Vol. 3, No. 1, pp. 22-40, (March 2022)
DOI: 10.21608/aujes.2021.104766.1046
Aswan University Journal of Environmental Studies (AUJES)
Online ISSN: 2735-4237, Print ISSN: 2735-4229
Journal homepage: https://aujes.journals.ekb.eg/ E-mail: AUJES@aswu.edu.eg

Original research

Evaluating Some Factors Which Influence Air Pollutant Concentration around the Warri Refining and Petrochemical Company (WRPC) of Nigeria

Verere S. Balogun*[1], Peter A. O. Odjugo[2]
[1] *University of Benin, Faculty of Social Sciences, Department of Geography and Regional Planning, Benin City, Nigeria*
[2] *University of Benin, Faculty of Social Sciences, Department of Geography and Regional Planning, Benin City, Nigeria*

Received: 7/11/2021 Accepted: 10/12/2021

Abstract:

The study assesses potential variables which influence the concentration of air pollution around a point source. Seven categories of air pollutants were monitored around the Warri Refining and Petrochemical Company (WRPC) of Nigeria, which comprised carbon monoxide (CO), volatile organic compounds (VOC), Hydrogen sulphide (H_2S), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2) and Particulate Matter ($PM_{2.5}$ and PM_{10}). Sampling points were located in the range of 1.5 km to 16 km. Air quality was sampled intermittently and weekly for one year. T-test analyses was used to determine significant differences in air pollutant concentration on the basis of orientation and seasonality. Regression analysis was also used to assess the influence of selected predictors on pollutant concentration around WRPC. Except for H_2S, the prediction models for CO, VOC, SO_2, NO_2, $PM_{2.5}$ and PM_{10} were statistically significant with R^2 values of 0.014, 0.215, 0.022, 0.582, 0.17 and 0.45, respectively. The results revealed that the concentration of pollutants was influenced by the combination of the factors (distance from WRPC, orientation from WRPC, seasonality and climatic variables such as atmospheric temperature, relative humidity and wind speed), which served as the predictors in the model. The study recommends that arrangements of industrial and residential land uses by urban planning authorities be patterned, taking into consideration factors such as distance and orientation from pollution point-sources.

Keywords: Air pollutants, Point-source, Predictors, Seasonality, Orientation, Climatic variables

1- Introduction

Due to increasing population pressure, more people tend to live around point sources of pollutants such as industrial zones, gas flare and mining sites, thereby exposing themselves to increased risk of health problems arising from inhaling pollutants (Tawari and Abowei, 2012; Igile *et al*, 2015; Akpan and Udo, 2016; Onakpohor *et al,* 2021). Such point sources include natural sources such as volcanoes, sea-sprays, underground methane leaks etc.; and anthropogenic sources such as traffic, incinerators, power stations, flare points and industries which include refineries.

Corresponding authors*: E-mail addresses: verere.sido@uniben.edu

Most industries release gaseous pollutants from stacks erected at such height capable of dispersing pollutants at a high altitude, to prevent the mixing of pollutants at a lower altitude, where people inhabit (Abdel-rahman, 2008). However, factors such as terrain, distance from the point source and meteorological conditions could influence the effectiveness of dispersion, thus resulting in poor air quality at ground level, close to the point source (Kibble and Harrison, 2005).

Warri Refining and Petrochemical Company (WRPC) is a petrochemical refining plant where crude oil is refined into useful petroleum products such as gasoline, diesel fuel, asphalt base, heating oil, kerosene and liquefied (Basorun and Olamiju, 2013). The refining process releases several types of air pollutants which include hydrocarbon compounds, carbon monoxide, (CO), oxides of sulphur (SO_X), oxides of nitrogen (NOx), particulate matter (PM), benzene, Lead (Pb) etc. (Onokpohor *et al,* 2020; Fakinle *et al,* 2020). Apart from WRPC, other secondary pollutant sources include mobile sources such as moving vehicles and stationary sources such as power generating sets at homes and hotels, kitchen fire places, petrol stations and vehicle servicing stations. Fugitive sources of pollutants such as leakages from pipes, windblown particulates from stockpiles and unpaved roads also produce significant levels of air pollution at a local level (Kibble and Harrison, 2005; Manisalidis *et al,* 2020).

The increasing number of people settling in the communities around WRPC are undoubtedly exposed to air pollution emanating from point sources (stacks) at the refinery, in addition to secondary and fugitive sources in the area. Studies show that the health of residents living near refineries is at risk of diseases such as pertussis, pneumonia, chronic bronchitis, upper respiratory tract infections, leukemia and other blood-related diseases. These health risks have been associated with the absorption of air pollutants, either directly through inhalation or through contaminated food and water (Nwachukwu *et al.,* 2012; Akpan and Udo, 2016; Manisalidis *et al,* 2020).

The ecological environment around WRPC is undoubtedly affected as well. According to Tawari and Abowei (2012), air pollutants from refineries and gas flares in the Niger Delta Region can dissolve in rainwater, forming acid rains. These acid rains lower the pH values of soils, leading to low soil fertility. They further state that the environment, especially around refineries and flare sites, is affected by unusual hot conditions and soot, which damage vegetation and affect the health of people living close by. Eneh and Agbazue (2011); Emoyan *et al* (2008); Manisalidis *et al,* 2020 state that air pollutants from various sources including refineries result in global warming and its attending consequences (such as sea-level rise, unusual climatic conditions, floods, salt water intrusion, habitat modification, etc.), 'biomagnification' (a situation where pollutants move through trophic levels, becoming exponentially more concentrated in the process), acidification of soils and water bodies, the introduction of invasive species replacing native species, frequent occurrence of smog and haze etc.

Following these, there is the need for constant monitoring of air pollution around point sources, to determine what factors predispose people more to pollution exposure. Previous studies (Kozlov and Haukioja, 1997; De Santis *et al,* 2004; Abdulkareem, 2005; Highwood and Kinnersley, 2006; Abdel-rahman, 2008; Fagbeja, 2008; Thambiran and Diab, 2010; Abdelrasoul *et al,* 2010; Liu and Shen, 2014; Muhaimin *et al,* 2015; Amuho *et al,* 2016; Radaideh, 2017) have shown that there are several factors which can influence the concentration of pollutants around a point source. These include the distance from the point source itself, orientation (upwind or downwind sides of the point source), seasonality, atmospheric temperature, relative humidity and wind speed. For effective planning of settlements (with respect to arrangements and separation of land-use types) and proper management of ecological units close to point sources of pollutants, it is necessary that these factors be put into consideration to reduce the risk of human exposure to air pollution.

These factors are also necessary for determining the extent of buffers around a point source of pollutant, in order to protect the ecological functioning of sensitive land uses located close by. Previous studies have explained pollution concentration around point sources, on the basis of isolated variables which influence variations in pollutant concentration. This study further attempts to assess the contributions of variables (distance from WRPC, orientation from WRPC, seasonality and climatic variables such as atmospheric temperature, relative humidity and wind speed), which combine to influence pollution concentration around a point source. In addition to previous findings, this study regresses these factors or variables affecting the concentration of pollutants around WRPC, with the aim of identifying the most pressing conditions which place people and the environment at greater risk of exposure to air pollution around WRPC. This would guide urban planners on appropriate zoning, buffer extent, and separation arrangements, between incompatible land use types, taking into consideration air polluting potentials from a point-source.

2- Materials and Methods

2.1 Study Area

Ubeji, Ifie-kporo, Jeddo, and Ekpan, which are host communities to WRPC are located in three Local Government Areas (LGAs) in Delta State. Ubeji and Ifie-Kporo communities are located in Warri-South LGA, Jeddo community is located in Okpe LGA, while Ekpan Community is located in Uvwie LGA (Figure 1). The boundaries of WRPC are located on the coordinates 5°34’18” N and 5°42’33” E (North Western boundary), 5°34’19” N and 5°43’19” E (North Eastern boundary), 5°33’36” N and 5°42’33” E (South Western boundary), and 5°33’35” N and 5°43’25” E (South Eastern boundary), as shown in Figure 2. The refinery which covers a total land area of 1,104,014 hectares is located in Ubeji community, Warri-South L.G.A. of Delta State. (www.wrpcnnpc.com.ng). Delta State is one of the 36 states in Nigeria and a part of the oil-producing region of the Niger-Delta, Nigeria.

The vegetation type is classified as a low-lying mangrove swamp. The swamps are intercepted by meandering streams, rivers and creeks (Ana, 2011). The topography is generally flat, with an average relief height of about 13 meters above sea level (Mode *et al*, 2010). The climate of the selected area is classified as Koppen’s ‘Af’ type, which is the tropical wet climate (Hess, 2014). 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, with intermittent precipitation during the dry season (November –March). The two major prevailing wind systems in the region are the South-West Trade wind, which is associated with the rainy season, and the North-East trade wind, which is associated with the dry season (Ojeh, 2012). Mean annual temperature ranges from 26^0C-28^0C (Odjugo, 2004).

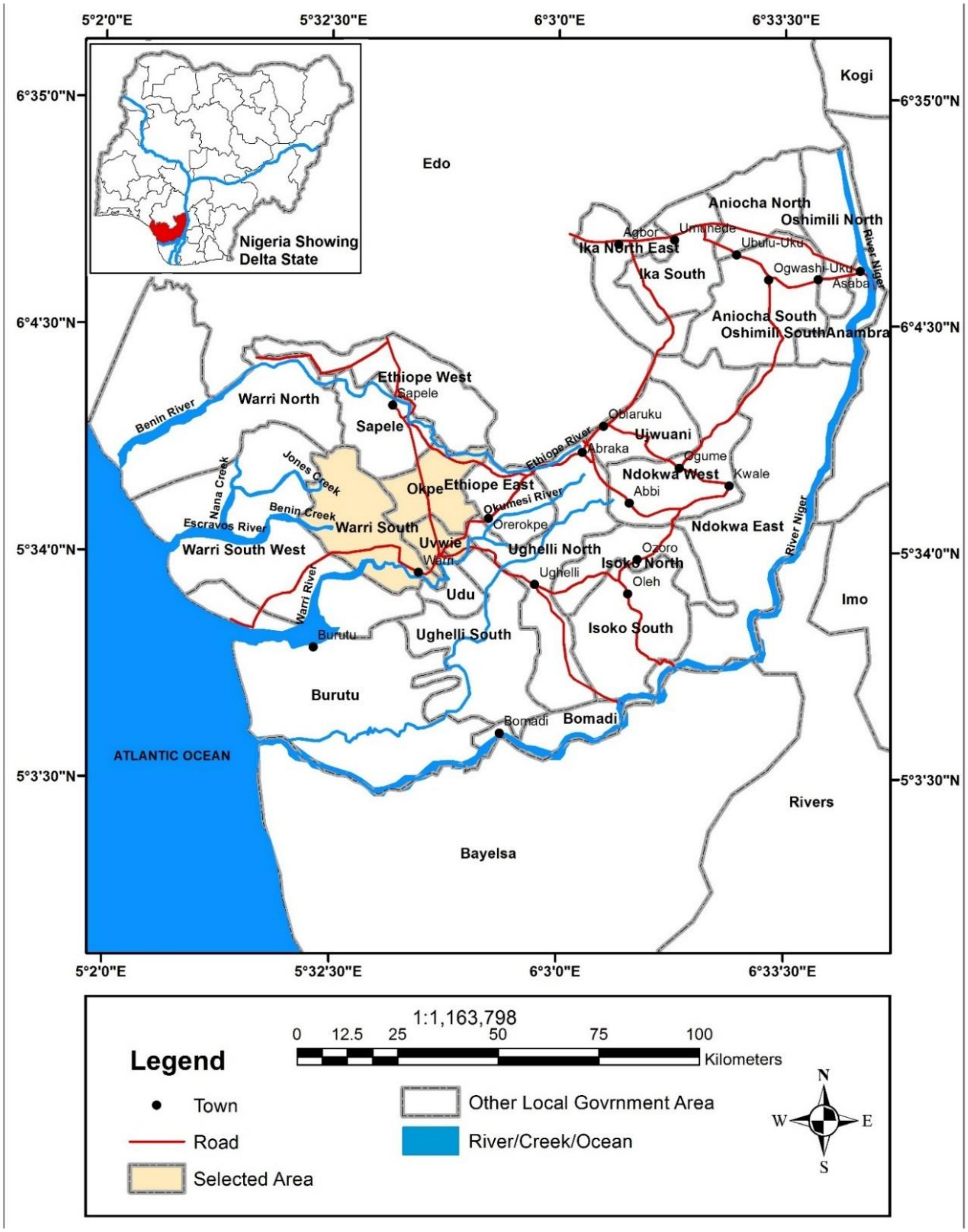

Fig. 1. Delta State Showing Uvwie, Okpe and Warri-South Local Government Areas
Source; Department of Geography and Regional Planning, University of Benin, Nigeria (2019)

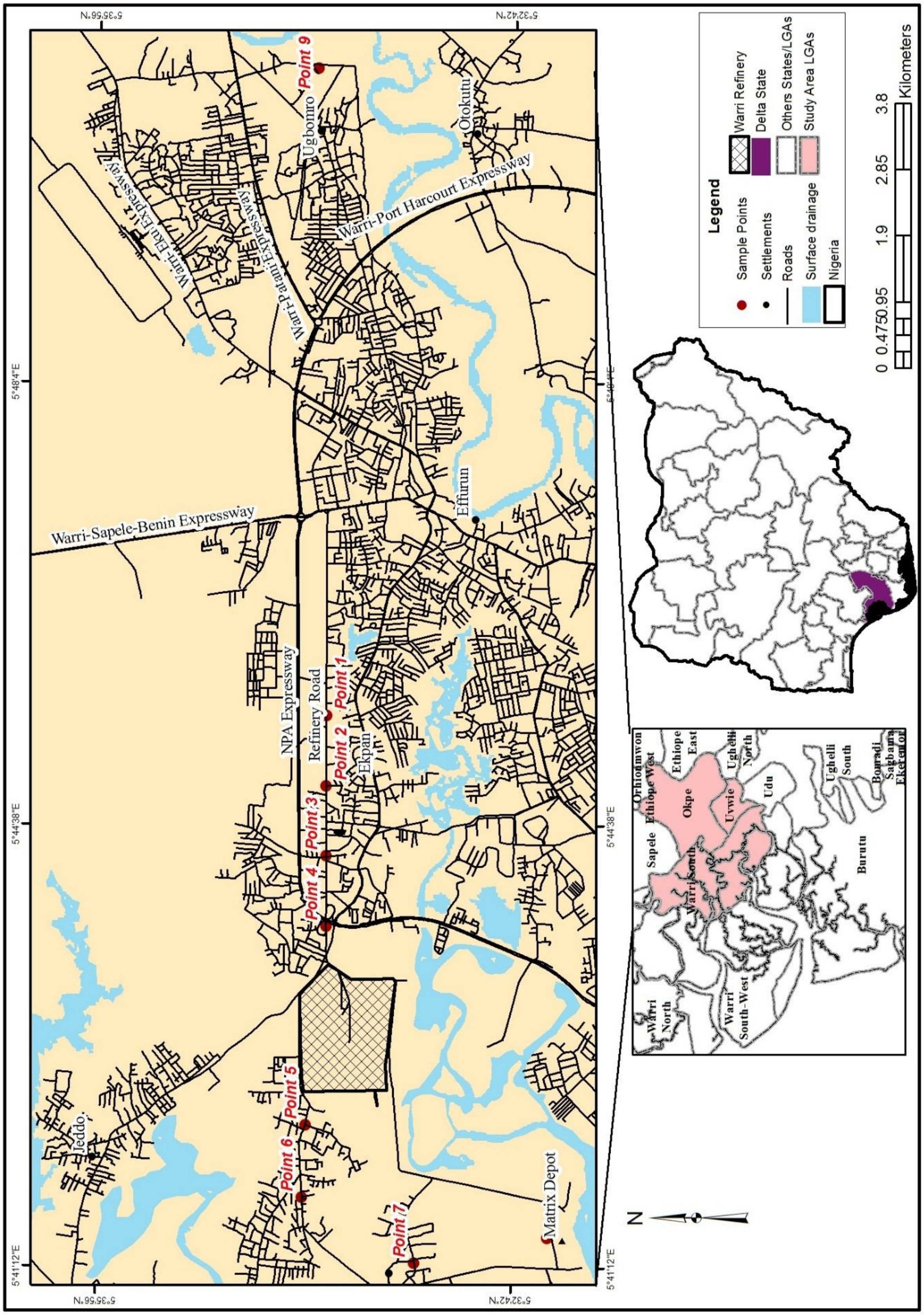

Fig. 2. WRPC and Air Quality Sampling Points
Source: Department of Geography and Regional Planning, University of Benin, Nigeria (2019).

2.2 Data Source and Analysis

The study involved the use of primary data on air quality, which included direct field measurements of Particulate Matter ($PM_{2.5\mu m,}$ and $PM_{10\mu m}$), Carbon monoxide (CO), Volatile Organic Compounds (VOCs), Hydrogen sulphide (H_2S), Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2). $PM_{2.5\mu m}$ and $PM_{10\mu m}$ were measured using a digital hand-held probe (HoldPeak Laser PM meter – HP 5800D, Zhuhai Jida Huapu Instrument Company Limited, China). CO concentration was measured using Benetech GM8805 Carbon monoxide 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. All equipments were calibrated in a controlled environment in order to obtain accurate air quality data.

The siting of sampling units was based on the Australian Standard - AS2922. This stipulates that sampling points that are categorized as peak stations, should be located at areas likely to produce maximum ground concentration levels of pollutants. Therefore, sampling points (except the control point) were located between 1,500 meters and 4,500 meters from WRPC, which were points at which maximum concentrations were expected (Australian Standard - AS2922, 1987). Sampling points were located off the major roads, at 1500, 2500, 3500 and 4500 meters from the centroid of the refinery in the northeast and southwest direction of the prevailing winds as shown in Figure 2. These distances were chosen because they fall within and beyond the 2,000 meters minimum separation distance of refineries, as recommended by Environmental Protection Agencies of some developed countries of the world (EPA South Australia, 2000; EPA Western Australia, 2005; EPA, Victoria, 2012). The geographical coordinates of sampling points were captured with the use of GPS (Global Positioning System) device.

Interfering emissions from anthropogenic sources were reduced by siting sampling stations away from unsealed roads, vegetation and dump sites. A control point was located at Ugbomro Community, Effurun, Delta state (16 km from WRPC). This served as an appropriate choice as there are the 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). 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. Sampling period covered the wet season months from April to October and dry season months from November to March. This satisfied the requirements of the DPR's Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN, Part III, Section E 4.4.4, 2002), which stipulates monitoring of air emissions on a monthly basis. A sampling day was selected within each week (Mondays to Saturdays) on a sequential basis. This ensured that every week day, apart from Sunday (based on religious concerns) was incorporated in the sampling process. Monitoring height was between 1 and 2 meters from the ground, which is a suitable height for assessing air quality impact on humans as this is the general height at which people breath (Environmental Agency – United Kingdom, 2011). Ethical clearance for the study was obtained from the Department of Petroleum Resources (DPR), Nigeria, and the Ministry of Environment, Delta State, Nigeria.

3. Results and Discussion

WRPC is located in the southern part of Nigeria, close to the coast, and is under the influence of the two Trade Winds (North East and South West Trade Winds), which blow seasonally across

Nigeria. The N.E Trade Wind is prevalent during the dry season, while the S.W Trade Wind is prevalent during the wet season. To determine the influence of the two major wind systems in Nigeria in influencing the concentration of pollutants at the upwind and downwind orientations, t-test was used to analyze the variation in concentration of pollutants at the N. E. and S. W. orientations of WRPC. The results of the independent samples t-test in Table 1 reveal that concentration values for VOC, NO_2, $PM_{2.5}$ and PM_{10} in the N.E Orientation {(M = 4.2847, SD = 1.7989), (M = 0.4908, SD = 0.2391,), (M = 33.83, SD = 30.62) and (M = 80.45, SD = 156.06), respectively} were significantly less than their concentration values in the S.W orientation {(M = 4.7514, SD = 1.3087), (M = 0.5707, SD = 0.0955), (M = 39.57, SD = 39.47) and (M = 105.84, SD = 156.06), respectively}; t (934) = -4.590, -6.958, -2.439, -2.626, respectively, $p< 0.05$, two-tailed. Concentration values for CO, H_2S and SO_2 between the N.E and S.W orientations were not significantly different at t (934) = -1.097, -0.224 and -1.864, respectively, $p > 0.05$, two-tailed.

Table 1. T-test Analysis on Variations in Air Pollutant Concentration in N.E. and S.W. Orientations of WRPC

Air Pollutants	*t* – Value	Degree of Freedom (n-2)	p value
CO	-1.097	934	0.273
VOC*	-4.590	934	0.000
H_2S	-0.224	934	0.823
SO_2	-1.864	934	0.063
NO_2*	-6.958	934	0.000
$PM_{2.5}$*	-2.439	934	0.015
PM_{10}*	-2.626	934	0.009

* = $p< 0.05$

WRPC is located in the southern-most part of the country close to the coast, which is under the influence of the S.W trade wind most parts of the year. As such higher concentration of pollutants are expected to be recorded at the windward direction, which is the N.E orientation of WRPC. But field observation revealed that the presence of a secondary pollutant source (which is the Matrix Depot as shown in Figure 2) may have altered this pattern. The Matrix Depot is located at the S.W orientation of WRPC, and contributes significantly to high levels of pollutants in the S.W orientation of the WRPC. Pollutants from the S.W orientation of Matrix Depot are blown by the prevailing S.W wind to the N.E orientation of the depot, which is also the S.W orientation of WRPC. This explains why significantly higher concentrations were recorded in the S.W orientation, compared to the N.E orientation of WRPC. This result attests to the study by Abdelrasoul *et al*, (2010) which reported that air pollutants were of higher concentration in the downwind direction of a point source in Kuwait, due to the influence of the prevailing wind system. The findings by Fagbeja (2008) also support the fact that concentrations of pollutants are higher downwind of their sources in the Niger Delta Region of Nigeria. This implies that the Matrix Depot contributes significantly as a secondary pollutant source in the area, as it invariably influences the concentration of pollutants in the S.W orientation of WRPC.

The influence of seasonality in the concentration of pollutants in the communities around WRPC was examined using the independent samples t-test. The results in Table 2 reveal that dry season values for VOC, NO_2, $PM_{2.5}$ and PM_{10} {(M = 4.79, SD = 1.70), (M = 0.57, SD = 0.21,), (M = 48.40, SD = 32.67) and (M = 174.22, SD = 224.58) , respectively} were significantly higher than their wet season values {(M = 4.36, SD = 1.56), (M = 0.51, SD = 0.18), (M = 31.04, SD = 34.59) and (M = 50.07, SD = 60.48), respectively}; t (934) = 3.725, 4.48, 7.365 and 8.862, respectively, $p < 0.05$, two-tailed. While dry season values for H_2S and SO_2 {(M = 0.00, SD = 0.00) and (M = 0.00, SD = 0.00) respectively} were significantly less than their wet season values {(M = 0.0006, SD = 0.008) and (M = 0.0091, SD = 0.056), respectively}; t (934) = -2.005 and -4.173, $p< 0.005$, two-tailed. Dry season values for CO (M = 0.075, SD = 8.32) was not significantly less than wet season values CO (M = 0.04, SD = 0.46); t (934) = 1.45, $p< 0.05$, two-tailed.

Table 2. T-test Analysis on Pollutant Concentration between Dry and Wet Seasons

Air Pollutant	*t* – Value	Degree of Freedom (n-2)	p Value
CO	1.450	934	0.148
VOC	3.725	934	0.000
H_2S	-2.005	934	0.045
SO_2	-4.173	934	0.000
NO_2	4.477	934	0.000
$PM_{2.5}$	7.365	934	0.000
PM_{10}	8.862	934	0.000

The highest concentration of pollutants in the dry season is similar to findings by Fagbeja (2008); Muhaimin *et al* (2015) and Igile *et al* (2015), who reported that pollutant concentration during the dry season were significantly higher than concentration values during the wet season. Fagbeja (2008) opined that variations in rainfall and humidity between seasons, had effect on the concentration of pollutant gases in the Niger Delta Region of Nigeria. Regular rainfall dissolves atmospheric gases and particulates results in constant clean-up of the atmosphere during the wet season (Rim-Rukeh, 2009). This implies that greater concern for the possible impacts of air pollutants on the health of residents around WRPC especially during the dry season. As such more effort should be made to reduce pollution, and protect residents of the area by creating awareness on the use of face masks, and reducing out-door activities, during the dry season, when impacts are on the high side.

Regression analyses were carried out on selected pollutants, to determine the level of contribution of each of the factors or predictors (distance from WRPC, orientation from WRPC, seasonality, atmospheric temperature, relative humidity and wind speed) to pollutant concentration in communities around WRPC. The sub-divisions within categorical variables (such as orientation from WRPC and seasonality) were assigned nominal values to allow for interpretation of regression output. The correlation of the variables for CO concentration in Table 3 reveals a statistically significant relationship between CO and (seasonality, atmospheric temperature and relative humidity). The prediction model was statistically significant, F (6, 928) = 2.181, $p \leq 0.05$ and accounted for approximately 1.4% of the variance in CO concentration ($R^2 = 0.014$). Increasing CO concentration was primarily predicted by decreasing relative humidity readings, increasing atmospheric temperatures and seasonality. Beta values of the statistically significant correlated predictors reveal that relative humidity (-0.085) provided the highest contribution in determining concentration values of CO. This was followed by atmospheric temperature (0.033) and seasonality (-0.019). With some correlations between the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low.

Table 3. Multiple Standard Regression Results for CO Concentration

Model	ß	Standard Error	Beta	Pearson's Correlation (r)	sr^2 (Squared part correlation)	Structure Coefficient
Constant	1.845	3.575				
Distance from WRPC	0.00007	0.000	0.006	-0.006	0.000036	-0.050
Orientation from WRPC	0.070	0.352	0.008	0.040	0.000036	0.339
Seasonality*	-0.193	0.398	-0.019	-0.071*	0.00026	-0.602
Atmospheric Temperature*	0.065	0.083	0.033	0.087*	0.00068	0.737
Relative Humidity*	-0.035	0.019	-0.085	-0.108*	0.0036	-0.915
Wind Speed	-0.216	0.198	-0.037	-0.007	0.0013	-0.059

Note: Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R); R = 0.118, R^2 = 0.014, Adjusted R^2 = 0.008, $*p \leq 0.05$

A review of the structure coefficients suggests that the significant predictors (temperature and relative humidity) were strong indicators of CO concentration, while seasonality, whose correlation is still relatively substantial, was a moderate indicator of CO concentration. The significance of seasonality, as well as the relationship between temperature/relative humidity and CO concentrations, conforms to findings by Kozlov and Haukioja (1997) which observed higher concentration of pollutants during warmer days and lower concentrations of pollutants in cooler days. This however negates findings by Odat (2009), which indicated an inverse relationship between pollutants and temperature, which was explained to be the result of rapid vertical mixing and replacement of warmer air (warmed by household and municipal heating appliances) with cooler air. Such vertical mixing was likely responsible for the dispersal of pollutants to higher altitudes.

The correlation of the variables for VOC concentration in Table 4 reveals statistically significant correlations between VOC and (distance, orientation, seasonality, atmospheric temperature and relative humidity). The prediction model was statistically significant, F (6, 928) = 42.314, $p \leq 0.05$ and accounted for approximately 21.5% of the variance in VOC concentration ($R^2 = 0.215$). The increase in VOC concentration was primarily predicted by decreasing distance from WRPC, decreasing relative humidity readings, decreasing atmospheric temperatures, orientation and seasonality. Beta values of the statistically significant correlated predictors reveal that distance (-0.403) provided the highest contribution in determining concentration values of VOC. This was followed by relative humidity (-0.230), atmospheric temperature (-0.053), orientation (-0.027) and seasonality (-0.022). With correlations between some of the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low, except for distance.

Assessment of the structure coefficients suggests that distance from WRPC provided the strongest indicator of VOC concentration, while relative humidity was a moderate indicator.

Significantly higher concentrations of VOC at sampling points closer to WRPC validate findings by Ragothaman and Anderson (2017), who have identified the petrochemical industry, vehicle exhaust and liquefied petroleum gas usage as some of the most significant contributors to VOC concentrations in Wuhan, China.

Table 4. Multiple Standard Regression Results for VOC Concentration

Model	Raw Regression Coefficient (*ß*)	Standard Error	Standardized Regression Coefficient (Beta)	Pearson's Correlation (r)	Squared part correlation (sr^2)	Structure Coefficient
Constant	9.576	1.112				
Distance from WRPC*	0.000	0.000	-0.403	-0.416*	0.144	-0.898
Orientation from WRPC*	-0.089	0.109	-0.027	0.144*	0.0006	0.311
Seasonality*	-0.078	0.124	-0.022	-0.121*	0.0003	-0.261
Atmospheric Temperature*	-0.036	0.026	-0.053	0.087*	0.002	0.187
Relative Humidity*	-0.033	0.006	-0.230	-0.229*	0.026	-0.495
Wind Speed	-0.062	0.061	-0.031	-0.010	0.0008	-0.022

Note: Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R); $R = 0.463$, $R^2 = 0.014$, Adjusted $R^2 = 0.215$, $*p \leq 0.05$

Correlation analysis between H_2S and predictor variables (as listed in columns 2-7) in Table 5 reveals that there was no significant correlation between H_2S and the same predictor variables. The prediction model was statistically non-significant, $F(6, 928) = 0.658$, $p > 0.05$.

Table 5. Correlations of the Variables in the Analysis of H_2S Concentration

Variables	2	3	4	5	6	7
H_2S Concentration	-.007	.007	.044	-.012	.000	.033
Distance from WRPC	-	-.306*	.000	-.021	.085*	.070*
Orientation from WRPC		-	.000	.349*	-.294*	.056*
Seasonality			-	-.371*	.536*	-.166*
Atmospheric Temperature				-	-.601*	.175*
Relative Humidity					-	-.242*
Wind Speed						-

* = Correlation is significant at the 0.05 level

Correlation of the variables for SO_2 concentration, in Table 6 reveals statistically significant correlations between SO_2 and orientation and between SO_2 and seasonality. The prediction model was statistically significant, $F(6, 928) = 3.398$, $p \leq 0.05$ and accounted for approximately 2.2% of the variance in SO_2 concentration ($R^2 = 0.022$). SO_2 concentration was primarily predicted by orientation and seasonality. Beta values of the statistically significant correlated predictors reveal that seasonality (0.13) provided the highest contribution in determining concentration values of

SO_2. Seasonality also served as a determining factor (0.02) in predicting SO_2 concentration. With correlations between the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low.
Inspection of the structure coefficients suggests that both orientation and seasonality were moderate indicators of SO_2 concentration. The fact that SO_2 had just two moderate predictors indicates that the sources of SO_2 were more widespread compared to other pollutants. The results of the study which indicated no strong predictor of SO_2 concentration, resonates with the findings by De Santis *et al*, (2004), whose study revealed similarity in average concentrations of SO_2 among sampling points. This was explained to have resulted from the point sources of SO_2, being more widespread in the area investigated.

Table 6. Multiple Standard Regression Results for SO_2 Concentration

Model	Raw Regression Coefficient *(ß)*	Standard Error	Standardized Regression Coefficient (Beta)	Pearson's Correlation (r)	Squared part correlation (sr^2)	Structure Coefficient
Constant	-.069	.036				
Distance from WRPC	-0.0000004314	.000	-.039	-.043	0.0014	-0.292
Orientation from WRPC*	.002	.004	.020	.064*	0.0003	0.435
Seasonality*	.013	.004	.130	.091*	0.0114	0.620
Atmospheric Temperature	.002	.001	.082	.051	0.0040	0.347
Relative Humidity	0.000002353	.000	.001	-.002	0.0000	0.014
Wind Speed	.003	0.198	-0.037	.046	0.0029	0.313

$R = 0.147$, $R^2 = 0.022$, Adjusted $R^2 = 0.015$, $*p \leq 0.05$
Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R)

The concentration of NO_2 is shown to correlate significantly with all the predictors in Table 7. The prediction model was statistically significant, F (6, 928) = 215.199, $p \leq 0.05$ and accounted for approximately 58.2% of the variance in NO_2 concentration ($R^2 = 0.582$). Increasing NO_2 concentration was primarily predicted by decreasing distance from WRPC, change in orientation from WRPC, change in season, increasing atmospheric temperature, decreasing in relative humidity and decreasing wind speed. Beta values of the statistically significant correlated predictors reveal that distance from WRPC (-0.748) provided the highest contribution in determining concentration values of NO_2. This was followed by changing seasons (-0.158), atmospheric temperature (0.085), wind speed (-0.076), relative humidity (0.044) and lastly, orientation (-0.036). With correlations between the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low, except for distance, which was relatively high (0.498).

Inspection of the structure coefficients suggests that only distance from WRPC was a strong indicator of NO_2 concentration. The other significant predictors were weak indicators of NO_2 concentration. This implied that there were more significant concentrations of NO_2 at sampling points closer to the refinery. This aligns with findings by Igile *et al*, (2015), indicating that NO_2 concentrations were significantly higher at sampling points closer to WRPC. Higher concentrations of NO_2 close to WRPC could also be the result of added input by secondary sources mainly vehicular traffic, which were more congested at road sections linked to the entrance of the refinery. Traffic congestions are a daily occurrence at the popular Ekpan route leading to the refinery, because of the line-up of heavy-duty trucks waiting to lift and dispatch petroleum products. De Satis *et al* (2004) and Ukpebor (2000) have also reported higher levels of NO_2 concentrations along transportation routes or road side locations.

Table 7. Multiple Standard Regression Results for NO_2 Concentration

Model	Raw Regression Coefficient *(ß)*	Standard Error	Standardized Regression Coefficient (Beta)	Pearson's Correlation (r)	Squared part correlation (sr^2)	Structure Coefficient
Constant	.550	.097				
Distance from WRPC	-0.00003425	.000	-.748	-.740*	0.498	-0.97
Orientation from WRPC	-.014	.010	-.036	.206*	0.001	0.27
Seasonality*	-.066	.011	-.158	-.154*	0.017	-0.20
Atmospheric Temperature*	.007	.002	.085	.107*	0.004	0.14
Relative Humidity*	.001	.001	.044	-.126*	0.001	-0.17
Wind Speed	-.018	.005	-.076	-.100*	0.005	-0.13

$R = 0.763$, $R^2 = 0.582$, Adjusted $R^2 = 0.579$, $*p \leq 0.05$
Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R)

The correlation of the variables for $PM_{2.5}$ concentration in Table 8 reveals statistically significant correlations between $PM_{2.5}$ and some of the predictors (distance from WRPC, orientation, seasonality and relative humidity). The prediction model was statistically significant, F (6, 928) = 30.863, $p \leq 0.05$ and accounted for approximately 16.6% of the variance in $PM_{2.5}$ concentration ($R^2 = 0.166$). Increasing $PM_{2.5}$ concentration was primarily predicted by decreasing distance from WRPC, change in orientation from WRPC, change in season and decreasing in relative humidity. Beta values of the statistically significant correlated predictors reveal that relative humidity (-0.261) provided the highest contribution in determining concentration values of $PM_{2.5}$. This was followed by changing seasons (-0.229), distance from WRPC (-0.217), and lastly, orientation (0.082). With correlations between the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low.

The structure coefficients suggests relative humidity, seasonality and distance from WRPC, as moderate indicators of $PM_{2.5}$ concentration, while orientation is a weak indicator of $PM_{2.5}$ concentration. Distance from WRPC as a moderate predictor of particulate matter attest to the fact that its concentration is usually clustered around its sources as confirmed by Ukpebor *et al*, (2006). The particulate matter was significantly less during the wet season, due to frequent precipitation which dissolves particulates and cleans up the atmosphere. The relative humidity is higher during the wet season in the tropics and is therefore, a significant predictor of particulate matter concentration, as shown from findings by Radaidey (2017).

Table 8. Multiple Standard Regression Results for $PM_{2.5}$ Concentration

Model	Raw Regression Coefficient *(ß)*	Standard Error	Standardized Regression Coefficient (Beta)	Pearson's Correlation (r)	Squared part correlation (sr^2)	Structure Coefficient
Constant	273.157	24.765				
Distance from WRPC*	-.002	.000	-.182	-.217*	0.030	-0.53
Orientation from WRPC*	1.856	2.436	.026	.082*	0.0005	0.20
Seasonality*	-12.410	2.760	-.164	-.229*	0.018	-0.56
Atmospheric Temperature	-3.883	.573	-.265	-.007	0.041	-0.02
Relative Humidity*	-1.019	.134	-.324	-.261*	0.052	-0.64
Wind Speed	-2.606	1.369	-.059	-.011	0.003	-0.03

$R = 0.408$, $R^2 = 0.166$, Adjusted $R^2 = 0.161$, $*p \leq 0.05$
Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R)

The correlation of the variables for PM_{10} concentration in Table 9 reveals statistically significant correlations between PM_{10} and all the predictors. The prediction model was statistically significant, F (6, 928) = 124.894, $p \leq 0.05$ and accounted for approximately 44.7% of the variance in PM_{10} concentration ($R^2 = 0.447$). Increasing PM_{10} concentration was predicted by decreasing distance from WRPC, change in orientation from WRPC, change in season, increasing atmospheric temperature, decreasing relative humidity and increasing wind speed. Beta values of the statistically significant correlated predictors reveal that relative humidity (-0.742) provided the highest contribution in determining concentration values of PM_{10}. This was followed by atmospheric temperature (-0.314), distance from WRPC (-0.128), changing seasons (-0.109), wind speed (-0.064), and lastly, orientation (-0.057). With correlations between the predictors, the unique variances explained by each of the predictors, indexed by the squared part correlations were quite low, except for relative humidity, which was relatively higher (0.271). An assessment of the structure coefficients suggests that only relative humidity was a strong indicator of PM_{10} concentration, while seasonality was a moderate indicator. The other significant predictors were weak indicators of PM_{10} concentration.

The regression analyses of selected pollutants analyzed in the study show that the concentration of pollutants was influenced by the combination of the factors (distance from WRPC, orientation from WRPC, seasonality, atmospheric temperature, relative humidity and wind speed), which served as the predictors in the model. The results show that seasonality was the most common predictor of pollutant concentration. This was followed respectively by orientation, relative humidity, distance from WRPC and atmospheric temperature. Wind speed was the least in the predictability of air pollutant concentration, as it could only predict concentrations for NO_2 and PM_{10}. However, based on the structure coefficients in the regression analyses for the various pollutants, relative humidity, distance from WRPC and changing seasons were relatively stronger indicators of pollutant concentration in the study.

Table 9. Multiple Standard Regression Results for PM_{10} Concentration

Model	Raw Regression Coefficient *(ß)*	Standard Error	Standardized Regression Coefficient (Beta)	Pearson's Correlation (r)	Squared part correlation (sr^2)	Structure Coefficient
Constant	1653.125	83.780				
Distance from WRPC*	-.004	.001	-.128	-.172*	0.015	-0.257
Orientation from WRPC*	-16.637	8.241	-.057	.087*	0.002	0.130
Seasonality*	-34.247	9.339	-.109	-.379*	0.008	-0.567
Atmospheric Temperature*	-19.124	1.939	-.314	.144*	0.058	0.216
Relative Humidity*	-9.701	.454	-.742	-.590*	0.271	-0.883
Wind Speed*	-11.784	4.632	-.064	.066*	0.004	0.099

$R = 0.668$, $R^2 = 0.447$, Adjusted $R^2 = 0.443$, $*p \leq 0.05$
Structure Coefficient = Pearson's Correlation (r) ÷ Multiple Correlation (R)
Source: Author's Fieldwork, 2018

The results of the study indicate that all the predictors used for the regression analyses were capable of influencing pollution around a point source. Distance as a strong predictor of pollutant concentration is supported by the findings of De Santis *et al*, (2004); Abdulkareem, (2005) and Igile *et al*, (2015), which suggest that pollutant concentrations are inversely related to distance from its point source. However, Fakinle *et al*, (2021) opines that Benzene is not retained for long around its point of release, as it has the potential of being transported far from its point of release. Such pollutant would thus have an inverse relationship with distance. Seasonality is another strong predictor of pollutant concentration, which aligns with findings by Fagbeja (2008); Muhaimin *et al*, (2015) and Igile *et al*, (2015), which reveal that the concentration of pollutants is significantly higher during dry seasons, compared to wet seasons in the tropics. Apart from wind speed, other climatic variables (i.e. temperature and relative humidity), which were strong predictors of air pollution, substantiate studies by Kozlov and Haukioja, (1997); Highwood and Kinnersley, (2006); Weng and Yang, (2006); Thambiran and Diab (2010); Liu and Shen (2014), which indicate that climatic parameters such as atmospheric temperature, relative humidity and wind direction and speed significantly influence the concentration of pollutants and vice versa. Wind speed was a weak predictor of pollutant concentration in the study area, due to notably stable conditions observed during intermittent sampling periods. Stable atmospheric conditions are likely to have less impact on the rate of dispersal of air pollutants (Abdel-rahman, 2008). Orientation (downwind or upwind from a point source) as a predictor of pollutant concentration agrees with the observations of Abdelrasoul *et al*, (2010) and Fagbeja (2008) that pollutant concentration is significantly higher at the downwind side of a point source of pollutant. This implies that the people and environment on the downwind side of a point-source are likely to be more impacted by emissions.

The observation that a high concentration of pollutants around a point source is likely to have much impact on the environment and health of people living in the host communities around WRPC is affirmed by the result of studies by Balogun (2020). The study involved the use of Land Surface Temperature (LST) maps which revealed that the temperatures of areas around WRPC and along transportation routes and were warmer than surrounding areas, resulting in the occurrence of a heat island around WRPC and its vicinities. Other studies have further revealed that pollution emission from WRPC and associated secondary sources impact the environment around the WRPC, and is evidenced by acid rains, which are responsible for the quick rusting of roof tops (Amuho *et al*, 2016) and deterioration of soils and vegetation (Ene and Agbazue, 2011; Basorun and Olamiju, 2013). These findings buttress the fact that the activities within and around WRPC are capable of impacting negatively on the local environment.

4. Conclusion and Recommendation

The results of the study indicate that climatic parameters (temperature, relative humidity and wind), distance, seasonality and orientation are important factors, which influence the concentration of air pollutants around a point source. For the fact that the distance from the point source of pollutants and orientation (upwind or downwind from the point source) are significant predictors of pollutant concentration, special attention should be given to the pattern of arrangement of residential land use in relation to industrial land use. The results which indicate that pollutant concentration is significantly higher in areas downwind, and of close proximity to pollutant sources, implies that zoning arrangements should position residential layouts upwind, and at maximum separation distances from industrial layouts. The use of buffer zones around industrial layouts can serve better in protecting sensitive land uses from the harmful effects of pollutants.

The study also suggests that more effort be made by the Nigerian Government and private sector towards innovating and developing newer eco-friendly technologies, such as solar-based, hydro-powered and wind-powered technologies, to reduce reliance on petroleum products. Improving hydroelectric generation and distribution (as an alternative to fossil fuel use) can also help to reduce emissions from the refining of petroleum products. The study is limited by the use of intermittent sampling technique, as well as the monitoring of a limited number of pollutants and sampling points. To better understand the dynamics of air pollutant concentration around point sources, the study recommends continuous air monitoring around point sources, the use of satellite data for pollution monitoring in inaccessible areas and the use of complex model analysis (incorporating added factors such as emission rates, the height of point source, time, terrain, vegetation, etc.) to predict the nature of pollutant dispersal around point sources. This would provide urban planning authorities the necessary guide for zoning and arrangement of industries, in relation to other sensitive land uses. It would also sustain the ecosystem around the areas that are exposed to the negative effects of air pollutants.

Data Availability Statement

Raw data on air quality were generated directly from field measurements and can be made available by the corresponding author upon request. The source of data for figures and tables are indicated in the paper.

References

Abdel-rahman, A. A. (2008). On the Atmospheric Dispersion and Gaussian Plume Model. In N. E. Mastorakis, M., Poulos, V., Mladenov, Z., Bojkovic, D., Simian, S., Kartalopoulos, A., Varonides, C., Udriste (Eds.), *Proceedings at the 2nd International Conference on*

Waste Management, Water Pollution, Air Pollution, Indoor Climate, (pp. 31-39). Corfu, Greece: WSEAS press. Retrieved from https://repositorium.sdum.uminho.pt/bitstream/1822/18821/1/wwai30a.pdf

Abdelrasoul, A. M. W., Al-hadad, A. and Khan, A. R. (2010). Oil Refineries Emissions Impact on Urban Localities Using AERMOD. *American Journal of Environmental Sciences, 6* (6), 505-515

Abdulkareem, A. S. (2005). Urban Air pollution Evaluation by Computer Simulation: A Case Study Of Petroleum Refining Company Nigeria. *Leonardo Journal of Sciences, 6,* 17-28.

Akpan, A. O. and Udo, H. I. (2016). Challenges of Air Pollution on Human Health in Nigeria. *Nigerian Journal of Health Promotion, 9.*

Amuho, U. E., Amoo, I. A., Ajayi, O. O., Aiyesanmi, A. F. and Akinnifesi, T. A. (2016). Outdoor Air Quality and Acid Rains within Warri Refinery and Its Environs. *British Journal of Applied Science and Technology, 15*(1), 1-6. DOI: 10.9734/BJAST/2016/23688

Ana, G. R. (2011). Air Pollution in the Niger Delta: Scope, Challenges and Remedies. In M. Khallaf (Ed.), *The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources,* (pp. 181 – 198). Croatia: In Tech.

Australian Standard 2922 (1987). *Ambient Air – Guide for the Siting of Sampling Units*. Standards Association of Australia, Home bush NSW, Australia.

Balogun, V. S. (2020). *Assessment of Air Quality and the Socio-Economic Impacts of the Warri Refining and Petrochemical Company (WRPC), Nigeria.* (Doctoral dissertation), University of Benin, Benin City, Nigeria.

Balogun, V. S. and Orimoogunje, O. O. I. (2015). The Correlation between Land Use Activities and Air Pollution in a Part of Southern Nigeria. *Nigerian Geographical Journal. 10* (2), 92-109.

Basorun, J. O. and Olamiju, I. O. (2013). Environmental Pollution and Refinery Operations in an Oil Producing Region of Nigeria: A Focus on Warri Petrochemical Company. *Journal of Environmental Science, Toxicology and Food Technology, 2* (6),18-23.

De Santis, F., Fino, S., Menichelli, Vazzana, C. and Allegrini, I. (2004). Monitoring the Air Quality around an Oil Refinery through the use of Diffusive Sampling. *Analytical and Bioanalytical Chemistry, 378*, 782–788. DOI 10.1007/s00216-003-2389-9

DPR (2002). *Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN),* Department of Petroleum Resources, Lagos, Nigeria.

Emoyan, O. O., Akpoborie, I. A. and Akporhonor, E. E. (2008). The Oil and Gas Industry and the Niger Delta: Implications for the Environment. *Journal of Applied Sciences and Environmental Management, 12* (3), 29 – 37.

Eneh, O. C. and Agbazue, V. C. (2011). Protection of Nigeria's Environment: A Critical Policy Review. *Journal of Environmental Science and Technology, 4* (5), 490-497.

Environment Agency, United Kingdom (2011). *Technical Guidance Note: M8 Monitoring Ambient Air, Version 2.* Retrieved from the UK Environment Agency website: http://www.mcerts.net

Environmental Protection Agency, EPA Victoria (2012). *Recommended Separation Distances for Industrial Residual Air Emissions.* Publication No. 1506, USA.

EPA South Australia, (2000). *Consultation Draft: Guidelines for Separation Distances*. Government of South Australia.

EPA Western Australia (2005). *Guidance for the Assessment of Environmental Factors: Separation Distances between Industrial and Sensitive Land Uses.* Government of Western Australia.

Fagbeja, M. (2008). *Applying Remote Sensing and GIS Techniques to Air quality and Carbon Management – A Case Study of Gas Flaring in the Niger Delta.* A Ph. D. Thesis, Faculty of Environment and Technology, University of West of England, Bristol.

Fakinle,B. S., Olalekan, A. P., Odekanle, E. L., Bakut, C. B., Ogundokun, R. O., Sonibare, J. A. and Aremu, C. O. (2021). Assessment of the Contribution of Hazardous Air Pollutants from Nigeria's Petroleum Refineries to Ambient Air Quality - Part 1. *Cogent Engineering, 8* (1), https://doi.org/10.1080/23311916.2020.1870792

Hess, D. (2014). *McKnight's Physical Geography: A Landscape Appreciation* (11th edition). USA: Pearson Educational Inc.

Highwood, E. J. and Kinnersley, R. P. (2006). When Smoke gets in our Eyes: The Multiple Impacts of Atmospheric Black Carbon on Climate, Air Quality and Health. *Environment International, 32*, 560-566.

Igile, G. O., Uboh, F. E., Luke, U. O., Ufot, S. U., Robert, A. E. and Ebong, P. E. (2015). Environmental Quality in Communities around Warri Refining and Petrochemical Company (WRPC), Niger Delta Region, Nigeria. *Journal of Scientific Research and Reports, 7*(6), 400-412. DOI: 10.9734/JSRR/2015/13627

Kibble, A. and Harrison, R. (2005). Point Sources of Air Pollution, *Occupational medicine, 55,* 425 – 431.

Kozlov, M. and Haukioja, E. (1997). Microclimate Changes along a Strong Pollution Gradient in Northern Boreal Forest Zone. *Transactions on Ecology and the Environment, 16.* www.witpress.com

Kozlov, M. and Haukioja, E. (1997). Microclimate Changes along a Strong Pollution Gradient in Northern Boreal Forest Zone. *Transactions on Ecology and the Environment, 16.* www.witpress.com

Liu, H. L. and Shen, Y. S. (2014). The Impact of Green Space Changes on Air Pollution and Microclimates: A Case Study of the Taipei Metropolitan Area. *Sustainability 6*,8827-8855; https://doi:10.3390/su6128827

Manisalidis, I., Stavropoulou, E., Stavropoulos, A. and Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. *Frontiers in Public Health 8* (14). https://doi: 10.3389/fpubh.2020.00014

Mode, A. W., Onokwai, N. G., Onwuka, O. S., Ekwe, A. C. and Oha, I. A. (2010). Integrating Geographic Information System (GIS) and Hydrochemistry for Heavy Metal Pollution Studies: The Case of Ubeji and Omadino Areas of Delta State, Southern Nigeria. *Journal of Geology and Mining Research, 2* (7), 183-196.

Muhaimin, M., Sugiharto, E. and Suratman, A. (2015). Air Pollution Modeling For Carbon Monoxide and Total Particle from Coal-Fired Power Plant Activity. *Proceedings of the 1st International Seminar on Chemical Education 2015,* Islamic University of Indonesia: https://www.researchgate.net/publication/295626394

Nwachukwu, A. N., Chukwuocha, E. O. and Igbudu O. (2012). A survey on the effects of air pollution on diseases of the people of Rivers State, Nigeria. *African Journal of Environmental Science and Technology, 6* (10),371-379 . *(http://www.academicjournals.org/AJEST)*

Odat, S. A. (2009). Diurnal and Seasonal Variation of Air Pollution at Al-Hashimeya Town, Jordan. *Jordan Journal of Earth and Environmental Sciences, 2* (1), 1 – 6.

Odjugo, P. A. O. (2004). Effects of Gas Flaring on Atmospheric Quality: The Case of Niger-Delta Region, Nigeria. *International Journal of Ecology and Environmental Dynamics, 2,* 12 – 33.

Ojeh, V. N. (2012). Sustainable Development and Gas Flaring Activities: A Case Study of Ebedei Area of Ukwuani LGA, Delta State, Nigeria. *Resources and Environment, 2* (4), 169 – 174.

Oladimeji, T. E.1, Sonibare J. A., Odunfa, K. M. and Oresegun, O. R. (2015). Environmental Impact Analysis of the Emission from Petroleum Refineries in Nigeria. *Canadian Center of Science and Education, Energy and Environment Research, (5),* 1.

Onakpohor, A., Fakinle, B. S., Sonibare, J. A., Oke, M. A. and Akeredolu, F. A. (2020). Investigation of Air Emissions from Artisanal Petroleum Refineries in the Niger-Delta Nigeria. *Heliyon 6* (11). https://doi.org/10.1016/j.heliyon.2020.e05608.

Radaidey, J. A. (2017). Effect of Meteorological Variables on Air Pollutants Variation in Arid Climates. *Journal of Environmental and Analytical Toxicology, 7* (4). doi: 10.4172/2161-0525.1000478

Ragothaman, A. and Anderson, W. A. (2017). Air Quality Impacts of Petroleum Refining and Petrochemical Industries. *Environments, 4* (66), 1-16. doi:10.3390/environments4030066

Rim-Rukeh, A. (2009). *Environmental Science: An Introduction.* Ibadan, Nigeria: Kraft Books Limited.

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

Thambiran, T. and Diab, R. D. (2010). A Review of Scientific Linkages and Interactions between Climate Change and Air Quality, with Implications for Air Quality Management in South Africa. *South African Journal of Science, 106* (3/4). DOI:10.4102/sajs.v106i3/4.56.

Ukpebor, E. E. and Ahonkhai, S. I. (2000). Spatial and Temporal Variation of Nitrogen Dioxide Concentration in Benin City using Passive Samplers. *Nigerian Journal of Applied Science, 18,* 72-77.

Ukpebor, E. E., Ukpebor, J. E., Oviasogie, P. O., Odiase, J. I. and Egbeme, M. A., (2006). Field Comparison of Total Suspended Particulates (TSP) Samplers to Assess Spatial Variation. *International Journal of Environmental Studies, 63* (5), 567 – 577.

Weng, Q. and Yang, S. (2006). Urban Air Pollution Patterns, Land Use, and Thermal Landscape: An Examination of the Linkage Using GIS. *Environmental Monitoring and Assessment Journal, (2006)* 117, 463 – 489.