WHO limit; (M = 0.0076, SD = 0.00).

Table 6. Paired Sampled T-Test between Measured Values of Air Pollutants and WHO Permissible Limits

Air Pollutants		Number of Samples	Standard Deviation	t – value	p value
Pair 1 (CO)					
Measured Value	0.25 ppm	936	4.64	-163.30	0.00
Permissible Limit by WHO	25 ppm		0.00		
Pair 2 (H_2S)					
Measured Value	0.0004 ppm	936	0.01	-537.06	0.00
Permissible Limit by WHO	0.115 ppm		0.00		
Pair 3 (SO_2)					
Measured Value	0.0063 ppm	936	0.05	-0.86	.039
Permissible Limit by WHO	0.0076 ppm		0.00		
Pair 4 (NO_2)					
Measured Value	0.53 ppm	936	0.19	67.47	0.00
Permissible Limit by WHO	0.1 ppm		0.00		
Pair 5 ($PM_{2.5}$)					
Measured Value	36.38 µg/m^3	936	34.93	9.97	0.00
Permissible Limit by WHO	25.00 µg/m^3		0.00		
Pair 6 (PM_{10})					
Measured Value	91.74 µg/m^3	936	145.05	8.80	0.00
Permissible Limit by WHO	50 µg/m^3		0.00		

Measured values for NO_2, $PM_{2.5}$ and PM_{10} which exceeded WHO regulatory limits were observed to be the result of combination of emissions from the refinery, as well as secondary emission sources which include large and small vehicles running on Premium Motor Spirit (PMS) and diesel, power generating sets, municipal waste burning and fugitive dust from non-tar roads and fields.

Discussion

The results of the study which showed that air pollution in areas close to the refinery were significantly higher than air pollution in areas further away from the refinery (control point), align with studies by De Santis *et al*., (2004); Odjugo, (2004); Abdulkareem (2005) and Ighile *et al*., (2015); Mbaneme *et al*., (2014), who have determined that pollutant concentrations were higher and more impactful in areas closer to point sources of air pollutants which included refineries and gas flare points, compared to their control points. On the relationship between distance from a pollution source and pollution concentration, most findings have shown that concentration of pollutants generally tends to correlate negatively with distance, and decrease with increasing distance from its point source (Abdulkareem, 2005; Ighile *et al*., 2015 and De Santis *et al*., 2004). This was the case for CO, H_2S, SO_2 and PM_{10} in the study. However, it is worth taking note that meteorological variables strongly influence the concentration and transportation of air pollutants (Radaideh, 2017; Jacobson, 2005). As such, the influence of the distance factor in some cases may be subsumed by the influence of other variables such as Temperature, Humidity and Terrain, which could also affect the concentration of these pollutants at various distances from the point source. This is in accordance with the study by Odat, (2009).

It has been noted by (Amuho et al., 2016) that higher concentration of pollutants at Ekpan (a community comparatively farther from the WRPC), compared with Ubeji (a community closest to the WRPC) could be attributed to heavier emissions from vehicular traffic at Ekpan, which is more populated than Ubeji. According to Al-Haddad et al., (2012), secondary pollution sources such as traffic and power generating plants have contributed immensely to air pollution around refineries. De Santis *et al,* (2004) have also observed that large portion of pollutants in areas surrounding point-source pollutants actually emanate from urban area sources. Vehicular movements along busy roads, which lead in and out of industrial complexes enhance pollution concentrations around point sources.

In study area, it was observed that vehicular traffic congestion along Ekpan road, leading unto the WRPC is a consistent problem, especially during days when petrol/diesel trucks queue up to load petroleum products. This could account for higher concentrations in sampling points which were farther from the refinery. Based on this argument, it may not be out of place when higher concentration values of pollutants are noted at points farther from the WRPC, even as these ‘points’ are still within the sphere of influence of activities which are themselves related to the operations of the WRPC.

Grigoras et al., (2012) have also reported that higher concentration of pollutants at sampling points much further away from a point source may be due to emissions from secondary sources apart from the point source. A number of secondary pollutant sources such as transportation activities and cooking gas sales outlets and privately owned electric power generating sets for hotels along the Refinery road were noted during the course of sampling. It was observed that vehicular traffic congestion along the Refinery road, leading to WRPC is a consistent problem, especially during days when petrol tankers queue up to load petroleum products. This could account for higher concentrations in sampling points which were farther from the refinery.

The results of pollutant variations across selected communities around WRPC are similar with findings by Amuho et al., (2016), who noted that higher concentration of NO_2 at Ekpan (a community comparatively farther from WRPC), compared with Ubeji (a community closest to WRPC) could be attributed to heavier emissions from vehicular traffic at Ekpan, which is more populated than Ubeji. Al-Haddad et al., (2012) opined that secondary pollution sources such as traffic and power generating plants contribute immensely to air pollution around refineries. De Santis *et al*., (2004) have also hinted that large portion of pollutants in areas surrounding point-source pollutants actually emanate from municipal activities in urban area, which include vehicular movements along busy roads, leading in and out of industrial complexes. A major source of secondary pollutants in the study area was the Matrix Depot, though relatively further from WRPC, yet contributed immensely to high pollution values recorded at 4,500meters from WRPC.

The results comparing measured values of air pollutants and regulatory limits indicated significantly higher mean values of NO_2, $PM_{2.5}$ and PM_{10}, compared with their corresponding WHO regulatory limits. This may be the result of air polluting activities of WRPC, as well as secondary sources such as automobiles. This result aligns with findings by Tawari and Abowei (2012) and Abdulkareem (2005) which showed that measured pollutant values around refineries exceeded regulatory limits.

On the other hand, findings from the study which indicated that the mean values of CO and H_2S were significantly lower than the WHO regulatory limit aligns with findings by Khanfar (2015), which revealed that the average concentrations of criteria air pollutants around a refinery in Kuwait were below stipulated standards as prescribed by the Kuwait EPA. Also, measured mean values of SO_2 which were less than WHO regulatory limits, aligns with the study by Alanezi (2013), where in was discovered that all SO_2 measurements taken were below the Kuwait EPA ambient air quality standard. Despite having mean concentration values of air pollutants lower than regulatory limits, data of this sort remain useful for future comparisons, to aid future air quality management strategies.

Conclusion and Recommendation

The study has monitored and analysed pollution levels at varying distances and across communities around the WRPC in Delta State. The results indicate that air pollution concentration around point sources vary significantly with distance. Having concentration values of NO_2, $PM_{2.5}$ and PM_{10}, which were above regulatory limits at all sampling points around the refinery suggests that refineries should be isolated from residential housing units, in order to reduce risks associated with exposure to air pollution.

The study recommends that buffer extent be indicated in more specific terms, by making amendments within industry regulatory documents, such as the FEPA 1991 and EGASPIN 2002. Being that it was observed that measured values for NO_2, $PM_{2.5}$ and PM_{10} were slightly above regulatory limits at 16,000 meters from the refinery, it is suggested that 10,250 meters be adopted as minimum extent of buffers around refineries. But considering present day economic realities in Nigeria, relocating settlers up to 10,250 meters from WRPC may not be a feasible option. As such, short-term strategies should be considered. Short term mitigating strategies include sanitation (which could involve the technical practice of installing air purifiers at strategic locations in the vicinity, as practiced in developed countries), tree planting/green spaces (to serve as carbon sinks and for the reduction of urban atmospheric temperatures) and improved health care. Long term strategies could include specification and enforcement of minimum isolation extent of refineries in Nigeria, adoption of cleaner technology/energy sources (such as the use of electric powered automobiles) and the revamp of the hydroelectricity power sector to enable less dependence on the fossil fuels as source of power. Improvement in the hydroelectric sector will be significant in enabling Nigeria drive one of her strategies, which is the INDC (Intended Nationally Determined Contribution) goal of reducing 20% and 45% GHG emissions unconditionally and conditionally in year 2030.

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