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The Influence of Atmospheric Parameters on Production and Distribution of Air Pollutants in Bayelsa: A State in the Niger Delta Region of Nigeria

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Abstract

Air pollution is a primary environmental problem in the Niger Delta region of Nigeria due to oil spills including the gas emissions associated with industrial effluents. However, a good understanding and quantification of atmospheric parameters (wind speed, wind direction, temperature, relative humidity, solar radiation and cloud cover) that influence air pollution (CH_4, NO_2 and O_3) concentrations in this region could assist in the mitigation and distribution of these pollutants. This work examines the influence of atmospheric parameters on the production and distribution of air pollutants in the Niger Delta region of Nigeria for the development of control strategies that will enhance the mitigation and amelioration of the significant impacts that these atmospheric pollutants could have on the populace in this part of the country. The CH_4 and NO_2 data utilized in this study were sourced from the European Space Agency (ESA), while that of tropospheric ozone (O_3) was obtained from the National Aeronautics and Space Administration (NASA), and the atmospheric parameters data were provided by the Nigeria Meteorological Agencies (NIMET), Lagos. The analysis of the daily pollutants (CH_4, NO_2 and O_3) including the atmospheric parameters in this region of the Niger Delta for the period 2003 to 2010 was carried out using standard statistical approach including the graphical method, stepwise regression model, least-square method, and correlation analysis. The Mann-Kendal rank statistics was also utilized in identifying the meaningful long-term trends, validation and testing of the homogeneity of the concentrations of the pollutants. The results of the correlations of CH_4, NO_2 and O_3 concentrations with their previous day's concentrations showed a strong significance in regression analysis for both CH_4 and O_3. The coefficient of determination of CH_4 and O_3 was obtained as

0.654 and 0.810 respectively, while a very weak correlation was obtained for NO_2. However, despite that a very strong negative correlation of −0.809 and −0.900 was obtained between wind speed and both the CH_4 and O_3 pollutants respectively, a moderate correlation was obtained between the wind speed and NO_2. This implies that amongst the atmospheric parameters considered in this study for the region of the Niger Delta in Nigeria, wind speed has much influence on the variation of both CH_4 and O_3 concentrations, but with a little influence on the NO_2 concentrations.

Keywords

Air Pollution, Atmospheric Parameters, Atmospheric Pollutants, Regression Analysis, Correlations

1. Introduction

Air pollution is the emission of chemical effluents from numerous sources into the atmosphere which could cause harm to both man and plants including damage to life and property. These pollutants are of many forms including ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrogen sulphide (H_2S), hydrogen fluoride (HF) and volatile organic compounds (VOC) [1]. Also, the chemical effluents being referred to as pollutants are been influenced by so many factors including wind speed, temperature and humidity. The wind speed influences the quantity of the pollutants to be dispersed, while temperature assists in transforming the pollutants to other forms [2].

The discovery of oil has been causing series of negative environmental effects in the Niger Delta region, where all the petroleum exploration and production has been taking place in Nigeria [3] [4]. In this region, gas flaring which is thought to be very important in the elimination of gas, especially when the volume is thought to be economically insufficient to warrant recovery or collection is on the increase in recent years, thereby causing many health hazards both to people and to animals [5]. The increasing effect of the rapid population growth in the Niger Delta region, including the industrialization, and increased use of vehicles has also made the situation in this region to become worse. Moreover, the Niger Delta has been witnessing water and land contamination with consequent degradation of the agricultural land with the effective enforcement of regulatory measures yielding no measurable results. Activities related to petroleum exploration, development and production operations have local disadvantages and effects on the atmosphere, soils and sediments, surfaces and groundwater, marine environment, biologically diversity and sustainability of terrestrial ecosystems in the Niger Delta [6]. Furthermore, [4] carried out systematic studies of the air quality of the Niger Delta region and found out that carbon monoxide, nitrogen dioxide, sulphur dioxide and carbon dioxide effluents vary in the Niger

Delta. Also, [7] carried out the analysis of carbon monoxide concentrations with some selected meteorological variables such as temperature, relative humidity and wind speed in ten major urban centres in the south eastern part of Nigeria. The correlation analysis reveals that among the meteorological parameters studied; only wind speed is strongly correlated with carbon monoxide in the south eastern Nigeria. However, there are other sources of pollution in Nigeria which include those from vehicular sources [8] [9] [10] [11].

This work is focused on the Bayelsa state of Nigeria (**Figure 1**) which is one of the nine states in the Niger Delta region, due to its been exposed to much environmental degradation and health hazards as a result of oil spills and gas emissions associated with the industrial effluents in this area.

2. Materials and Methods

The CH_4 and NO_2 data utilized in this study were sourced from the European Space Agency (ESA), while that of tropospheric ozone (O_3) was obtained from the National Aeronautics and Space Administration (NASA), and the atmospheric parameters data were provided by the Nigeria Meteorological Agencies (NIMET), Lagos.

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3. Results and Discussion

The result of the regression statistics showed that wind speed has a greater negative influence on the concentration of CH_4 and Ozone (O_3) respectively. The decrease in the wind speed increases the concentration of the pollutants for they tends to accumulate near the source point but the decrease in the wind speed decreases the concentrations of these pollutants as much pollutants will be dispersed by wind. The measured and the predicted values of these pollutants (CH_4 and O_3) as observed from the regression equation were presented in **Table 1**.

The result of the correlation analysis showed that only wind speed among all the meteorological parameters considered has the strongest negative influence on these pollutants with the value 81% and 91% for CH4 and O_3 respectively (**Table 2**). **Tables 3-7** which showed the minimum and the maximum annual trends values of the pollutants within the period considered was utilized in

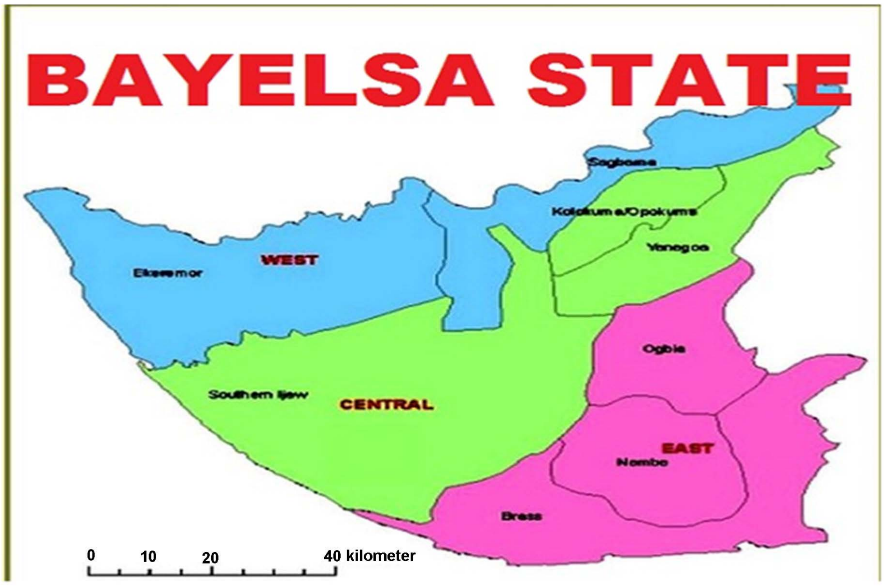


Figure 1. Map of Bayelsa State showing the study area (Apoi Creek) Southern Ijaw, sourced from NARSDA.

Table 1. The measured and the predicted values of CH_4 and O_3.

Years	CH_4 (measured)	Wind Speed	CH_4 (predicted)	O_3 (measured)	Wind Speed	O_3 (predicted)
2003	1733.685	4.828965	1735.945	0.005655	4.828965	0.005657
2004	1729.42	6.687811	1728.642	0.005602	6.687811	0.005525
2005	1729.149	6.676661	1728.685	0.005479	6.676661	0.005526
2006	1722.8	6.471819	1729.49	0.005629	6.471819	0.00554
2007	1734.205	6.729039	1728.48	0.005566	6.729039	0.005522
2008	1736.168	4.23183	1738.291	0.005741	4.23183	0.005699
2009	1741.963	4.02259	1739.113	0.005784	4.02259	0.005714
2010	1740.801	3.91419	1739.539	0.005746	3.91419	0.005722

Table 2. Pearson correlation of some meteorological parameters against the pollutant concentrations.

	SR	RH	WNDSPD	WNDDR	CC	TMIN	TMAX
Methane Pearson Correlation	−0.357	0.236	−0.809*	-0.332	0.118	−0.219	−0.329
NO_2 Pearson Correlation	−0.412	0.396	0.213	0.568	0.375	0.337	0.181
OZONE Pearson Correlation	−0.310	0.364	−0.900**	−0.445	0.018	−0.288	0.059

SR = Solar Radiation, RH = Relative Humidity, WNDSPD = Wind Speed, WNDDR = Wind direction, CC = Cloud Cover, TMIN = Minimum Temperature, TMAX = Maximum Temperature.

deducing the spatial interpretations of the pollutants' concentrations in Niger Delta while **Table 8** and **Table 9** shows the Man-Kendal rank statistical table within the period of studies. The regression analysis between the measured and predicted CH_4 (**Figure 2**) has a relationship expressed as:

Table 3. Basic statistics of monthly averages of air pollutant concentrations and their maximum and minimum values within the period of investigation Methane.

Year	Mean	Standard deviation	Variance	Minimum	Maximum
2003	1733.686	21.807	475.546	1701.84	1775.74
2004	1729.420	13.769	189.583	1704.10	1747.80
2005	1729.149	8.200	67.243	1718.19	1741.13
2006	1722.800	14.219	202.175	1705.71	1754.33
2007	1732.205	15.786	249.204	1709.77	1758.43
2008	1736.168	14.241	202.814	1703.48	1754.65
2009	1741.963	11.775	138.641	1723.35	1764.90
2010	1740.801	7.691	59.146	1728.65	1756.84
2011	1755.575	22.918	525.236	1722.90	1793.17
2012	1763.733	14.424	202.045	1740.48	1785.71

Table 4. Basic statistics of monthly averages of air pollutant concentrations and their maximum and minimum values within the period of investigation NO_2.

Year	Mean ($\times 10^{-5}$)	Standard deviation ($\times 10^{-6}$)	Minimum ($\times 10^{-5}$)	Maximum ($\times 10^{-5}$)
2003	5.246	3.141	4.9	6.0
2004	4.637	4.542	4.0	5.3
2005	4.307	4.860	3.9	5.7
2006	4.092	3.555	3.6	4.6
2007	3.771	2.708	3.5	4.4
2008	3.834	2.110	3.5	4.1
2009	3.752	1.554	3.6	4.0
2010	3.849	1.969	3.4	4.2
2011	3.943	1.611	3.7	4.2
2012	3.982	2.056	3.7	4.3

Table 5. Basic statistics of monthly averages of air pollutant concentrations and their maximum and minimum values within the period of investigation ozone.

Year	Mean ($\times 10^{-3}$)	Standard deviation ($\times 10^{-4}$)	Minimum ($\times 10^{-3}$)	Maximum ($\times 10^{-3}$)
2003	5.655	3.006	5.243	6.109
2004	5.602	2.367	5.289	5.944
2005	5.479	1.948	5.091	5.732
2006	5.630	3.389	5.098	6.012
2007	5.566	2.004	5.251	5.792
2008	5.741	3.580	5.228	6.174
2009	5.784	2.742	5.360	6.132
2010	5.746	2.934	5.316	6.138
2011	5.789	2.224	5.434	6.078
2012	5.689	3.037	5.238	6.073

Table 6. Basic statistics of monthly averages of air pollutant concentrations and their maximum and minimum values within the period of investigation CO_2.

Year	Mean	Standard deviation	Variance	Minimum	Maximum
2009	387.149	28.710	824.269	372.948	477.398
2010	381.162	4.386	19.239	372.887	387.056
2011	382.833	4.778	22.826	372.579	388.765
2012	386.839	4.639	21.524	380.198	398.513
2013	388.241	4.004	16.035	382.363	393.243

Table 7. Basic statistics of annual averages of air pollutant concentrations and their maximum and minimum values within the period of investigation.

Pollutants	Mean	Standard deviation	Variance	Minimum	Maximum
Methane	1738.7500	12.50933	156.483	1722.80	1763.73
NO_2	4.139×10^{-5}	4.771×10^{-6}	-	3.8×10^{-5}	5.2×10^{-5}
Ozone	5.668×10^{-2}	1.01×10^{-4}	-	5.4790×10^{-2}	5.7887×10^{-2}
CO_2	385.245	3.0675	9.409	381.1618	388.2413

Table 8. Man-Kendall rank statistical table for various pollutants.

YEARS	CH_4	$U(t_i)$	$U'(t_i)$	NO_2	$U(t_i)$	$U'(t_i)$	OZONE	$U(t_i)$	$U'(t_i)$
2003	1733.685	0.154	−0.77	5.25E−06	3.696	−1.848	0.005655	4.466	−2.618
2004	1729.42	1.848	−0.62	4.64E−06	2.464	−0.195	0.005602	2.926	−2.464
2005	1729.149	0.154	−0.62	4.31E−06	1.386	−1.694	0.005479	5.389	−3.542
2006	1722.8	2.002	−0.154	4.09E−06	3.079	−1.232	0.005629	2.772	−2.772
2007	1734.205	1.539	0.308	3.77E−06	0.769	−0.769	0.005566	4.004	−2.156
2008	1736.168	0	−1.694	3.83E−06	2.926	−1.078	0.005741	4.158	−2.772
2009	1741.963	3.079	−1.232	3.75E−06	2.156	−0.616	0.005784	4.928	−3.388
2010	1740.801	−0.154	−2.309	3.82E−06	1.848	−1.848	0.005746	3.388	−2.002
2011	1755.575	0.769	1.078	3.94E−06	0.154	−0.616	0.005789	3.542	−3.079
2012	1763.733	0.616	−0.616	3.98E−06	0.769	−1.848	0.00569	3.849	−3.388

Table 9. Man-Kendall rank statistical table for CO_2.

YEARS	CO_2	$U(t_i)$	$U'(t)$
2009	387.1489	1.694	−1.078
2010	381.1618	1.539	−1.232
2011	382.8326	0.769	1.078
2012	386.8387	2.309	0.924
2013	388.2413	1.386	−1.078

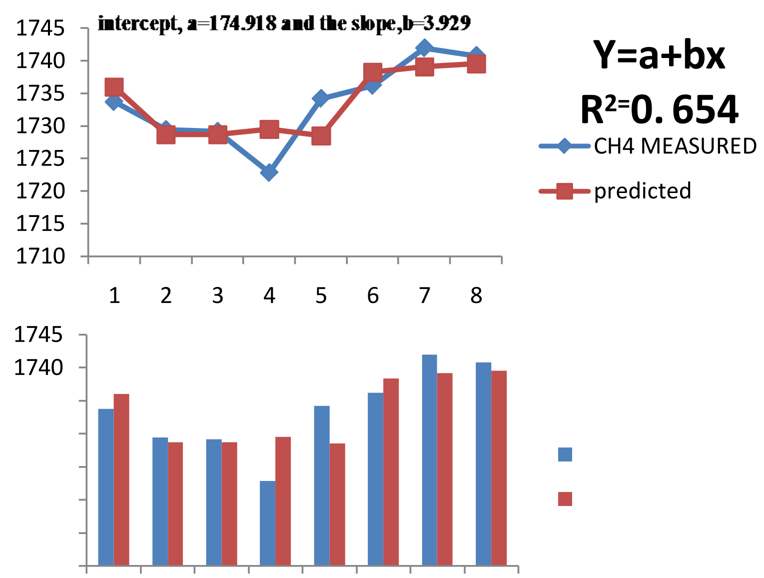


Figure 2. Graph of agreement between measured and predicted value of methane.

$$Y = a + bX \tag{1}$$

where,

Y is the CH_4 concentration,

X is the wind speed,

a = 174.918 is the intercept,

b = 3.929, and the slope,

R^2 = 0.654 (significant at 1 percentile).

Also, the concentration of the variables were input into the regression equation and Methane (CH_4) with all the weather parameters show a weak significance in the statistical analysis with none of the parameters meeting the entry requirement for NO_2 when analysed in the regression equation.

The regression analysis between the measured and predicted O_3 (Figure 3) a relationship expressed as:

$$Y = a + bX \tag{2}$$

where,

Y is the O_3 concentration,

X is the wind speed,

a = 0.006 is the intercept,

b = 7.101E−005, and the slope,

R^2 = 0.810 (significant at 1 percentile).

Figure 4(A)-(D) showed that the pollutants' trends in the Niger Delta are temporal but with high concentration during the dry season.

Figure 4(A)-(C), Figure 5(A) and Figure 5(B) respectively showed a non-linear trend in the mean annual concentration plots for CH_4, NO_2, O_3 and CO_2. While Figure 5(C) shows the mean annual concentrations of NO_2 and average temperature.

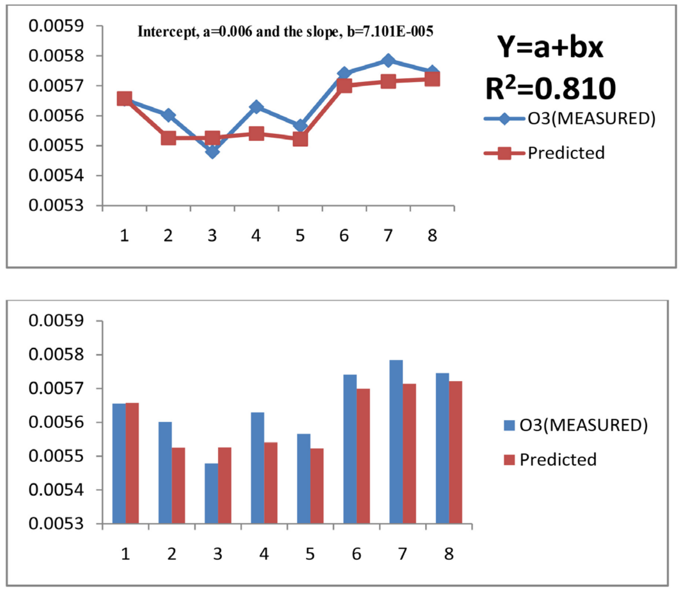


Figure 3. Graph of agreement between measured and predicted value of ozone.

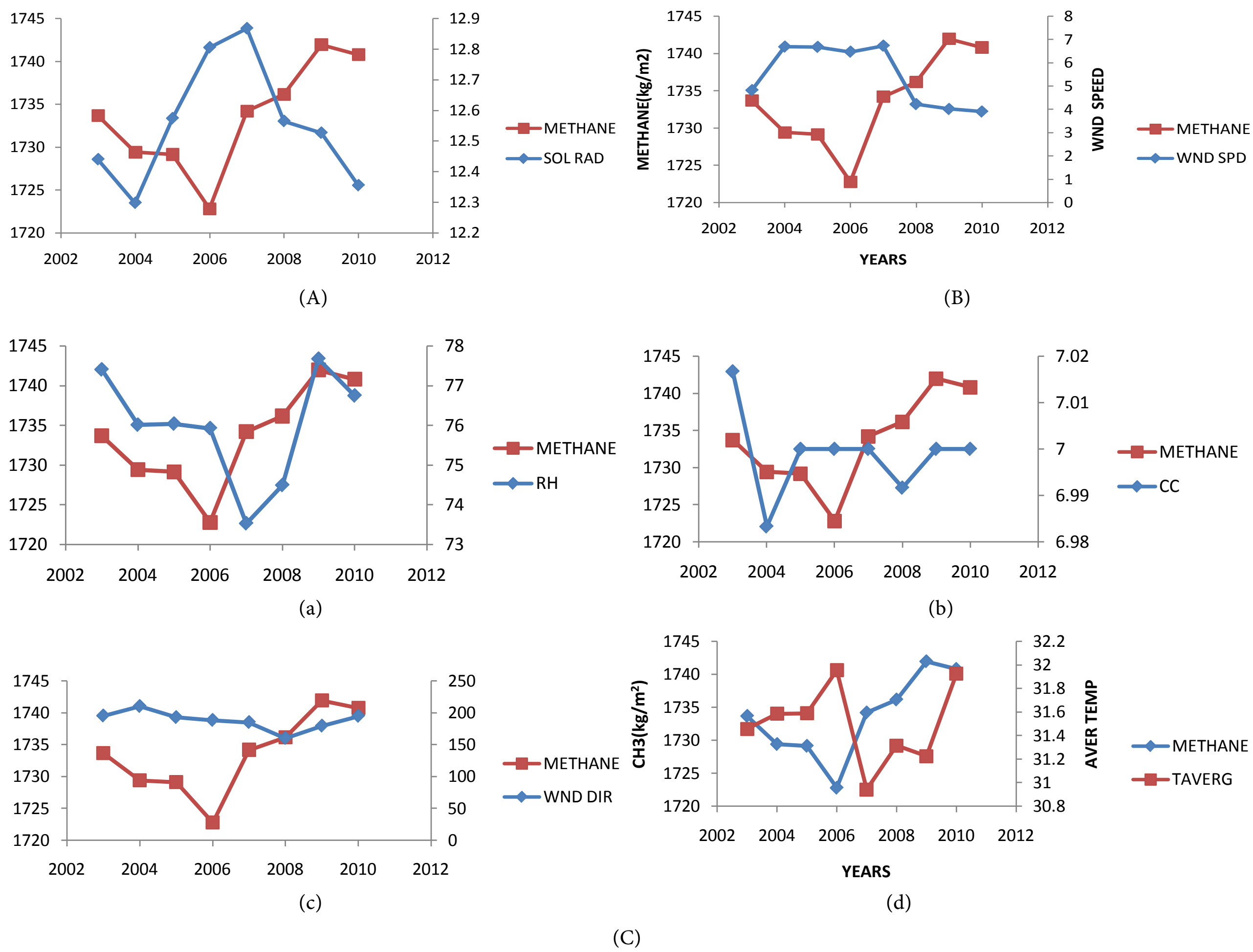
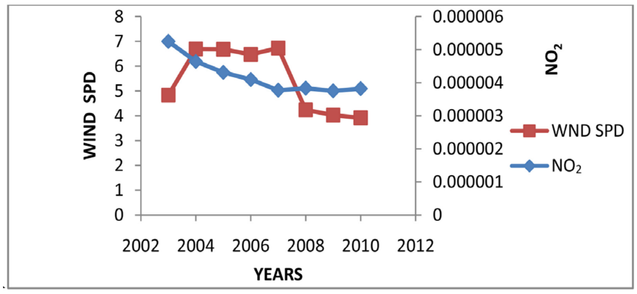
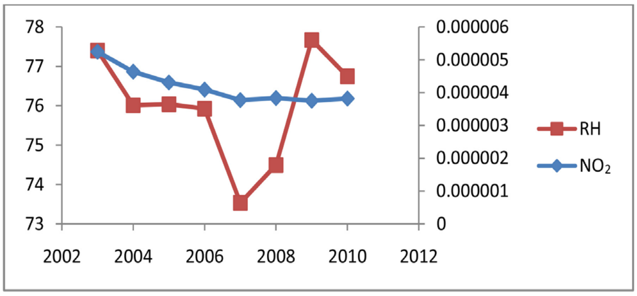


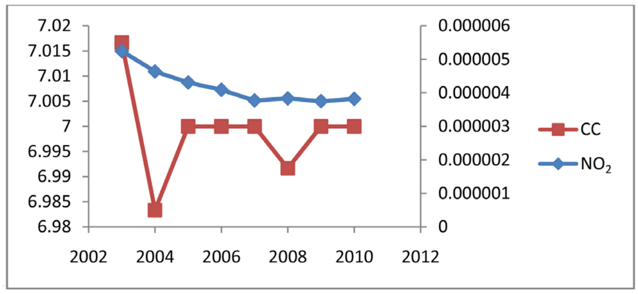
Figure 4. (A) Methane Correlation with Solar radiation; (B) Methane correlation with wind speed; (C) Methane concentration correlation with (a) Relative humidity, (b) cloud cover, (c) wind direction and (d) temperature.


WIND SPD
NO2
YEARS
WND SPD
NO2

(a)

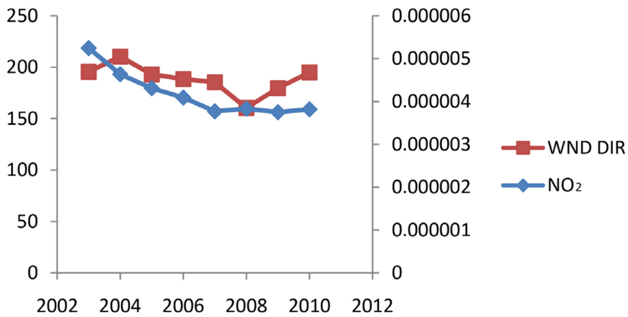

RH
NO2

(b)

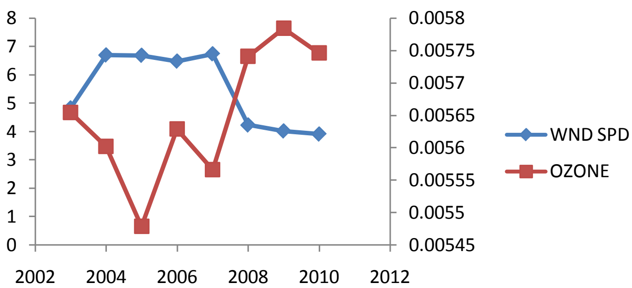

CC
NO2

(c)

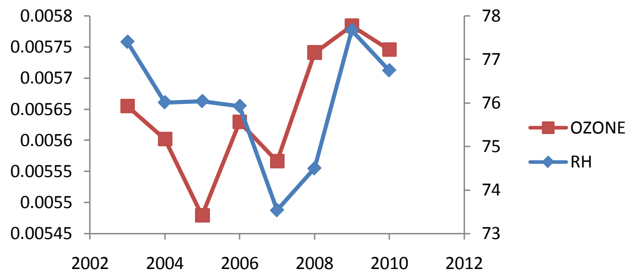
(A)


WND DIR
NO2

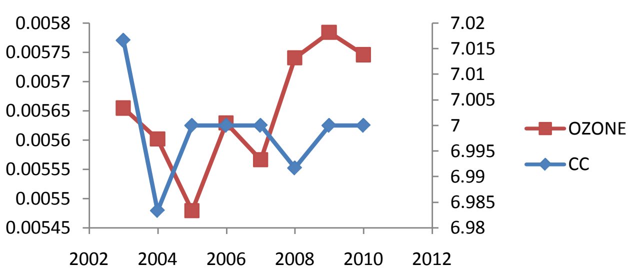
(a)


WND SPD
OZONE

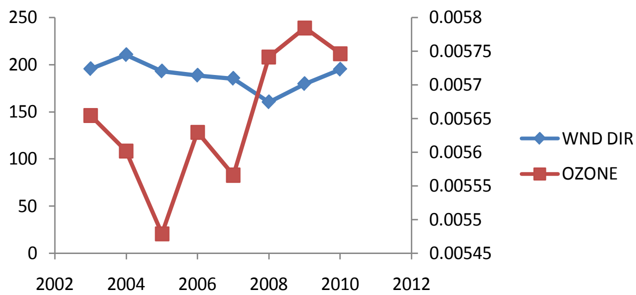
(b)


OZONE
RH

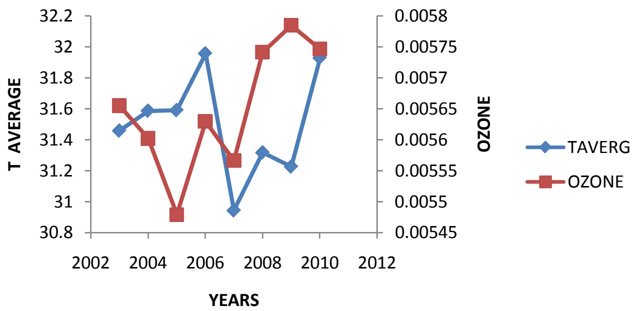
(c)


OZONE
CC

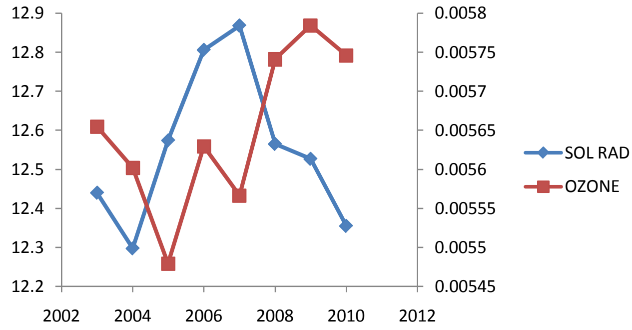
(d)


WND DIR
OZONE

(e)

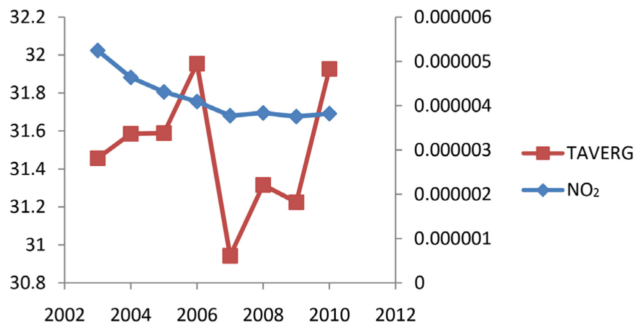


(f)



(g)

(B)



(C)

Figure 5. (A) NO_2 concentration correlation with (a) wind speed; (b) relative humidity; (c) cloud cover; (B*)* Ozone concentration correlation with all the parameters; (C) NO_2 concentration correlation with wind direction and temperature.

The Mann-Kendal rank statistics showed that the standardization variables $U'(t_i)$ for all the pollutants between the period of studies (2003-2012) has a sequential fluctuating behaviour around a zero level and which confirms validity of the trends used and the homogeneity of the pollutants considered in the region **Figures 6(A)-(D)**.

The CH_4, NO_2 and O_3 concentrations are the dependent variables, while meteorological factors are the independent variables. In this study, because the statistical analysis of the relative humidity showed an insignificant value, it was therefore not imputed into the equation for CH_4. It was only the wind speed that survived among the parameter utilized in this work because of its very high significance value in the statistical analysis. Also, the other parameters such as temperature, cloud cover and solar radiations were eliminated from the regression equation for CH_4 because of their very weak significant values in the statistical analysis. For NO_2, none of the parameters meet up with the entry requirement in the equation because all the other parameters showed a weak correlation with it (NO_2), hence the equation terminated when the regression analysis was carried out.

The remaining parameters considered in this work also showed weak relationship with tropospheric ozone except the wind speed which showed a very strong relationship with ozone. Hence, it was the only surviving parameter in the regression equation analysis.

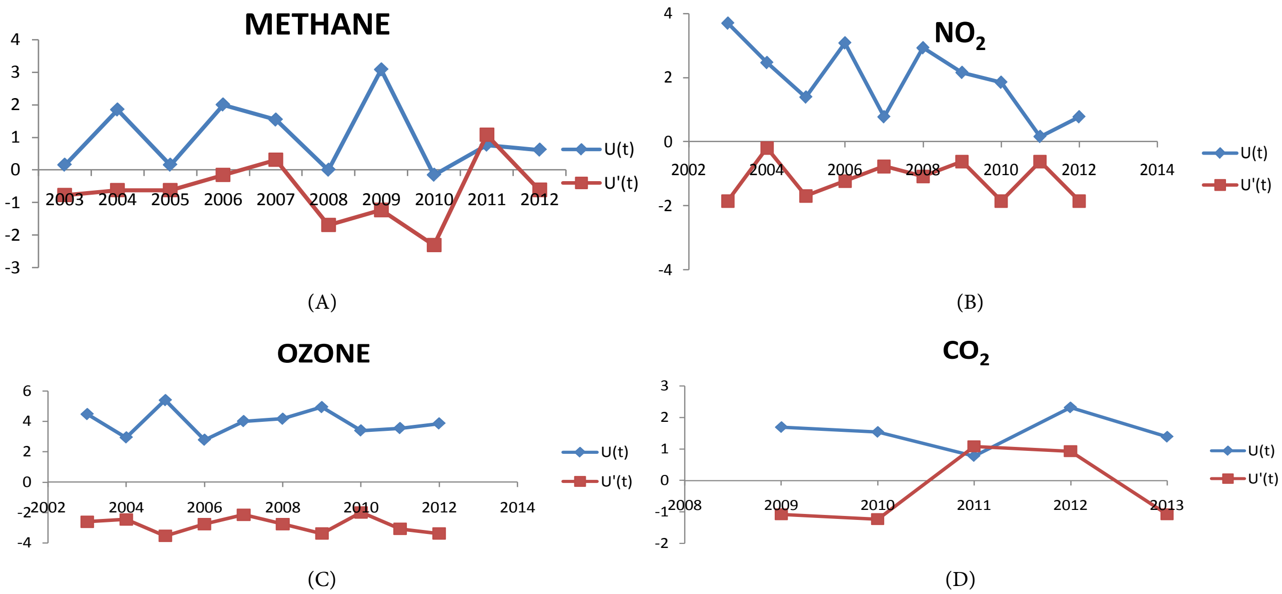


Figure 6. (A) Graph of Man-Kendall trend validation statistics for Methane; (B) Graph of Man-Kendall trend validation statistics for NO_2; (C) Graph of Man-Kendall trend validation statistics for ozone; (D) Graph of Man-Kendal trend validation statistics for CO_2.

There was a very strong correlation and a good coefficient of determination of about (81%) between O_3 concentration and the previous year's ozone concentration with the following parameters: wind speed, temperature, relative humidity, cloud cover, in which 19% is undetermined. In a similar way, there was also a strong dependence of CH_4 concentration and the previous year's concentration on the following parameters: wind speed, temperature, relative humidity. The regression model in Equation (1) showed that 65% of CH_4 has a very good dependence on these factors; where as 35% is undetermined. However, because of the weak dependence of NO_2 concentration on these factors, it was not possible for it to be modelled. The value from the correlation table is very low (0.213) for wind speed. This value cannot be modelled as the model will not survive the values below 0.5. The coefficient of determination was not obtained and so the rate of dependence is generally indeterminate.

A Pearson correlation was carried out on the 10 years data set. CH_4, O_3 and NO_2 monthly concentrations were correlated against monthly meteorological parameters (Table 2). This correlation was carried out to ascertain which of the atmospheric parameters were important in describing the behaviour of pollutants.

The Pearson correlation coefficient shows that solar radiation has a negative correlation with methane indicating that the increase in solar radiation causes a decrease in methane's concentration. This behaviour may be attributed to increase in heat flux which causes dry deposition and pollutant fall out.

Wind speed has a very strong negative correlation with methane concentration in Niger Delta (Figure 2 and Figure 3). This implies that the high decrease in speed of wind causes much increase in the production of methane. This is because at low wind speed, the emitted pollutant (methane) tends to accumulate near the source area and disperses with an increasing wind speed due to higher ventilation.

Close observations reveals that solar radiation lowers the concentration of ozone in Niger Delta region as it shows negative correlation with ozone concentration. The concentration wind of ozone with speed shows a strong negative value. This implies that increase in wind speed decreases the accumulation of ozone as much speed of the wind tends to disperse the pollutants and decreases the concentrations due to higher ventilation. Relative humidity shows a moderate positive correlation with ozone concentration while cloud cover and temperature shows a very weak positive correlation with ozone. This implies that the increase in these parameters causes a slight increase in ozone concentration.

Figure 4(C) and **Figure 5(C)** showed that CH_4 and NO_2 concentration decreases with increasing temperature, while Ozone concentration is the opposite in which it increases as temperature also increases (**Figure 5(B)**). There is a very strong negative correlation between wind speed and the pollutant (O_3 and CH_4) concentrations ($P < 0.01$ for O_3 and CH_4) (**Figure 4(B)** and **Figure 5(B)**). This implies that wind speed, among all the meteorological parameters studied, has more influence on the variation of O_3, NO_2 and CH_4 concentrations in the region of the Niger Delta, giving as high as 81% and 64% for O_3 and CH_4 respectively (**Figure 2** and **Figure 3**), while all the parameters are of less significance with NO_2 (**Figure 5(B)** and **Figure 5(C)**).

Wind speed, temperature, and solar radiation are effective meteorological variables in decreasing CH_4 concentration. Solar radiation is also effective meteorological variable in decreasing NO_2 concentration. Wind speed, solar radiation, wind direction, and minimum temperature are effective meteorological variable in decreasing $O_{3,}$ concentration. Whereas, maximum temperature, relative humidity and cloud cover promotes O_3 concentration although it is only the effect of wind speed that is strongly significant ($P < 0.01$) [12].

4. Conclusion

The spatial and temporal distribution of daily CH_4 (Methane), NO_2 (nitrogen dioxides) and O_3 (ozone) concentration in the Niger Delta region was observed depend on the variations in atmospheric parameters. A very strong negative correlation was obtained between wind speed and both the CH_4 and O_3 pollutants respectively, and a moderate correlation was obtained between the wind speed and NO_2. This implies that amongst the atmospheric parameters considered in this study for the region of the Niger Delta in Nigeria, wind speed has much influence on the variation of both CH_4 and O_3 concentrations, but with a little influence on the NO_2 concentrations.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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