JES Vol. 30, No. 1, 10-25 (2023) 10
Journal of Environmental studies [JES] https://jesj.journals.ekb.eg/
An International Journal **doi:** *10.21608/JESJ.2023.205673.1045*

Seasonal Variations in the Concentration of some Atmospheric Pollutants along a major Highway in Southern Nigeria

Glory Richard[1,2], Sylvester Chibueze Izah[3], Ebiye Wisdom Sawyer[2] and Matthew Chidozie Ogwu[4]

[1]School of Community Health and Policy, Morgan State University, 4530 Portage Avenue Campus near, East Cold Spring Lane, Baltimore, MD 21239, USA

[2]Department of Community Medicine, Faculty of Clinical Sciences, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

[2]Department of Microbiology, Faculty of Science, Bayelsa Medical University, Yenagoa, Bayelsa State, Nigeria

[3]Goodnight Family Department of Sustainable Development, Appalachian State University, 212 Living Learning Center, 305 Bodenheimer Drive, Boone, NC 28608, USA

Citation: *Richard G., Izah S. C., Sawyer E. W. Ogwu M. C (2023). Seasonal Variations in the Concentration of some Atmospheric Pollutants along a major Highway in Southern Nigeria, Vol. 30(1): 10-25.*

Article Information
Received 12 April 2023,
Revised 14 April 2023,
Accepted 15 April 2023.
Published online
30 June 2023

Abstract: Human activities in Southern Nigeria constitute the major driver for atmospheric pollutants. In this study, 108 air samples were collected during the dry (November - March) and wet (May - September) seasons in Nigeria, and the concentrations of some particulates ($PM_{2.5}$ (particulate matter 2.5), PM_{10} (particulate matter 10), and TSP (total suspended particulate) were measured, whereas over the same period, some known gaseous pollutants (CO (carbon monoxide), NH_3 (ammonia), H_2S (hydrogen sulphide), VOC (volatile organic compound), NO_2 (nitrogen dioxide), and SO_2 (sulphur dioxide)) were monitored. The results were in the range 0.00 – 0.30 ppm, 0.00 – 0.20 ppm, 0.00 – 0.70 ppm, 0.00 – 0.30 ppm, 0.00 – 0.20 ppm, 4.20–19.60 ppm, 16.30–51.40 µg/m^3, 43.20–266.00 µg/m^3 and 56.30 – 434.60 µg/m^3 for NH_3, H_2S, CO, NO_2, SO_2, VOC, $PM_{2.5}$, PM_{10} and TSP, respectively. Statistically significant variations (at $p<0.05$) were found in the concentrations of most air pollutants during the dry and wet seasons except for NH_3, H_2S, and CO. The concentrations of some gaseous pollutants (CO, NO_2, SO_2) and particulate TSP were within the limits specified by the Nigerian Ambient Air Quality Standard. However, $PM_{2.5}$ and PM_{10} exceeded the World Health Organization limits of 25µg/m^3 and 50µg/m^3 for a 24-hourly average. These significant variations may be connected to the seasonal influence of thermodynamic actors such as temperature and wind as well as anthropogenic activities.

Keywords: Air pollutants, Aerosol, Environmental Health, Public health.

Introduction

Globally, the rate and severity of human-driven environmental degradation are on the increase. As such, pollutants constitute a multidimensional macro-micro scale environmental sustainability challenge. Moreover, population growth in most regions of the world has led to increased industrialization with a concomitant increase in pollution and environmental degradation. Together, these are exacerbating the cataclysmic condition known as climate change through the emission of greenhouse gases. carbon oxides) and heavy metals (Lei *et al.*, 2011) It is known that human activities impact ambient air quality through the release of noxious gases (such as the oxides of sulphur, nitrogen and carbon, volatile organic compounds, ammonia, etc) and particulates

* Corresponding author E-mail: ogwumc@appstate.edu

(fine i.e., with an aerodynamic diameter of ≤ 2.5µm and coarse i.e., with an aerodynamic diameter of 10µm). These are some of the commonly studied atmospheric pollutants with human and environmental impacts because of their abundance and reactive nature such as photochemical processing. (Uzoekwe & Ajayi, 2018; Uzoekwe *et al*., 2021; Jariwala & Kapadia 2021). Previous studies indicate that human activities impact the concentration of pollutant gases and particulates in oil palm processing facilities (Ohimain *et al*., 2013; Ohimain & Izah, 2013**)**, waste dumpsites **(**Ezekwe & Arokoyu, 2017; Weli & Adekunle, 2014; Ezekwe *et al*., 2016; Richard *et al*., $2019_{a\text{-}c}$; Richard *et al*., 2021_{a}) cassava processing facility (Richard, 2019, 2021), outdoor combustion of biomass (Richard *et al*., $2021_{a,\ b}$) and urban centres (Efe, 2008). Studies have indicated that emissions of fossil fuel, emissions from fired power plants, smelters, industrial boilers, petroleum refineries, manufacturing facilities, biomass combustion, cooking, and gas flaring are some of the human activities leading to the presence of aerosols and gases (Pagadala *et al*., 2018; Richard *et al*., $2021_{a,\ b}$). According to Acharya *et al*. (2020); Ibe *et al*. 2020), particulate matter, formaldehyde, VOC, NO_2, SO_2, CO_2, and CO, are some primary chemicals that alter the ambient air quality of an area.

Medically, these air pollutants could lead to respiratory issues (emphysema, pneumonia, bronchitis, asthma, etc.) in humans as well as, cardiovascular, and vascular dysfunction, increased thrombosis, autoimmune diseases, and irritation of the sensory organs such as eyes, nose, skin, and throat (Umesi *et al*., 2009; Ohimain *et al*., 2013; Seiyaboh & Izah, 2019; Rezaeinia & Ebrahimi, 2020; Jalili *et al*., 2020). Biodiversity decline, loss of artefacts, and low agricultural productivity are some of the environmental and socioeconomic effects of these pollutants (Osawaru *et al*., $2013_{a;\ b}$; Ogwu *et al*., 2014; Osawaru & Ogwu, 2014; Vwioko *et al*., 2018; Ogwu, $2019a_{b,c}$; Ikhajiagbe *et al*., 2020; $2021_{a,b}$; 2022). Metrological indicators such as relative humidity, temperature, and wind speed may be used to convey information about the distribution of pollutant gases and also contribute to the dispersion of air pollutants (Seiyaboh & Izah, 2019).

Using multivariate analysis, this study focuses on seasonality in the distribution of air pollutants (gases and particulates) around markets along East-West Road [Lat. 5° 06 ꞌ N and Long. 6° 48ꞌ E – Lat. 5°11ꞌ N and Long. 6° 38 ꞌ E] in Southern Nigeria. While other studies have determined the concentration of air pollutants and the associated health risk index in the Niger Delta region of Nigeria none has adopted a multivariate approach to discussing their implications. Specifically, this study seeks to assess seasonal variations in the concentrations of major air pollutants and to determine the sources and implications of these air pollutants using PCA (Principal components analysis) and HCA (Hierarchical cluster analysis). The finding of this study may be useful to inhabitants of the area, environmentalists and environmental health experts, policymakers, and others interested in a sustainable environment.

Materials and methods

Study area

In the Niger Delta region of Nigeria, major markets are located mostly along highways. The region has several road streams viz: trunk A (Federal roads), trunk B (State roads), and trunk C (local roads). In many areas of Nigeria Federal and State roads are very busy (with high traffic) as compared to local roads. The East-West Road is one of the major roads linking the western to the eastern region. The road cut across several states, including Delta, Bayelsa, Rivers, etc. This study was carried out in Elele in Rivers States Road [Lat. 5° 06 ꞌ N and Long. 6° 48ꞌ E] and Zarama in the Bayelsa States [Lat. 5°11ꞌ N and Long. 6° 38 ꞌ E] along the East-west expressway. In markets that are transacted along the East-West road, several perishable edible products are sold. For instance, in Zarama market, which is situated along with East-West road in Yenagoa Local Government Area of Bayelsa State, several food crops are displayed on bare ground (e.g. yam, plantain, etc.), either exposed or slightly covered (*garri* – cassava product) (Richard & Aseibai, 2021). In the region, two predominant seasons - wet and dry are notable. The seasons have different meteorological characteristics such as temperature, solar radiation, WS (wind speed), RH (relative humidity), etc.

Sample collection

A total of 108 samples were collected in a windward direction within a 50 feet distance from each market i.e., Zarama market in Bayelsa State and Elele market in Rivers State, hence a total of 54 samples were collected from each market. The samples were collected bimonthly from November 2016 to September 2017). The wet season samples were collected in May, July, and September 2017, while the dry season sample was collected in November 2016, January, and March 2017).

Measurement of pollutant gases and meteorological indicators

The pollutant gases were measured with a portable multiprobe AEROQUAL meter (Aeroqual Limited Auckland-New Zealand-Series 300) as described by Richard *et al*. (2019b); Richard (2019). The pollutant gases head probe was attached to the AEROQUAL meter and switched on. The range of detection was between 0 -100 ppm for CO, NO_2, and NH_3, 0 – 10 ppm for SO_2 and H_2S, and 0 -25 ppm for VOC. The pollutant gases were measured by holding the sensor in the direction of the prevailing wind until the reading stabilizes. The temperature, RH and WS were measured with a portable meteorological indicator Kestrel (model: 4500 NV).

Statistical Analysis

Data analyses were carried out using Statistical Package for Social Sciences. Data were expressed as mean ± standard deviation. A two-way analysis of variance was carried out at p = 0.05. Waller Duncan statistics were used to discern the source of the observed differences among atmospheric pollutants and meteorological indicators. The interactions of the months and locations were also determined. HCA using squared Euclidean Distance and Ward Linkage was used to show the relationship between the variables, while PCA (Principal components analysis) was used to indicate the distribution and source of variables.

Results

Seasonal Variations in the Concentration of Some Atmospheric Pollutants

Results presented in Tables 1 – 3 show the summary of seasonality (wet and dry seasons) in the concentration of atmospheric pollutants and meteorological indicators in the study area. In Bayelsa State, the concentration was 0.06 ppm and 0.03 ppm in dry and wet seasons, being not significantly different (p=0.131) (Table 1). In Rivers State, the concentration was 0.03 ppm and 0.05 ppm in dry and wet seasons (with a non-significant *p-value* of 0.170) (Table 2). Overall, the concentration was 0.04 ppm and 0.04 ppm in dry and wet seasons, which was not significantly different with a *p*-value of 0.771) (Table 3). Dry and wet season concentrations in Bayelsa State were respectively 0.08ppm and 0.03ppm, which was not statistically significant with a *p*-value of 0.096) (Table 1), and 0.03ppm and 0.01 ppm, respectively for Rivers State and not significantly different (with a *p*-value of 0.357) (Table 2). Overall, the concentration was 0.05 ppm and 0.02 ppm in dry and wet seasons (with a *p*-value of 0.059) (Table 3). The mean values of NH_3 for each of the months ranged from 0.00–0.09 ppm (Figure 1A). The mean concentration of CO across the months ranged from 0.00–0.16 ppm and showed statistical deviation (at *p* = 0.037) across the various months for each of the locations (Figure 1B). The mean value of H_2S across the months ranged from 0.00 – 0.08ppm (Figure 1C) and is not statistically different (as *p*-value = 0.492). Based on seasonality, in the dry and wet seasons, the concentration was 0.05 ppm and 0.05ppm, respectively being not significantly different (p=1.000), for Bayelsa State (Table 1), 0.02 ppm and 0.05ppm (with a non-significant *p*-value of 1.882), for Rivers State (Table 2). Overall, the concentration was 0.04 ppm and 0.05 ppm in the dry and wet seasons, respectively at *p* = 0.059 (Table 3). The mean concentration of SO_2 ranged from 0.00 – 0.12 ppm (Figure 1D), being statistically different (p=0.002) across the months and locations. On seasonality, the mean concentration in the dry and wet seasons was 0.03ppm and 0.05 ppm, respectively being not statistically different (p=0.325) for Bayelsa State (Table 1), and 0.02ppm and 0.08ppm, which was statistically significant with a *p*-value of p=0.000 in Rivers State (Table 2). Overall, the concentration for the dry and wet seasons was 0.02 ppm and 0.06 ppm with a statistically significant *p*-value of 0.002. The values for Rivers State and overall concentration in the wet season were statistically higher. The mean concentration of VOCs ranged from 6.11 to 17.40 ppm (Figure 1E). Statistically, there were significant variations (with *p* = 0.000) across the mean values of the various months. Based on seasonality, dry and wet season concentrations were 14.37 ppm and 10.10 ppm and statistically significant (at *p* = 0.000) for Bayelsa State (Table 1), and 15.10 ppm and 6.37 ppm with a statistical difference at *p* =0.000 for Rivers State (Table 2). Overall, the concentration was 14.73 ppm and 8.23 ppm with a statistically significant *p*-value of 0.000) (Table 3). The level of NO_2 ranged from 0.00 – 0.04 ppm (Figure 1F), which was not statistically significant (with a *p*-value of -0.055) across the various months for each of the locations. Based on seasonality, the concentration in the dry and wet seasons was 0.00ppm and 0.02 ppm and statistically significant with a *p*-value of 0.009) for Bayelsa State (Table 1), and 0.00 ppm and 0.04 ppm, which was also statistically significant (with a *p*-value of 0.001) for River State (Table 2). Overall, the concentration in the dry and wet seasons was 0.00 ppm and 0.03 ppm, respectively which suggests a significantly different (with *p* = 0.000). In all cases, NO_2 was detected only in the dry season in both locations.

The mean values of $PM_{2.5}$, $PM_{10,}$ and TSP ranged from 19.69–45.21 µg/m^3, 54.21–179.09 µg/m^{3,} and 71.14–339.08 µg/m^3, respectively across the months and locations of study (Figure 2A, B and C). Statistically, there was significant variation (*p*=0.000) in the distribution of the particulates. Based on seasons, the

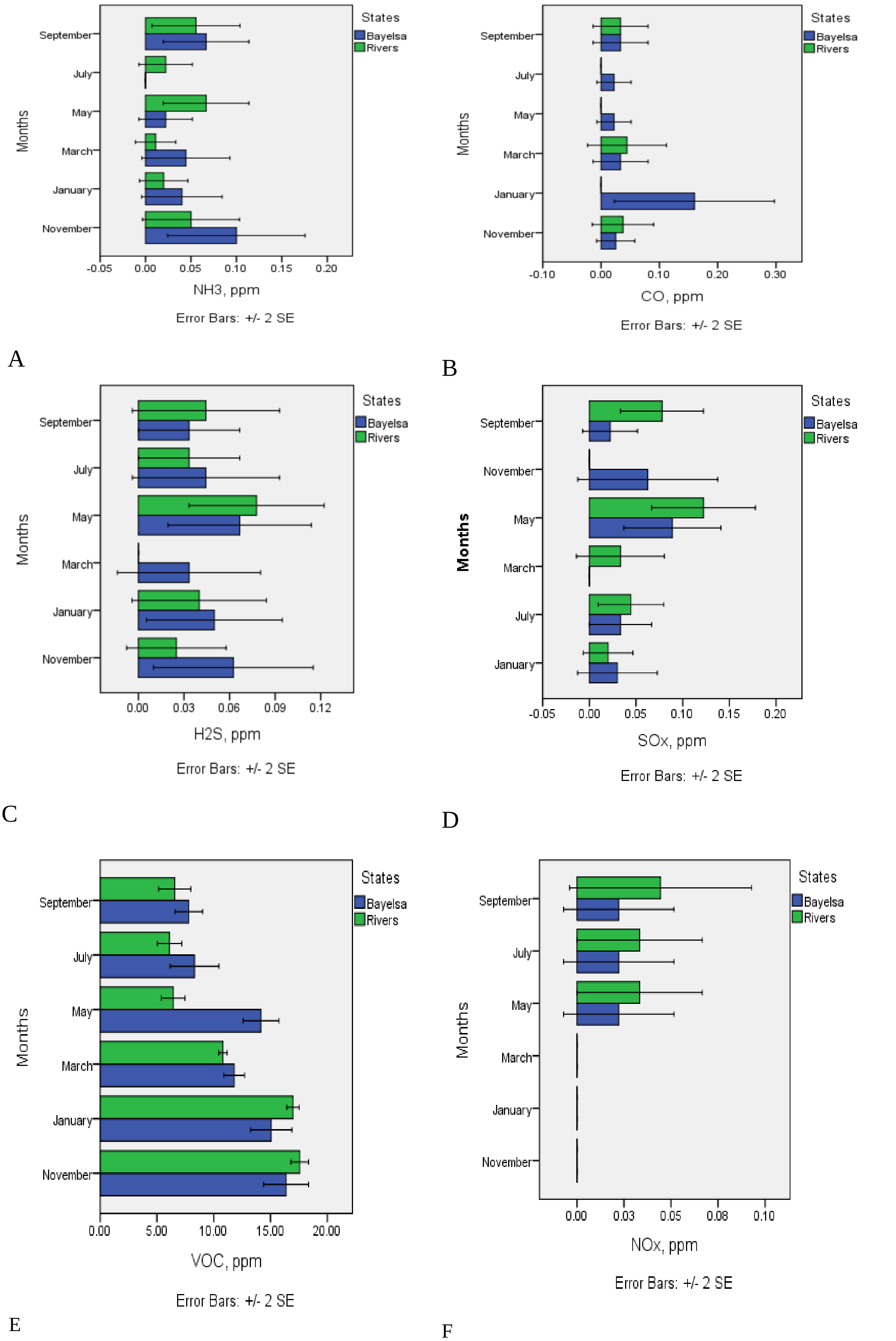


Figure 1: Seasonality in the concentration of pollutant gases in Zarama and Elele markets in Bayelsa and Rivers States, respectively along East-West road in Southern Nigeria.

Table 1: Seasonality in the atmospheric pollutant concentration in Zarama market along East-West road, Bayelsa State, Southern Nigeria

Parameters	N	Dry season				Wet season				t-value	*p-value*
		Min	Max	Mean	SE	Min	Max	Mean	SE		
NH_3	27	0.00	0.30	0.06	0.02	0.00	0.20	0.03	0.01	1.535	0.131
H_2S	27	0.00	0.20	0.05	0.01	0.00	0.20	0.05	0.01	1.000	1.000
CO	27	0.00	0.70	0.08	0.03	0.00	0.20	0.03	0.01	1.693	0.096
SO_2	27	0.00	0.30	0.03	0.01	0.00	0.20	0.05	0.01	-0.993	0.325
NO_2	27	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.01	-2.726	0.009
VOC	27	10.00	19.60	14.37	0.58	4.90	17.60	10.10	0.73	4.551	0.000
WS	27	0.50	1.70	0.97	0.06	0.20	1.30	0.63	0.06	4.259	0.000
Temp	27	30.00	32.90	31.43	0.18	27.00	31.10	28.80	0.32	7.205	0.000
RH	27	55.00	69.00	62.15	0.87	65.00	83.00	74.44	1.33	-7.748	0.000
$PM_{2.5}$	27	21.80	51.40	34.70	1.69	19.70	30.20	24.50	0.49	5.800	0.000
PM_{10}	27	76.30	266.00	138.23	10.37	43.20	103.40	60.11	3.50	7.139	0.000
TSP	27	91.20	434.60	235.61	19.87	61.50	152.10	82.75	4.85	7.475	0.000

Table 2: Seasonality in the atmospheric pollutant concentration in Elele market along East-West road, Rivers State, Southern Nigeria

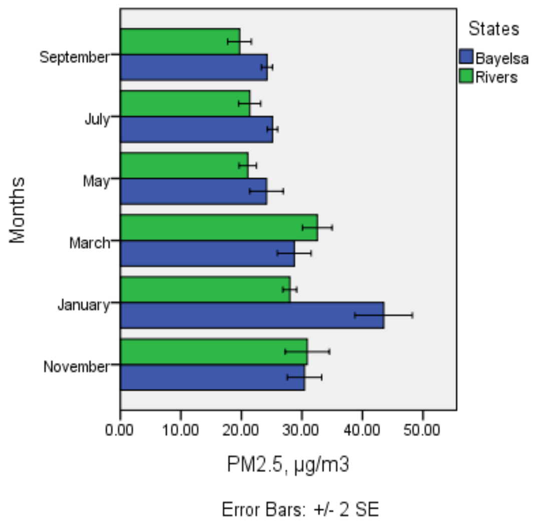
Parameters	N	Dry season				Wet season				T-value	*p-value*
		Min	Max	Mean	SE	Min	Max	Mean	SE		
NH_3	27	0.00	0.20	0.03	0.01	0.00	0.20	0.05	0.01	-1.391	0.170
H_2S	27	0.00	0.20	0.02	0.01	0.00	0.20	0.05	0.01	-1.882	0.065
CO	27	0.00	0.30	0.03	0.01	0.00	0.20	0.01	0.01	0.929	0.357
SO_2	27	0.00	0.20	0.02	0.01	0.00	0.30	0.08	0.01	-3.717	0.000
NO_2	27	0.00	0.00	0.00	0.00	0.00	0.20	0.04	0.01	-3.407	0.001
VOC	27	10.00	19.10	15.10	0.62	4.20	9.50	6.37	0.33	12.453	0.000
WS	27	0.50	1.70	1.01	0.06	0.20	1.10	0.63	0.04	5.345	0.000
Temp	27	30.70	33.60	32.13	0.21	27.70	31.60	30.12	0.32	5.243	0.000
RH	27	52.00	67.00	59.00	1.00	62.00	73.00	66.63	0.81	-5.955	0.000
$PM_{2.5}$	27	25.40	41.00	30.37	0.78	16.30	25.20	20.71	0.51	10.416	0.000
PM_{10}	27	72.20	152.10	105.78	4.54	46.40	78.70	60.29	1.93	9.223	0.000
TSP	27	97.40	304.20	193.37	12.64	56.30	102.30	74.70	2.45	9.219	0.000

Keys: CO (carbon monoxide), NH_3 (ammonia), H_2S (hydrogen sulphide), VOC (volatile organic compound), NO_2 (nitrogen dioxide), SO_2 (sulphur dioxide), $PM_{2.5}$ (particulate matter 2.5, PM_{10} (particulate matter 10), TSP (total suspended particulate), RH (relative humidity), WS (wind speed), SE (standard error), N (sample size), Min (minimum), Max (maximum)

concentrations in the dry and wet seasons were 34.70 µg/m^3 and 24.50 µg/m^3, respectively for $PM_{2.5}$, 138.23 µg/m^{3,} and 60.11 µg/m^3, for PM_{10}, and 235.61 µg/m^3 and 82.75 µg/m^3, for TSP for Bayelsa State (Table 1), 30.37 µg/m^3 and 20.71 µg/m^3, respectively for $PM_{2.5}$, 105.78 µg/m^{3,} and 60.29 µg/m^3, for PM_{10}, and 193.37 µg/m^3 and 74.70 µg/m^3, for TSP for Rivers State (Table 2), 32.54 µg/m^3 and 22.61 µg/m^3, respectively for $PM_{2.5}$, 122.01 µg/m^{3,} and 60.20 µg/m^3, for PM_{10}, and 214.49 µg/m^3 and 78.72 µg/m^3, for TSP for the overall (combination of Bayelsa and Rivers State) (Table 3). Statistically, there were variations in the concentrations of particulates in Bayelsa and Rivers States and the overall (combination of Bayelsa and Rivers State).

Table 3: Overall seasonality in the atmospheric pollutant concentration in Zarama and Elele markets along East-West road in Southern Nigeria through the period of study

Parameters	N	Dry season				Wet season				T-value	*p-value*
		Min	Max	Mean	SE	Min	Max	Mean	SE		
NH_3	54	0.00	0.30	0.04	0.01	0.00	0.20	0.04	0.01	0.292	0.771
H_2S	54	0.00	0.20	0.04	0.01	0.00	0.20	0.05	0.01	-1.276	0.223
CO	54	0.00	0.70	0.05	0.02	0.00	0.20	0.02	0.01	1.905	0.059
SO_2	54	0.00	0.30	0.02	0.01	0.00	0.30	0.06	0.01	-3.207	0.002
NO_2	54	0.00	0.00	0.00	0.00	0.00	0.20	0.03	0.01	-4.353	0.000
VOC	54	10.00	19.60	14.73	0.42	4.20	17.60	8.23	0.47	10.220	0.000
WS	54	0.50	1.70	0.99	0.04	0.20	1.30	0.63	0.04	6.781	0.000
Temp	54	30.00	33.60	31.78	0.15	27.00	31.60	29.46	0.24	8.242	0.000
RH	54	52.00	69.00	60.57	0.69	62.00	83.00	70.54	0.94	-8.558	0.000
$PM_{2.5}$	54	21.80	51.40	32.54	0.97	16.30	30.20	22.61	0.44	9.357	0.000
PM_{10}	54	72.20	266.00	122.01	6.03	43.20	103.40	60.20	1.98	9.735	0.000
TSP	54	91.20	434.60	214.49	12.02	56.30	152.10	78.72	2.75	11.014	0.000



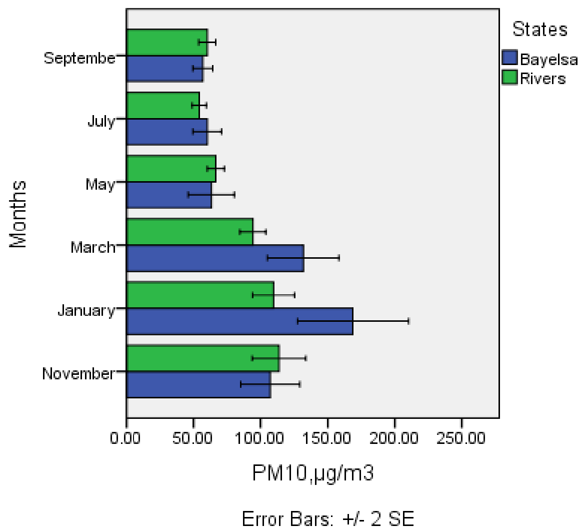
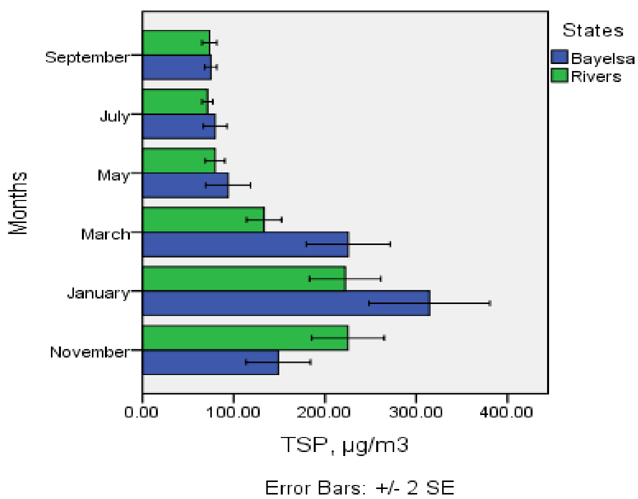


Figure 2: Seasonality in the concentration of particulates PM2.5 in Zarama and Elele markets in Bayelsa and Rivers States, respectively along East-West road in Southern Nigeria



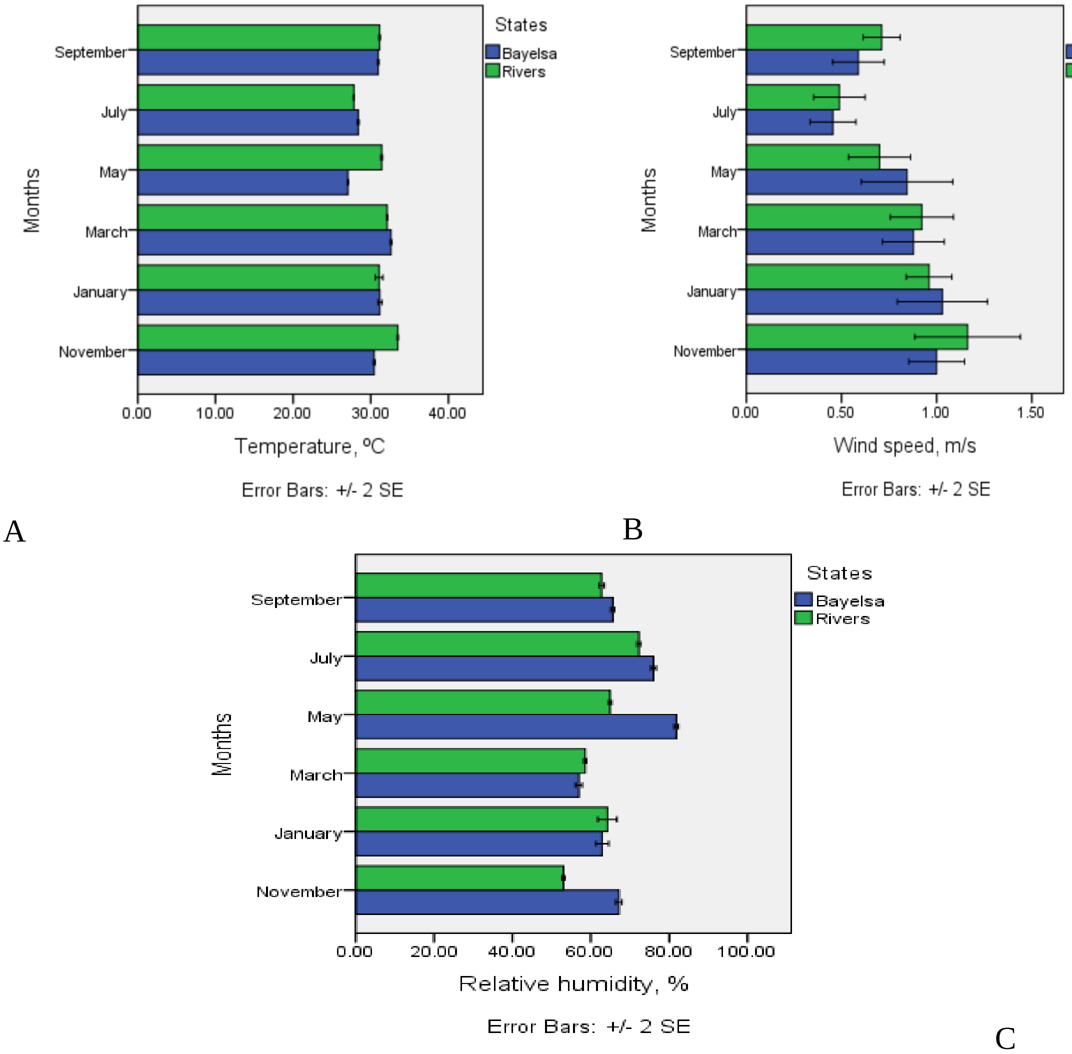


Figure 3: Seasonal variations in the temperature (A), wind speed (B) and relative humidity (C) in Zarama and Elele markets in Bayelsa and Rivers States respectively along East-West road in Southern Nigeria.

Effects of Meteorological Indicators (temperature, WS, and RH)

Figure 3 suggest seasonal variations in the temperature, wind speed and relative humidity in Zarama and Elele markets in Bayelsa and Rivers States respectively along East-West road in Southern Nigeria. The mean value of temperature, RH, and WS ranged from 27.06 – 33.46 ºC (Figure 3A), 53.11 – 81.78 % (Figure 3B,) and 0.46 – 1.17 m/s (Figure 3C), respectively. There was a statistical difference (p=0.000) across the months for each of the months and locations. Based on seasonality, the mean value of temperature, RH, and WS in the dry and wet seasons were 31.43 ºC and 28.80 ºC, 62.15% and 74.44%, and 0.97 and 0.63m/s, respectively for Bayelsa State (Table 1), 32.13 ºC and 30.12 ºC, 59.00% and 66.63%, and 1.01 and 0.63m/s, respectively for Rivers State, and 31.78 ºC and 29.46 ºC, 60.57% and 70.54%, and0.99 and 0.64m/s, respectively for the overall (i.e. Bayelsa and Rivers State). Statistically, there were deviations (at p = 0.000) in the mean values of both seasons for Rivers and the Bayelsa States and the overall (i.e. Bayelsa and Rivers State). The observed significant deviation depicts seasonal influence.

Correlation Analysis of the Impacts of Meteorological Indicators on Seasonal Variations and Concentrations of Some Atmospheric Pollutants

Correlation (cluster) analysis, and principal component analysis were used for the source apportionment. Tables 4 and 5 showed the Spearman's rho correlation of atmospheric pollutants in dry and wet seasons respectively in some markets alongEast-West road in Southern Nigeria. In the dry season, NH_3 showed significant positive correlations with H_2S, SO_2, VOC, and PM_{10} at $p < 0.01$. H_2S positively

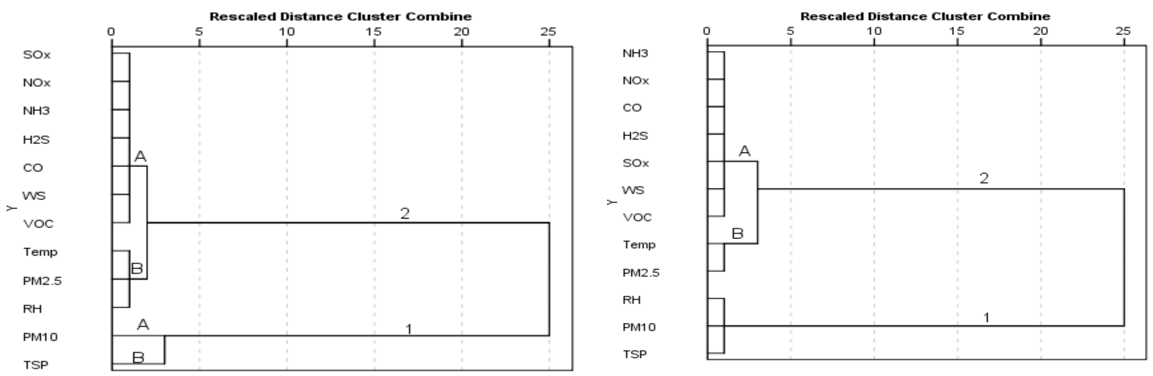
Table 4: Spearman's rho correlation (dry season) of atmospheric pollutant concentration in Zarama and Elele markets along East-West road in Southern Nigeria

Parameters	NH_3	H_2S	CO	SO_2	VOC	WS	Temp	RH	$PM_{2.5}$	PM_{10}	TSP
NH_3	1.000										
H_2S	0.535**	1.000									
CO	0.154	-0.120	1.000								
SO_2	0.384**	0.378**	-0.130	1.000							
VOC	0.447**	0.465**	-0.061	0.347*	1.000						
WS	-0.178	0.001	-0.071	-0.178	-0.009	1.000					
Temp	-0.064	-0.152	-0.035	-0.249	-0.133	0.098	1.000				
RH	0.058	0.166	0.013	0.269*	0.166	-0.145	-0.971**	1.000			
$PM_{2.5}$	0.208	0.377**	0.180	0.358**	0.155	-0.049	0.052	-0.057	1.000		
PM_{10}	0.384**	0.482**	0.069	0.317*	0.479**	-0.051	0.178	-0.105	0.625**	1.000	
TSP	0.260	0.416**	0.074	0.165	0.526**	0.007	0.233	-0.169	0.521**	0.914**	1.000

Table 5: Spearman's rho correlation (wet season) of atmospheric pollutant concentration in Zarama and Elele markets along East-West road in Southern Nigeria

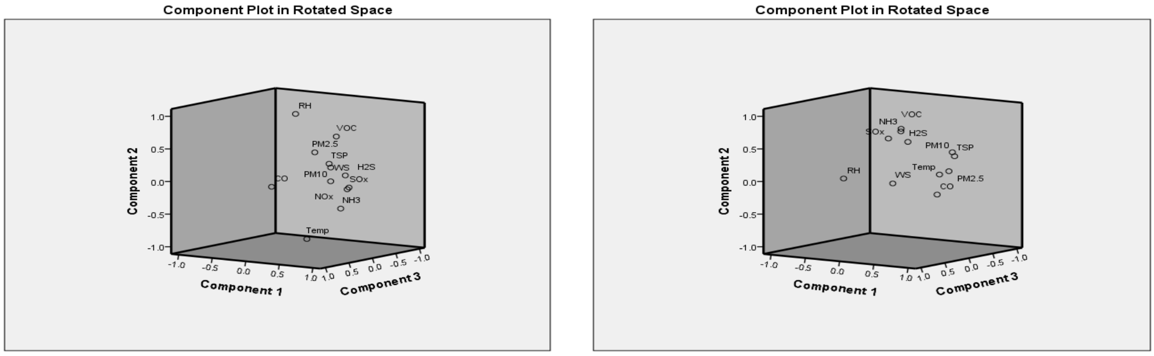
Parameters	NH3	H2S	CO	SO2	NO2	VOC	WS	Temp	RH	PM2.5	PM10	TSP
NH3	1.000											
H2S	0.350**	1.000										
CO	0.220	0.207	1.000									
SO2	0.471**	0.520**	0.245	1.000								
NO2	0.565**	0.565**	0.290*	0.549**	1.000							
VOC	0.296*	0.460**	0.280*	0.460**	0.470**	1.000						
WS	-0.212	-0.089	-.406**	-0.197	-0.266	-0.058	1.000					
Temp	0.269*	-0.025	-0.008	0.118	0.044	-0.447**	0.080	1.000				
RH	-0.335*	0.031	-0.027	-0.131	-0.084	0.488**	-0.048	-0.833**	1.000			
PM2.5	0.273*	0.438**	0.275*	0.185	0.516**	0.619**	-0.378**	-0.304*	0.454**	1.000		
PM10	0.528**	0.592**	0.399**	0.640**	0.667**	0.357**	-0.429**	0.298*	-0.248	0.450**	1.000	
TSP	0.560**	0.618**	0.388**	0.658**	0.705**	0.713**	-0.367**	-0.055	0.080	0.677**	0.812**	1.000

**. Correlation is significant at the 0.01 level (2-tailed) (very strong).
*. Correlation is significant at the 0.05 level (2-tailed) (strong).
N=45



A. Dry season B. Wet season

Figure 4: Hierarchical cluster analysis of atmospheric pollutants and meteorological indicators in some markets along East-West road in Southern Nigeria in the dry/Harmattan season (A) and wet/rainy season (B).



Wet season (A) Dry season (B)

Figure 5: Principal components plots of atmospheric pollutants in some markets along East-West road in Southern Nigeria in the wet/rainy season (A) and dry/Harmattan season (B).

Table 6: Total Variance of atmospheric pollutant concentration (dry season) in Zarama and Elele markets along East-West road in Southern Nigeria

Total Variance Explained									
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	3.799	34.533	34.533	3.799	34.533	34.533	2.673	24.302	24.302
2	2.150	19.543	54.076	2.150	19.543	54.076	2.421	22.010	46.312
3	1.233	11.210	65.285	1.233	11.210	65.285	2.028	18.432	64.744
4	1.117	10.152	75.438	1.117	10.152	75.438	1.176	10.693	75.438
5	0.787	7.153	82.591						
6	0.666	6.054	88.645						
7	0.561	5.100	93.745						
8	0.412	3.745	97.490						
9	0.223	2.027	99.517						
10	0.039	0.351	99.868						
11	0.014	0.132	100.000						

correlates with SO_2, VOC and $PM_{2.5}$, $PM_{10,}$ and TSP. SO_2 showed a strong correlation with VOC, $PM_{10,}$ and RH at p < 0.05 and a very strong correlation with $PM_{2.5}$ at p < 0.01. $PM_{2.5}$ showed a very strong relationship with PM_{10} and TSP, while PM_{10} also strongly correlates with TSP (Table 4). In the wet season, the atmospheric pollutants (gases and particulates) showed significant relationships except for a few instances, i.e. between NH_3 and CO and $PM_{2.5}$, between H_2S and CO). There were instances when meteorological indicators showed both positive and negative relationships with gases and particulates. For example, RH showed a significant negative relationship with NH_3 at $p < 0.05$ and positively correlated with VOC at $p < 0.01$. Temperature also revealed an essential negative relationship with VOC at $p < 0.01$, and a positive correlation with NH_3 at $p <$ 0.05.WS showed a strong significant relationship with particulates. A significant positive correlation suggeststhat the parameters are from similar sources. Figure 4 present the hierarchical cluster analysis of atmospheric pollutants and meteorological indicators in some markets along East-West road in Southern Nigeria in the dry/Harmattan season and wet/rainy season.

Figure 5 present the results of the principal components analysis of atmospheric pollutants in some markets along East-West road in Southern Nigeria in the wet/rainy season and dry/Harmattan season in Southern Nigeria. The PCA of atmospheric

Table 7: Extracted and Rotated Component Matrix of atmospheric pollutant concentration in dry season in Zarama and Elele markets along East-West road in Southern Nigeria

	Extracted Component Matrix				**Rotated Component Matrix**			
	Component				**Factor**			
	PC-1	**PC-2**	**PC-3**	**PC-4**	**F-1**	**F-2**	**F-3**	**F-4**
NH_3	**0.602**	-0.119	**0.550**	-0.127	0.092	**0.764**	-0.041	-0.318
H_2S	**0.656**	-0.104	0.141	0.227	0.322	**0.613**	0.146	0.112
CO	0.427	0.146	-0.491	-0.395	**0.703**	-0.166	0.080	-0.268
SO_2	**0.523**	-0.304	0.401	-0.125	0.058	**0.642**	0.175	-0.310
VOC	**0.631**	-0.101	0.307	0.402	0.181	**0.752**	0.091	0.241
WS	**0.742**	0.236	-0.381	-0.023	**0.841**	0.199	0.032	0.052
Temp	**0.907**	0.253	-0.114	-0.081	**0.819**	0.473	-0.073	-0.076
RH	**0.819**	0.367	-0.187	0.136	**0.805**	0.400	-0.138	0.177
$PM_{2.5}$	-0.175	0.225	-0.216	**0.824**	-0.046	-0.092	-0.065	**0.890**
PM_{10}	-0.198	**0.915**	0.325	-0.064	-0.010	-0.085	-0.988	0.051
TSP	0.197	-0.927	-0.262	0.089	-0.035	0.135	**0.977**	-0.044

Table 8: Total Variance of atmospheric pollutant concentration in dry season concentration in Zarama and Elele markets along East-West road in Southern Nigeria.

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	4.936	41.129	41.129	4.936	41.129	41.129	4.188	34.903	34.903
2	2.660	22.171	63.300	2.660	22.171	63.300	2.853	23.773	58.676
3	1.246	10.387	73.687	1.246	10.387	73.687	1.801	15.011	73.687
4	0.777	6.473	80.160						
5	0.636	5.297	85.457						
6	0.602	5.014	90.471						
7	0.435	3.625	94.096						
8	0.307	2.562	96.658						
9	0.235	1.956	98.613						
10	0.102	0.846	99.459						
11	0.041	0.342	99.802						
12	0.024	0.198	100.000						

pollutants and meteorological indicators of the study area is shown in Tables 6-9. The PCA was used to show the level of deviations in the variables. The total variance (75.438%) for the dry season (Table 6) showed only four components with initial eigenvalues >1.0, with components 1, 2, 3, and 4 accounting for 34.533 %, 19.543 %, 11.210 %, and 10.152 % of the variance (Table 6). The extracted components, PC-1 had a loading matrix on SO_2 (r = 0.523), NH_3 (r = 0.602), H_2S (r = 0.656), VOC (r = 0.631), $PM_{2.5}$ (r = 0.742), TSP (r = 0.819) and PM_{10} (r = 0.907); PC-2 had a loading matrix on temperature (r=0.915); PC-3 had a loading matrix on NH_3 (r = 0.550) and PC-4 had a loading matrix on WS (r = 0.824) (Table 7). The four components with eigenvalues > 1.0 were rotated and the components 1, 2, 3 and 4 had 24.302 %, 22.010 %, 18.432 %, and 10.693 % of the variance (Table 6), with F-1 having a loading of CO (r = 0.703), $PM_{2.5}$ (r = 0.841), TSP (r = 0.805) and PM_{10} (r = 0.819), F-2 had loading on NH_3 (r = 0.764), H_2S (r = 0.613), SO_2, (r = 0.642), VOC (r = 0.752), F-3 had loading on RH (r = 0.977) and F-4 had loading on WS (r = 0.890) (Table 7). The total variance (73.687 %) for the wet season (Table 8) showed that only three had initial eigenvalues ≥1.0, with components 1, 2, and 3 accounting for 41.129%, 22.171%, and 10.387% of the variance (Table 8). The extracted components, PC-1 had a loading matrix on SO_2 (r = 0.669), NH_3 (r =

0.521), H_2S (r = 0.716), VOC (r = 0.726), $PM_{2.5}$ (r = 0.757), TSP (r = 0.935) and PM_{10} (r = 0.897), PC-2 had a loading matrix on temperature (r = 0.914) and NH_3 (r = 0.565), and PC-3 had a loading matrix on WS (r = 0.739) (Table 9). The three components with eigenvalues ≥ 1.0 were rotated and the components 1, 2 and 3 had 41.129 %, 22.171 % and 10.387 % of the variance (Table 8), with F-1 having a loading on SO_2 (r = 0.775), NH_3 (r = 0.689), H_2S (r = 0.748), VOC (r = 0.586), $PM_{2.5}$ (r = 0.524), TSP (r = 0.761), PM_{10} (r = 0.797) and NO_2 (r = 0.819), F-2 had a loading on VOC (r = 0.704), $PM_{2.5}$ (r = 0.508) and RH (r = 0.974), and F-3 had loading on CO (r = 0.728) (Table 9).

Table 9: Extracted and rotated Component Matrix of atmospheric pollutant concentration in the wet season in Zarama and Elele markets along East-West road in Southern Nigeria

Parameters	Extracted Component Matrix			Rotated Component Matrix		
	Component			Factor		
	PC-1	PC-2	PC-3	F-1	F-2	F-3
NH_3	**0.521**	**0.565**	0.193	**0.689**	-0.383	0.074
H_2S	**0.716**	0.090	0.243	**0.748**	0.129	0.059
CO	0.378	0.112	-0.623	0.117	-0.013	**0.728**
SO_2	**0.669**	0.273	0.287	**0.775**	-0.059	0.018
NO_2	**0.726**	-0.508	0.231	**0.586**	**0.704**	0.020
VOC	**0.757**	-0.304	-0.139	**0.524**	**0.508**	0.390
WS	**0.897**	0.167	-0.089	**0.797**	0.099	0.441
Temp	**0.935**	-0.096	-0.080	**0.761**	0.362	0.423
RH	-0.406	-0.139	**0.739**	-0.104	0.033	-0.848
$PM_{2.5}$	-0.144	**0.914**	0.025	0.137	-0.915	0.006
PM_{10}	0.204	-0.955	0.043	-0.070	**0.974**	-0.050
TSP	0.745	0.303	0.210	0.819	-0.068	0.121

Discussion

The seasonal variation in the concentration of air pollutants (gaseous and particulate) has been monitored and assessed respectively. Based on Figure 1A, the NH_3 concentration fluctuates according to the months. But overall, the concentration in both locations showed an overlap in most of the cases. Hence, there is no clear trend indicating a rise in concentration in any particular season. NH_3 is one of the noxious gases frequently monitored in Nigeria both by independent and sponsored researchers (Seiyaboh & Izah, 2019). The effects of high NH_3 exposure include irritation of the sense organs and respiratory tracts where it causes obstruction. There is no Nigerian Ambient Air Quality Standard (NAAQS) limit for NH_3. But concentration recorded may not cause acute health problems upon exposure.

Although the mean concentration of CO across the months showed statistical deviation (at *p* = 0.037), it is likely that values from January in Bayelsa State were the source of observed deviation. CO gas is obtained from multiple sources, including fossil fuel, coal, and wood combustion. The health effects of CO include a deficiency in the supply of oxygen to the vital body organs, which could lead to the formation of carboxyhaemoglobin (Ohimain *et al.*, 2013). From the results, the concentrations of CO were within the NAAQS (Nigerian Ambient Air Quality Standard) recommended limits of 10 ppm for the daily hourly average and 20ppm for 8- the hourly average (FEPA, 1991; Ohimain *et al.*, 2013; Ohimain & Izah, 2013; Adeyanju & Manohar, 2017; DPR, 2002). This suggests that the likely effects that may be associated with the CO emitted in the study area may include acute respiratory conditions.

Both SO2 and H2S are from sulphur-containing compounds. They are released in trace amounts during the combustion of fossil fuel. There is no NAAQS limit for H2S with a maximum mean concentration of 0.05 ppm in the wet season. The concentrations of SO2 are within the NAAQS limits of 0.01 – 0.10 ppm for average hourly daily value (Adeyanju & Manohar, 2017). The concentrations of SO2 and H2S are relatively low in both seasons, depicting them as unlikely culprits in chronic health conditions in this study. In all of these cases, the concentrations were statistically higher in the dry season compared to the wet season. VOC is another important gas studied. On a short-term basis, high concentration could lead to irritation of the sensory organs. Also, this could aggravate the conditions of patients with liver and kidney diseases. However, there is no limit specified by NAAQS, and recorded values are low and unlikely to irritate the sensory organs.

NO2 is an acidic gas that is released during human activities such as the combustion of fossil fuel. It poses environmental and public health concerns because it contributes to greenhouse gases (Ohimain et al., 2013). However, the concentrations of NO2 recorded in this study are within tolerable limits and therefore not implicated as a causal factor detrimental to human health in both seasons. In addition, the concentrations of NO2 were lower than the NAAQS of 0.04 – 0.06ppm on a daily average hourly range (DPR, 2002; FEPA, 1991; Ohimain et al., 2013; Ohimain & Izah, 2013; Adeyanju & Manohar, 2017).

The concentration of pollutant gases recorded in this study has some similarities with concentrations reported in different activities in Southern Nigeria. For instance, Richard (2019) reported VOC in the range of 2.57 - 10.58 ppm and 1.79 - 12.07 ppm for the dry and wet seasons, respectively, in small-scale cassava processing mills in the Niger Delta (Bayelsa, Rivers, Abia, and Delta states). Ohimain et al. (2013) reported concentrations of <0.01- 1.167 ppm (NO2), <0.01 – 0.267 ppm (NH3), <0.01 – 27.167 ppm (CO), <0.01 – 2.400 ppm (H2S), <0.01 – 2.033 ppm (SO2) and 0.500 –13.933 ppm (VOC) in smallholder oil palm processing mill in Elele, Nigeria. Ohimain, & Izah, (2013) reported pollutant gases in the range of <0.01 – 0.2 ppm (NO2), <0.01 – 0.2 ppm (NH3), <0.01 – 0.7 ppm (CO), <0.01 – 0.4 ppm (H2S) and <0.01 ppm (SO2). Richard et al. (2021) reported CO, NO,2, and SO2 in the range of 0.00 - 1.58 ppm, 0.00 - 0.08 ppm, and 0.00 - 0.06 ppm, respectively, during outdoor combustion of biomass in some Niger Delta states. Richard et al. (2019a) reported NH3, H2S, CO, SO2, and NO2 in the range of 2.16 – 4.11 ppm, 1.86 – 4.92 ppm, 0.03 – 1.22 ppm, 0.14 – 0.30 and 0.02 – 0.30 ppm, respectively around waste dumpsite in the Niger Delta. There are, however, other reports that are at variance with these findings. For instance, Ibe et al. (2017) reported NO2, SO2, and CO in the range of 0.20 – 0.70 ppm, 0.17 – 0.73 ppm, and 26.00 – 51.00 ppm, respectively in Orlu, Imo State, Nigeria. Ibe et al. (2016) reported NO2, SO2, and CO in some parts of Imo State, in the range of 0.46 - 0.58 ppm, 0.46 - 0.56 ppm, and 30.15 – 40.98 ppm, respectively. Gobo et al. (2012) reported NO2, SO2, H2S, CO, NH3, and VOC in the range of 0.03 – 1.70 ppm, 0.03 – 1.4 ppm, 0.20 – 3.00 ppm, 0.50 – 10.30 ppm, 0.07 – 2.70 ppm and 0.10 – 5.2 µg/m3, respectively for dry season, and 0.02 – 0.10 ppm, 0.026 – 0.1 ppm, 0.05 – 0.10 ppm, 0.10 – 4.30ppm, 0.00 – 1.70 ppm and 0.04 – 7.0 µg/m3, respectively for wet season in Okirika communities in River State. The slight variation observed is due to differences in human activities such as vehicular emissions, combustions of biomass and fossil fuel, gas flaring, and industrial emissions in the vicinity where the various studies were carried out.

The study further showed that the concentration of the particulates was higher in the dry season compared to the wet season. This may be an indication of seasonal influence in the distribution of particulates across the study area. Further, particulates are generated from diverse sources, including the combustion of fossil fuel and biomass, dust, etc. Richard et al. (2021b) have reported that particulates can emanate from various sources, including organic and inorganic compounds, with major compositions being sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water. They were again showing that fossil fuels emit lesser TSP than wood fuels. Particulates are generated in different forms. According to Ana (2011), particulates in the form of carbon black, soot, and fly ash are major components of smoke. The values of PM2.5 and PM10 recorded occasionally exceeded the World Health Organization limits of 25µg/m3 and 50µg/m3 for a 24-hourly average. Similarly, PM10 and PM2.5 are within the respective National hourly value of 70µg/m3 and 30 µg/m3 as specified by Kanee et al. (2020); Edokpa & Ede (2019). While the TSP falls within the range of 250 - 600µg/m3 NAAQS limits as specified by FEPA (1991); DPR (2002); Ohimain et al. (2013). The particulates (PM2.5, PM10, and TSP) have some similarities with values previously reported in some activities in the Niger Delta. Richard et al. (2021b) reported PM2.5, PM10, and TSP in the range of 19.85 – 27.95 µg/m3, 55.66 – 80.59 µg/m3, and 74.29 – 140.44 µg/m3, respectively during outdoor combustion of biomass in the Niger Delta. Richard (2021) reported PM2.5, PM10, and TSP in the range of 26.12 – 36.04 µg/m3, 46.91 – 72.49 µg/m3, and 57.94 – 99.49 µg/m3, respectively, around smallholder gari processing facilities in some areas in Bayelsa, Rivers, Delta, and Abia states. Richard et al. (2019b) reported PM2.5, PM10, and TSP in the range of 26.44 – 40.10 µg/m3, 81.63–141.51 µg/m3, and 110.20–270.91 µg/m3, respectively around waste dumpsite in some Niger Delta States.

Other reports, however, show a divergent concentration in the particulate distribution in the Niger Delta. For instance, Akinfolarin et al. (2017) reported particulates in the wet and dry seasons in the range of 2.90- 34.75 µg/m3 and 143.80-300.35 µg/m3, respectively for PM2.5, 5.65-135.50 µg/m3, and 177.85-1926.30 µg/m3, respectively for PM10 in Port Harcourt Metropolis (Rumuolumeni, Oginigba, Eleme and Omuanwa), Rivers State. Gobo et al. (2012) reported PM2.5, PM10, and TSP in the range of 0.009 – 0.036 mg/m3, 0.061 – 0.378 mg/m3, and 0.070 – 0.503 mg/m3, respectively for dry season, and 0.001 – 0.008 mg/m3, 0.0010 – 0.0066 and 0.0012 – 0.0093 mg/m3, respectively for wet season in Okirika communities in River State. Ngele, & Onwu (2015) reported PM10 in the range of 55.81 - 921.34µg/m3 in the dry season and 14.38 - 266.06 µg/m3 in the wet season, respectively, and PM2.5 in the range of 21.69 - 122.88 µg/m3 in the dry season and 3.31- 11.44 µg/m3 in wet seasons, respectively in some area in southeastern Nigeria. Studies in smallholder oil palm processing mills in Elele, Rivers State, Nigeria show TSP in the range of 44 – 7853 µg/m3 (Ohimain et al., 2013), 24 – 74 µg/m3 from semi-mechanized palm oil processing mills in Elelebele, Bayelsa State (Ohimain & Izah, 2013), while PM10 has been recorded in the range of 3.40 – 11.53 mg/m3 in Orlu (Ibe et al., 2017), 5.22 – 7.43 mg/m3 in some part of Imo State (Ibe et al., 2016). Again, the variations could be due to differences in anthropogenic activities contributing to the concentrations of particulates as well as the seasonal influence (Harmattan) environment of the various studies. Seasonal variations in the temperature, wind speed, and relative humidity in Bayelsa and Rivers States are presented in Figure 3. The study clearly showed that temperature and WS were significantly higher in the dry season as compared to the wet season. But the RH was lower in the dry season as compared to the wet season. These trends have been widely reported in the literature.

The metrological indicators recorded in this study also have some similarities with the values previously reported in Bayelsa and Rivers states (study area). Ohimain & Izah (2013) reported temperature, RH, and wind speed in the range of 29.6 – 30.6 ºC, 71.8 – 79.6 %, and 0.5 – 0.9 m/s, respectively. Ohimain et al. (2013) reported temperature, RH and WS in the range of 27.17 – 35.93 °C, 60.79 – 86.60 %, and 0.100 – 1.567 m/s, respectively in a smallholder oil palm processing mill in Elele, Nigeria. Richard (2019) reported temperature, RH and WS in the range of 30.93 – 31.97 °C, 58.67 – 64.00 %, and 0.73 – 1.08 m/s, respectively for the wet season, and 28.56 – 30.24 °C, 65.33 – 76.33 %, and 0.42 – 1.20 m/s, respectively, for the dry season in smallholder cassava processing mill in the Niger Delta (Bayelsa, Rivers, Abia, and Delta states). Richard et al. (2019a) reported WS, temperature, and RH in the range of 0.27 – 2.97 m/s, 27.17 – 33.20 ºC, and 52.67 – 80.13 % respectively around waste dumpsites in the Niger Delta. High RH and low temperature have been variously reported in the Niger Delta region of Nigeria. According to Ohimain et al. (2013), high RH is associated with reduced cloud cover and the influence of moisture-laden tropical maritime air mass.

The values of meteorological indicators (temperature, WS, and RH) in this study indicate seasonality in the distribution of pollutant gases and particulates. This trend has also been reported by Richard et al. (2021a). Ibe et al. (2020) also reported that WS and wind direction tend to influence the level of pollutant gases and particulates. The authors further reported that the dispersion of atmospheric pollutant does not only depend on the source concentration but are influenced by the prevailing wind dynamics of the area. This may account for the patterns recorded in all the pollutant gases (Figure 1) and particulates (Figure 2). VOC and particulates (PM2.5, PM10, and TSP) were statistically higher during the dry season, traceable to vehicular emissions, burning of wastes, and the onset of the North-East trade wind with accompanying dust. The dust that is produced during the dry season may have contributed to the high particulates recorded. An increased incidence of SO2 and NO2 in the wet season suggests that their sources may be anthropogenic. According to Seiyaboh & Izah (2019), SO2 in the environmental matrix emanates from anthropogenic sources, including coal, oil, and gas combustion. The authors also reported that the anaerobic decomposition of waste emits SO2. During the wet season, wastes are heaped in different areas including along highways, market vicinity, uncompleted buildings, undeveloped plots, etc., creating anaerobic conditions in the dumps and giving rise to statistically higher concentrations in the dry season. Other pollutant gases such as NH3, H2S, and CO showed no statistical variation based on season, an indication that their release in the study area is relatively uniform throughout the year. CO was higher in the dry season but not statistically different when compared to wet season values, suggesting higher anthropogenic emissions of CO in the dry season as compared to the wet season. Some anthropogenic activities peculiar to the dry season include bush burning, burning of refuse, and outdoor biomass combustion, among others. Other workers have reported that concentration and exposure duration correlates with the impact of noxious pollutants on human (Seiyaboh and Izah, 2019; Richard et al., 2019a-c).

A strong negative correlation between CO and VOC in both seasons indicates the absence of photochemical reactions associated with natural effects; hence their occurrence is most likely anthropogenic. The strong correlation between particulates suggests similar pathways, including fossil fuel combustion by automobiles and other human activities, and in consonance with values previously reported in atmospheric pollutants in Gazipur, an industrial city of Bangladesh by Hossain et al. (2020). The dendrogram of the HCA (Hierarchical cluster analysis) of the atmospheric pollutants and some meteorological indicators of the study area is shown in Figure 4. In the dry season, two main clusters were formed. Cluster 1 had TSP and PM10, while cluster 2 had two sub-clusters viz: A (SO2, NO2, NH3, H2S, CO, VOC and WS, and B (temperature, PM2.5, and RH) (Figure 4A). In the wet season, two main clusters were also formed. Cluster 1 had TSP, PM10, and RH, while Cluster 2 had sub-clusters viz: A (PM2.5 and temperature) and B (NH3, NOx, H2S, CO, SOX, VOC, and WS) (Figure 4B). The HCA depicts their variations by the unequal distancing in the distribution of pollutants and metrological indicators. The HCA was carried out to discern the source and occurrence of the contaminants and their relationship with the meteorological indicators (Izah et al., 2017). The close distance cluster suggests a statistical relationship, while the distance cluster indicates the degree of association (Izah et al., 2017). From the study, the particulates (PM2.5, PM10, and TSP) and RH account for the main variations observed. The clusters grouped have a defined association (Ibe et al., 2020).

Also, it was observed that the factors in each principal component with < 0.50 correlation coefficient are not aggregated together because they do not form coherent components, like those with a coefficient> 0.50. The findings showed that there are variations in the PCA of both seasons (wet and dry). However, in the F1 of the extracted components, both had correlations co-efficient > 0.50 for the same parameters. The results of the PCA are in agreement with the correlation and HCA. A similar trend has been reported in surface soil contaminated by trace metals (Pobi *et al*., 2020). The principal plots (Figure 5) show that all the parameters are discretely located in both seasons except RH of the dry season. The reasonable dispersion of RH from other parameters is due to its outlier concentration (higher dry season concentration compared to corresponding wet season value) among the parameters. The AQI is an index developed to ascertain the health effects of pollutants over a period, usually a few hours to years. High air quality index often indicates a high concentration of atmospheric pollutants (particularly pollutant gases and particulates). According to Akinwumiju *et al*. (2021), air quality index >100 and <100 correspond to the Environmental Protection Agency and National Air Quality Standards (baseline) for pollution. Different indices are used for the determination of the air quality index (Tiwari, 2015; Richard *et al*., $2019_{a, b}$; $2021_{a, b}$). Ambient air quality is one of the determinants that show the quality of life in an area. The air quality of a site is unstable. The air quality index of the study area has been comprehensively documented by Richard et al. (2019_a, b, $2021_{a, b}$), Richard (2019, 2021). The study area has been rated to be below to severely contaminated by authors (Richard *et al*., $2019_{a, b}$, $2021_{a, b}$, 2019, 2021) with toxic and detrimental consequences for the vulnerable group mainly due to high particulate levels.

Conclusion

The study showed that the concentrations of CO, SO_2, NO_2, and TSP are within the level recommended by NAAQS, while the PM2.5 and PM10 often exceed regulatory limits. It also showed seasonal influence on the concentration of particulates ($PM_{2.5}$, PM_{10}, and TSP), VOC, SO_2, and NO_2 (Pollutants gases), and WS, RH, and temperature (meteorological indicators). In comparison, others such as NH_3, H_2S and CO showed no significant seasonal influence. PCA, and HCA revealed that most pollutants are from a similar source while being influenced by meteorology indicators such as temperature and WS. The contaminants were mainly from anthropogenic activities, i.e. vehicular emission, combustion of biomass and decompositions of waste materials. As such, there is a need to routinely monitor the level of atmospheric pollutants (gases and particulates) to forestall potential hazards to humans.

References

Acharya, S.R.; Moon, D.H.; Shin, Y.C. (2020). Assessment of VOCs, PM10, and Formaldehyde Exposure in the Hair Salons of South Korea. *Journal Environ Health Sustain Dev*, 5(4):1103-8.

Adeyanju, A.A.; Manohar, K. (2017). Biodiesel Production and Exhaust Emission Analysis for Environmental Pollution Control in Nigeria. *American Journal of Engineering Research*, 6(4): 80-94.

Akinfolarin, O.M.; Boisa, N.; Obunwo, C.C. (2017). Assessment of Particulate Matter-Based Air Quality Index in Port Harcourt, Nigeria. *Journal Environ Anal Chem*. 4: 224.

doi:10.4172/2380-2391.1000224.

Akinwumiju, A.S.; Ajisafe, T.; Adelodun, A.A. (2021). Airborne Particulate Matter Pollution in Akure Metro City, Southwestern Nigeria, West Africa: Attribution and Meteorological Influence. *Journal of Geovisualization and Spatial Analysis*, 5:11.

https://doi.org/10.1007/s41651-021-00079-6

Ana, G.; Adeniji, B.; Ige, O.; Oluwole, O.; Olopade, C. (2013). Exposure to emissions from firewood cooking stove and the pulmonary health of women in Olorunda community, Ibadan, Nigeria. *Air Qual Atmos Health*, 6:465–471.

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

Edokpa, D.O.; Ede, P.N. (2019). Preliminary Air Quality Index Estimates of Particulates Concentration in Port Harcourt during Soot Incidents. *Intern J Innov Stud Sci Eng Technol* 5(5): 25 – 29.

Efe, S.I. (2008). Spatial distribution of particulate air pollution in Nigerian cities: Implications for uman health. *J. Environ. Health Res*., 7(2): 107- 116.

Ezekwe, C.I.; Agbakogba, A.; Igbagara, P.W. (2016). Source gas emission and ambient air quality Around the Eneka co-disposal landfill in Port

Harcourt, Nigeria. *International Journal of Applied Chemistry and Industrial Sciences*, 2(1): 11 - 23.

Ezekwe, I.C.; Arokoyu, S.B. (2017). Landfill Emissions and their Urban Planning and Environmental Health Implications in Port Harcourt, South-South Nigeria. *Desenvolv. MeioAmbiente*, 42,224-241.

Federal Environmental Protection Agency, Nigeria (1991). Guidelines and Standards for Environmental Pollution Control in Nigeria. Federal Environmental Government Protection Agency.

Gobo, A.E.; Ideriah, T.J.K.; Francis, T.E.; Stanley, H.O. (2012). Assessment of Air Quality and Noise around Okrika Communities, Rivers State, Nigeria. *J. Appl. Sci. Environ. Manage*., 16 (1): 75 - 83

Hossain, M.N.; Mukta, T.A.; Hoque, M.M.M.; Sarker, M.E.; Biswas, G.K. (2020). Seasonal variations of gaseous air pollutants (SO2, NO2, O3, CO) and particulates (PM2.5, PM10) in Gazipur: an industrial city of Bangladesh. *Advances in Environmental Technology*, 6(4):

DOI 10.22104/AET.2021.4890.1320

Ibe, F.C.; Njoku, P.C.; Alinno, r.J.; Opara, A.I. (2016). Evaluation of Ambient Air quality in parts of Imo state, Nigeria. *Research Journal of Chemical Sciences*, 6(1): 41-52.

Ibe, F.C.; Opara, A.I.; Duru, C.E.; Obinna, I.B.; Enedoh, M.C. (2020). Statistical analysis of atmospheric pollutant concentrations in parts of Imo State, Southeastern Nigeria. *Scientific African*, 7: e00237.

Ibe, F.C.; Opara, A.I.; Njoku, P.C.; Alinnor, J.I. (2017). Ambient air quality assessment of Orlu, Southeastern Nigeria. *J. Appl. Sci*, 17: 441–451.

Ikhajiagbe, B.; Ogwu, M.C. (2020). Hazard quotient, microbial diversity and plant composition of spent crude oil polluted-soil. Beni-Suef University *Journal of Basic and Applied Sciences*, 9(26). http://doi.org/10.1186/s43088-020-00052-0

Ikhajiagbe, B.; Ogwu, M.C.; Ogochukwu, O.F.; Odozi, E.B.; Adekunle, I.J.; Omage, Z.E. (2021). The place of neglected and underutilized legumes in human nutrition and protein security, *Critical Reviews in Food Science and Nutrition*. http://doi.org/10.1080/10408398.2020.1871319

Ikhajiagbe, B.; Aituae, W.; Ogwu, M.C. (2022). Morpho-physiological assessment of oil palm(Elaeis guineensis Jacq.) seedlings exposed to simulated drought conditions. *Journal of Oil Palm Research*,34(1):26–34. http://doi.org/10.21894/jopr.202100018

Ikhajiagbe, B.; Ogwu, M.C.; Lato, N.F. (2021). Growth and yield response of soybean (Glycine max [L.] Merr.) accessions after exposure to cadmium. VEGETOS –*International Journal of Plant Research and Biotechnology*, http://doi.org/10.1007/s.42535-021-00189-y

Izah, S.C.; Bassey, S.E.; Ohimain, E.I. (2017). Assessment of heavy metal in cassava mill effluent contaminated soil in a rural community in the Niger Delta region of Nigeria. *EC Pharmacol Toxicol*, 4(5):186–201.

Jalili, M.; Mazidi, F.; Ehrampoosh, M.H.; Badeenezhad, A.; Ebrahimi, V.; Abbasi, F. (2020). Relationship of Air Pollution and Daily Hospital Admissions Due to Respiratory Disease: A Time Series Analysis. *J Environ Health Sustain Dev*., 5(1): 971-80.

Jariwala, N.; Kapadia, D. (2021). Statistical analysis of tropospheric ozone and its precursors using principal component analysis in an urban area of Surat, India. *Advances in Environmental Technology*, 7(1).

DOI 10.22104/AET.2021.4834.1308

Kanee, R.B.; Adeyemi, A.; Edokpa, D.O.; Ede, P.N. (2020). Particulate Matter-Based Air Quality Index Estimate for Abuja, Nigeria: Implications for Health. *J Geosci Environ Prot*, 8: 313-321.

Ngele, S.O.; Onwu, F.K. (2015). Measurements of Ambient Air Fine and Coarse Particulate Matter in ten South-East Nigerian cities. *Research Journal of Chemical Sciences*, 5(1): 71-77.

Ogwu, M.C. (2019). Ecologic and Economic Significance of Bryophyte. In: Current State and Future Impacts of Climate Change on Biodiversity. Rathoure, A.K. and Chauhan, P.B. (eds). I.G.I. Global, Pennsylvania, USA., 54-78pp. http://doi.org/10.4018/978-1-7998-1226-5.ch004

Ogwu, M.C. (2019). Towards Sustainable Development in Africa: The Challenge of Urbanization and Climate Change Adaptation. In: The Geography of Climate Change Adaptation in Urban Africa. Cobbinah, P.B. and Addaney, M. (eds.). Springer Nature, *Switzerland*, 29 – 55pp.

http://doi.org/10.1007/978-3-030-04873-02

Ogwu, M.C.; Osawaru, M.E.; Ahana, C.M. (2014). Challenges in conserving and utilizing plant genetic resources (PGR). *International Journal of Genetics and Molecular Biology*, 6(2): 16 – 22.

http://doi.org/10.5897/IJGMB2013.0083

Ohimain, E.I.; Izah, S.C. (2013). Gaseous emissions from a semi-mechanized oil palm processing mill in Bayelsa state, Nigeria. *Continental J Water Air Soil Pollut*, 4 (1): 15 – 25.

Ohimain, E.I.; Izah, S.C.; Abah, S.O. (2013). Air quality impacts of smallholder oil palm processing in Nigeria. *J Environ Protect*, 4: 83-98

Osawaru, M. E.; Ogwu, M.C. (2014). Conservation and utilization of plant genetic resources. In: Omokhafe, K. and Odewale, J. (eds.). Proceedings of 38th Annual Conference of The Genetics Society of Nigeria. *Empress Prints Nigeria Limited*. pp. 105-119.

Osawaru, M.E.; Ogwu, M.C.; Braimah, L. (2013). Growth responses of two cultivated Okra species (Abelmoschus caillei (A. Chev.) Stevels and Abelmoschus esculentus (Linn.) Moench) in crude oil contaminated soil. *Nigerian Journal of Basic and Applied Science*, 21(3): 215 – 226.

Osawaru, M.E.; Ogwu, M.C.; Chime, A.O. (2013). Assessment of growth performance of two Okra species (Abelmoschus esculentus [L.] Moench and Abelmoschus caillei [A. Chev.] Stevels) exposed to crude oil contaminated soil. *Nigerian Journal of Biotechnology*, 26: 11 – 20.

Pagadala, P.; Nerella, S.; Chandrashekhar, N.; Babu, M.R. (2018) A Review on Association of Air Pollution and Biomass Fumes on Respiratory System. *Journal of Clinical and Diagnostic Research*, 12(10):CE01-CE04.

Pobi, K.K.; Nayek, S.; Gope, M.; Rai, A.K.; Saha, R. (2020). Source evaluation, ecological and health risk assessment of potential toxic metals (PTMs) in surface soils of an industrial area, *India. Environ Geochem Health.*

https://doi.org/10.1007/s10653-020-00517-2.

Rezaeinia, S.; Ebrahimi, A.A. (2020). Air Pollution and its Effects on Autoimmune Diseases. *J Environ Health Sustain Dev*. 5(2): 982-4.

Richard, G. (2019). Influence of season on the distribution of volatile organic compounds from a small-holder cassava processing facility in the Niger Delta region of Nigeria, *Annals of Ecology and Environmental Science*, 3(4): 27– 35.

Richard, G. (2021). Particulates Distribution Around Smallholder Gari Production Facilities in the Niger Delta, *Nigeria. Academic Journal of Life Sciences*, 7(1): 17-21.

Richard, G.; Aseibai, E.R. (2021). Seasonal variation in mycological quality of air environment around a major market along East-West road in Bayelsa State, Nigeria. *International Journal of Healthcare and Medical Sciences*, 7(2):18 -25.

Richard, G.; Nwagbara, M.O.; Weli, V.E. (2019$_a$). Public Health Implications of Seasonality in Noxious Gases from Dumpsites in Some Niger Delta States, Nigeria. *International Journal of Research Studies in Biosciences*, 7(5): 1-14.

Richard, G.; Sawyer, W.E.; Izah, S.C. (2021$_a$). Outdoor Air Quality Index of Biomass Combustion in the Niger Delta, Nigeria: A Health Impact Perspective. Journal of Advanced Research in Medical Science and& Technology, 8(1): 19-28.

Richard, G.; Sawyer, W.E.; Izah, S.C. (2021$_b$). Health Implications of Air Quality Index of Fine and Coarse Particulates During Outdoor Combustion of Biomass in the Niger Delta, Nigeria. *International Journal of World Policy and Development Studies*, 7(2): 21-26.

Richard, G.; Weli, V.E.; Nwagbara, M.O. (2019$_b$). Seasonality in Particulates Distribution from Dumpsites in the Niger Delta Region of Nigeria: A Health Risk Assessment Approach. *International Journal of Research in Environmental Science*, 5(2): 7-15.

Seiyaboh, E.I.; Izah, S.C. (2019). Impacts of Soil Pollution on Air Quality under Nigerian Setting. *J Soil Water Sci*, 3(1):45-53.

Tiwari, P. (2015). Computational Methods of Air Quality Indices: A Literature Review. *IOSR J Environ Sci Toxicol Food Technol*, 1(5): 46-49

Umesi, N.O.; Ideria, J.T.; Abah, S. (2009). Background concentration of NO2 prior to Construction and Operation of a Gas-Fired Gas Plant in the Niger Delta Region of Nigeria. *Environment and Ecology*, 27 (2): 592-602.

Uzoekwe, S.A.; Ajayi, E.D. (2018). Trace metals concentration assessment in Urban particulate matter in Yenagoa and its environ. *J Appl Sci Environ Manage*, 22(1):134–140.

Uzoekwe, S.A.; Izah, S.C.; Aigberua, A.O. (2021). Environmental and human health risk of heavy metals in atmospheric particulate matter (PM10) around gas flaring vicinity in Bayelsa State, *Nigeria. Toxicol Environ Health Sci*. https://doi.org/10.1007/s13530-021-00085-7.

Vwioko, D.E.; Okoekhian, I.; Ogwu, M.C. (2018). Stress analysis of Amaranthus hybridus L. and Lycopersicon esculentum Mill. Exposed to Sulphur and nitrogen dioxide. *Pertanika Journal of Tropical Agricultural Sciences*, 41(3): 1169–1191.

Weli, V.E.; Adekunle, O. (2014). Air Quality in the Vicinity of a Landfill Site in Rumuolumeni, Port Harcourt, Nigeria. *Journal of Environment and Earth Science*, 4(10): 1 - 9.