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Industrial Air Pollutants Investigation in the Niger Delta Region of Nigeria

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Abstract

The discovery and exploitation of crude oil in the Niger Delta Region of Nigeria by the various Petroleum Companies have greatly enhanced the nation's economy. However, practices linked to their discovery, growth and production operations have important and detrimental local effects on the ambient atmosphere. A good understanding and quantification of the concentrations of the greenhouse gases in this region including those of CO_2, CH_4, O_3 and NO_2 as a by-product of crude oil and pollutants could assist in their mitigation. Thus, this work investigates the anomalous variation of these pollutants and their trends in the Niger Delta region to develop control strategies that will enhance the mitigations leading to air quality improvement in this region of Nigeria. The CH_4 and NO_2 data utilized in this work were sourced from the European Space Agency (ESA) for 10 years from January 2003 to December 2012. The same data period of 10 years was obtained for the tropospheric ozone (O_3) concentrations from the National Aeronautics and Space Administration (NASA), while a data period of six (6) years was obtained for CO_2 concentrations from six (6) experimental sites around the gas-flaring stations in the Niger Delta region from January 2005 to December 2010. However, 17 other sites with no gas-flaring records were selected as the control in both the Northern and Western regions of Nigeria. The analyses of the concentrations of these Pollutants were carried out using a descriptive statistical approach including regression and correlation analysis. The One-Way ANOVA was also utilized in comparing the concentrations of these pollutants in the flare region of the Niger Delta region to those of the non-flare region of Nigeria to be able to determine their statistical significance. The results of analyses showed that CH_4 concentrations were the main contributor to the air pollution problem in the Niger Delta region of Nigeria followed by CO_2. While for the non-flare stations considered, NO_2 has the highest concentration index aside from CO_2.

Subject Areas

Atmospheric Sciences, Environmental Sciences

Keywords

Industrial Air Pollutants, Crude Oil Pollutants, Anomalous Variation, Air Quality Improvement and Air Pollution Problem

1. Introduction

The Niger Delta region of Nigeria has been identified as one of the most polluted areas on the planet earth with air pollution as one of the most serious environmental issues ravaging the region [1]. The disposal of crude oil-related gases through flaring has been a crucial issue for the Nigerian oil and gas industries due to their non-economic viability. The subsequent repercussions of flaring these gases include the harm done to the environment as a result of the production of acid rain, the greenhouse effect, global warming, and ozone depletion. Although it was anticipated that the exploitation of natural resources such as crude oil and natural gas would accelerate and maintain the local development of the economy. Moreover, fossil fuel combustion had been producing greenhouse gases with additional pollutants enhancing climate change [2] [3]. However, in the Niger Delta, gas-flaring is a substantial cause of pollution. Also, the rapid oxidation or burning of natural gas and crude oil had been releasing heat matter and gaseous particulate into the atmosphere, which is harmful to the health of ecosystems [4] [5]. Greenhouse gases, volatile organic compounds, precursor gases, toxins (including benzene, hydrogen sulfide and toluene), and black carbon are all key components of flared gases damaging and destroying the environment [5] [6] [7] [8] [9]. Nigeria was ranked the fifth internationally among gas-flaring nations in 2014 as an improvement after consistently ranking second for three decades [5]. In 1970, 99% of the gases produced in Nigeria were flared. This fell to 51% in 2001 before rebounding to 53% in 2002 [10]. Although, in the year 2004/2005 the amount of gas flared accounted for about 39% of the total gas generated with only 10% of this flared in 2018. Thus, confirming a steady drop that began in 2002 [11]. However, the Nigerian government attempted to capitalize on the use of the associated gas by constructing a Liquefied Natural Gas (LNG) facility at Bonny. Nevertheless, there are still conflicting claims about the flaring of gases, in which the year 2018 was indicated as the year with the highest volume of gas emissions since the year 2012 [12]. In essence, there are indications that the practice of gas-flaring in Nigeria is worsening rather than improving despite that gas-flaring was originally outlawed in 1984, especially with another end-to-flaring date fixed for the year 2030 [13] [14]. Thus, this work is aimed at investigating the anomalous variation of greenhouse gases and their trends in the Niger Delta region with a view to developing control strategies that will enhance the mitigations leading to air quality improvement in this region of Nigeria.

2. Materials and Methods

The data for CH_4 and NO_2 concentrations 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), for the period of ten (10) years from January 2003 to December 2012 and that of Carbon dioxide (CO_2) for the period of six (6) years from January 2005 to December 2010. These data were collected from six (6) experimental sites around the gas-flaring station in the Niger Delta with additional seventeen (17) other sites with no gas-flaring records selected as the control in the Northern and the Western region of Nigeria.

The analysis of the concentrations of these pollutants (CH_4, NO_2, CO_2 and O_3) in this region of the Niger Delta was carried out using a descriptive statistical approach including regression and correlation analysis. The One-Way ANOVA was also utilized in comparing their concentrations in the flare region (Figure 1) with that of the non-flare region used as control (Table 1 and Figure 2) in order to determine their statistical significance.

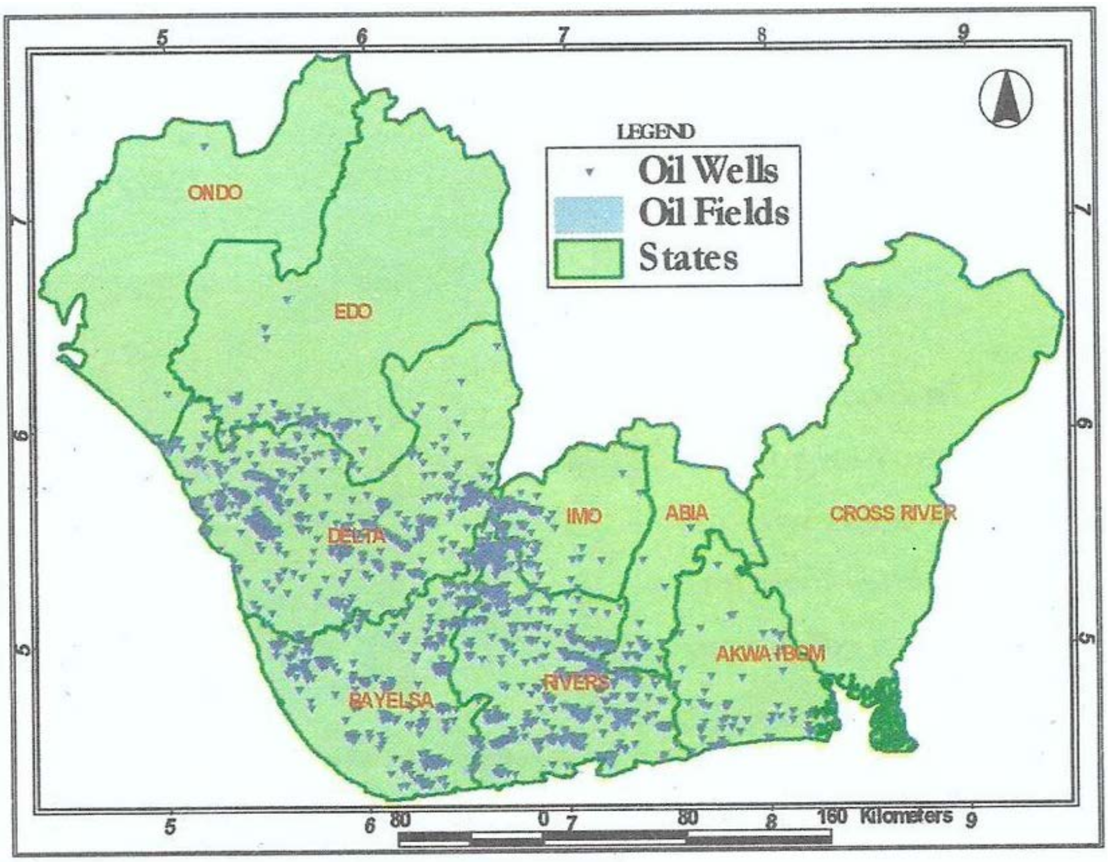


Figure 1. Map showing states in the Niger delta area with oilfields and wells concentration. Courtesy: UNDP, Niger Delta Human Development Report, 2006 [19].

Table 1. List of control stations used in this study.

Point	Location	Long.	Lat.	Elevation (m)
52	Ogun	3.00	6.75	321.5
53	Lagos	3.75	6.75	41.0
91	Abaji (Abuja)	6.75	8.25	220.0
92	Nasarawa	7.50	8.25	455.1
95	Taraba	9.75	8.25	293.0
108	F.C.T Abuja	6.75	9.00	455.9
109	Wuse 2 (Abuja)	7.50	9.00	49.0
111	Pankshin (Abuja)	9.00	9.00	1371.0
112	Tafawa Balewa	9.75	9.00	17.3
113	Liman Katagum	10.50	9.00	541.4
128	Jos Plateu	9.00	9.75	1220.0
129	Northern Bauchi	9.75	9.75	616.0
145	Southern Bauchi	9.00	10.50	600.0
161	Gandu Kano	8.25	11.25	508.0
162	Gwammaja	9.00	11.25	480.0
178	Kano North	8.25	12.00	488.0
179	Jigawa	9.00	12.00	459.0

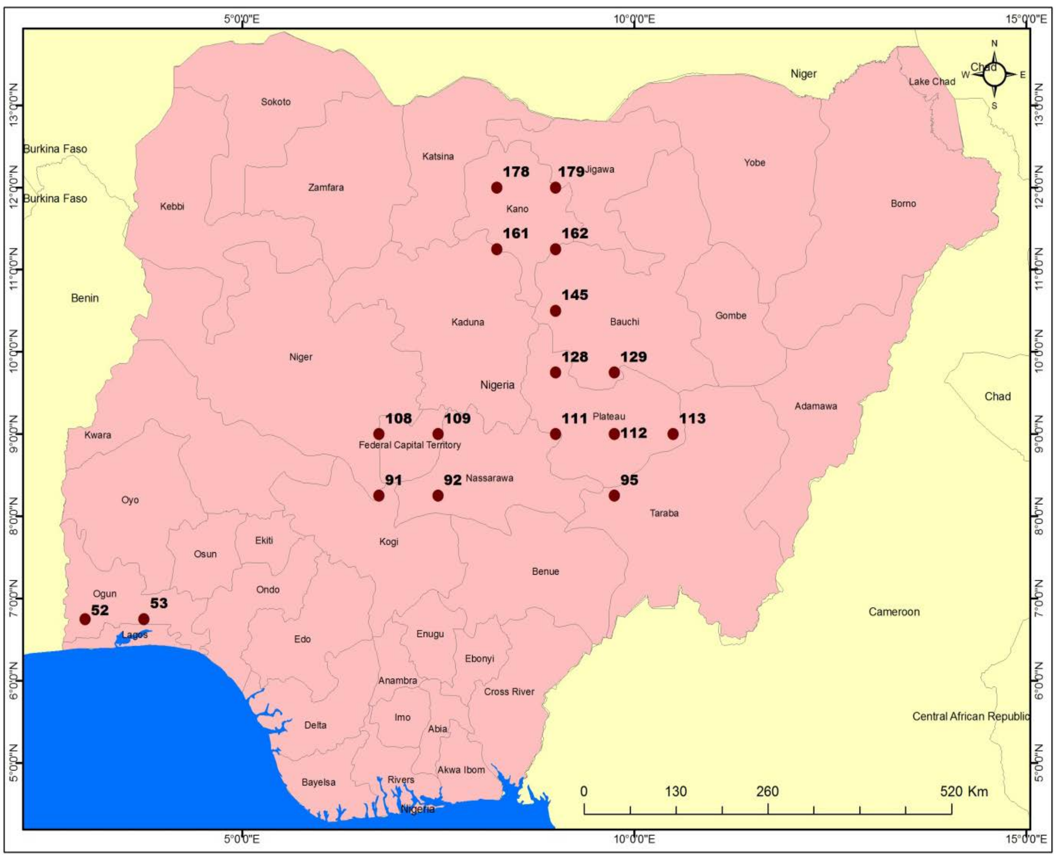


Figure 2. Map showing control stations and their pollutions emission points. (Source: NASRDA).

2.1. Regression Analysis

The linear regression involves examining the relationship between one independent variable (x) and another dependent variable (y). It is usually expressed as:

$$y = a + bx \tag{1}$$

where,

a is the intercept;

b is the regression coefficient.

The intercept could also be expressed as:

$$a = \frac{\sum y - b\sum x}{n} \tag{2}$$

While, the regression coefficient (*i.e.* slope or gradient) could be written as:

$$b = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \tag{3}$$

Also, linear regression could be expressed as:

$$y = a + bx + \varepsilon \tag{4}$$

where,

a is the intercept;

b is the regression coefficient;

ε is a random error component.

2.2. Trend Detection Using the ANOVA Test

The ANOVA test is a null hypothesis test used in analyzing the differences among the means of various groups. The observations in each group are independent of each other and obtained by a random sampling. The equations are generally written as:

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T} \tag{5}$$

$$SS_T = \sum_i \left(y_i - \bar{y}\right)^2 \tag{6}$$

$$SS_R = \sum_i \left(\hat{y}_i - \bar{y}\right)^2 \tag{7}$$

$$SS_E = \sum_i \left(y_i - \hat{y}_i\right)^2 \tag{8}$$

where,

SS_T is the total sum of squares;

SS_R is the sum of squares due to treatment;

SS_E is the sum of squares due to error.

A one-way ANOVA uses the following null and alternative hypotheses:

H_0 (null hypothesis): $\mu_1 = \mu_2 = \mu_3 = \cdots = \mu_k$ (The data are normally distributed).

H_1 (The data are not normally distributed): at least one data mean is different from the rest.

3. Result and Discussion

The average mean concentration of CH_4 in Niger Delta stations is 1740.77 ppm, while that of the non-flare stations is 3.55 ppm. Meanwhile, two (2) stations (Bayelsa and Portharcourt) in the Niger Delta stations have their mean CH_4 concentrations lower than that of the mean concentration of the entire Niger Delta stations considered (Tables 2-4). Also, five (5) stations (Abuja, Kano, Nasarawa, Taraba and Jigawa) in the non-flare stations have their mean methane concentrations lower than that of the mean concentration of the entire non-flare stations considered. However, it was observed that the closer the stations are to the source point (flare site), the higher the concentrations index except in Cross River station in 2008 (1597.793 ppm) which may be attributed to instrumentation breakdown or strong meteorological conditions within the station at that year. While in the non-flare station, the concentration did not follow the same trend as was observed in the Niger Delta stations.

Tables 2-4, further show that the standard deviation (SD) for methane in Bayelsa, Rivers and Delta states are 4.96, 4.98 and 4.80 respectively, while in Kano, Nasarawa and Jigawa (northern region) with less flares activities has SD of 0.02, 0.11 and 0.02 respectively, which are lower than unity (1). Thus, SD values in the northern region are lower than those of the Niger Delta region for the

Table 2. Comparison between mean concentrations of all the pollutants in Bayelsa station and other non-flare stations.

	RIVER	OGUN	LAGOS	ABUJA	KANO	NASARAWA	TARABA	JIGAWA
CH_4	1741 ± 4.96	6.97 ± 0.27	13.21 ± 0.5	0.049 ± 0.00	0.32 ± 0.02	1.68 ± 0.11	2.34 ± 0.12	0.32 ± 0.02
O_3	56.89 ± 0.53	329.6 ± 1.6	329.5 ± 1.3	329.5 ± 1.3	328.5 ± 0.7	329.3 ± 1.34	329.1 ± 1.4	328.5 ± 0.7
NO_2	187.1.3 ± 2.2	290.3 ± 5.1	296.7 ± 1.6	160.2 ± 2.3	138.3 ± 2.0	143.0 ± 1.09	280.5 ± 2.2	119.8 ± 1.3
CO_2	385.6 ± 2.10	393.0 ± 14	393.0 ± 1.4	392.7 ± 1.3	393.5 ± 1.5	393.7 ± 1.34	393.2 ± 1.4	394.1 ± 1.6

Table 3. Comparison between mean concentrations of all the pollutants in Rivers station and other non-flare stations.

	RIVER	OGUN	LAGOS	ABUJA	KANO	NASARAWA	TARABA	JIGAWA
CH_4	1742 ± 4.98	6.97 ± 0.27	13.21 ± 0.5	0.04 ± 0.00	0.32 ± 0.02	1.68 ± 0.11	2.34 ± 0.12	0.32 ± 0.02
O_3	56.89 ± 0.53	329.6 ± 1.6	329.5 ± 1.3	329.5 ± 1.3	328.5 ± 0.7	329.3 ± 1.34	329.1 ± 1.4	328.5 ± 0.7
NO_2	108.3 ± 2.43	290.3 ± 5.1	296.7 ± 1.6	160.2 ± 2.3	138.3 ± 2.0	143.0 ± 1.09	280.5 ± 2.2	119.8 ± 1.3
CO_2	385.6 ± 2.10	393.0 ± 14	393.0 ± 1.4	392.7 ± 1.3	393.5 ± 1.5	393.7 ± 1.34	393.2 ± 1.4	394.1 ± 1.6

Table 4. Comparison between mean concentrations of all the pollutants in Delta station and other non-flare stations.

	DELTA	OGUN	LAGOS	ABUJA	KANO	NASARAWA	TARABA	JIGAWA
CH_4	1748 ± 4.8	6.97 ± 0.3	13.21 ± 0.5	0.04 ± 0.00	0.32 ± 0.02	1.68 ± 0.11	2.34 ± 0.12	0.32 ± 0.02
O_3	56.98 ± 0.51	329.6 ± 1.6	329.5 ± 1.3	329.5 ± 1.26	328.5 ± 0.7	329.3 ± 1.34	329.1 ± 1.4	328.5 ± 0.66
NO_2	134.2 ± 2.15	290.3 ± 5.2	296.7 ± 1.6	160.2 ± 2.29	138.3 ± 2.0	143.0 ± 1.09	280.5 ± 2.2	119.8 ± 1.26
CO_2	385.6 ± 2.12	393.0 ± 1.4	393.0 ± 1.4	392.7 ± 1.34	393.5 ± 1.5	393.7 ± 1.34	393.2 ± 1.4	394.1 ± 1.61

same period of study. In essence, gas-flaring has more impact on the production and distribution of atmospheric pollution especially methane than any other sources, as a result of uncontrolled burning of natural gas and subsequent release to the atmosphere. Similarly, the SD values of CO_2 concentrations in Bayelsa, Rivers and Delta stations are 2.10, 2.10 and 2.12 respectively, while those of Kano, Nasarawa, Taraba and Jigawa (*i.e.* non-flares northern region) are 1.51, 1.34, 1.42 and 1.61, respectively, showing clear evidence that the CO_2 effluence is higher in the industrialized locations. This is due to the fact that Carbon dioxide is the most abundant pollutant gas in flare sites apart from methane due to its resident time in the atmosphere [15].

The result of ANOVA shows that CH_4 has the highest concentration index in the Niger Delta region where there was gas-flaring as compared to the stations without gas-flaring in the Western (Ogun and Lagos) and Northern (Abuja, Kano, Nasarawa, Taraba and Jigawa) locations. Thus, methane concentration is higher in the Niger Delta stations than those in the non-flare stations showing that methane is one of the major pollutants abundant in the gas flare stations (**Figures 3(a)-(c)**). This could be attributed to uncontrolled gas flare and some meteorological factors such as prevalent rainfall activities in the region that enhance its accumulation [16].

Figures 4(a)-(c) show the comparison between atmospheric Ozone (O_3) in Niger Delta (Bayelsa, Rivers and Delta) stations with non-flare stations. The results of the linear trend showed that the mean concentration plots for O_3 in the non-flare stations are increasing than those in Niger Delta stations. This indicates that tropospheric ozone is more abundant in other anthropogenic sources such as fossil fuel combustion, power plant and vehicular emission than in the gas-flaring sources.

Figures 5(a)-(c) show a non-linear trend in the mean annual concentration index of NO_2. Three (3) stations in the non-flare stations (Ogun, Lagos and

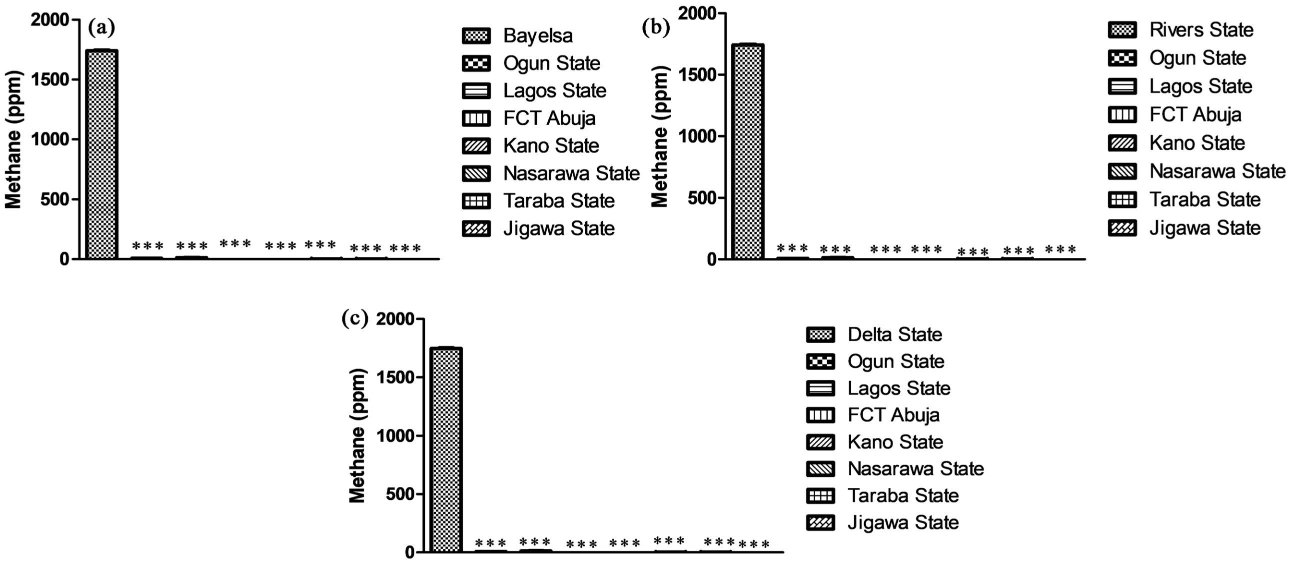


Figure 3. Comparison of methane between the flare region and non flare region.

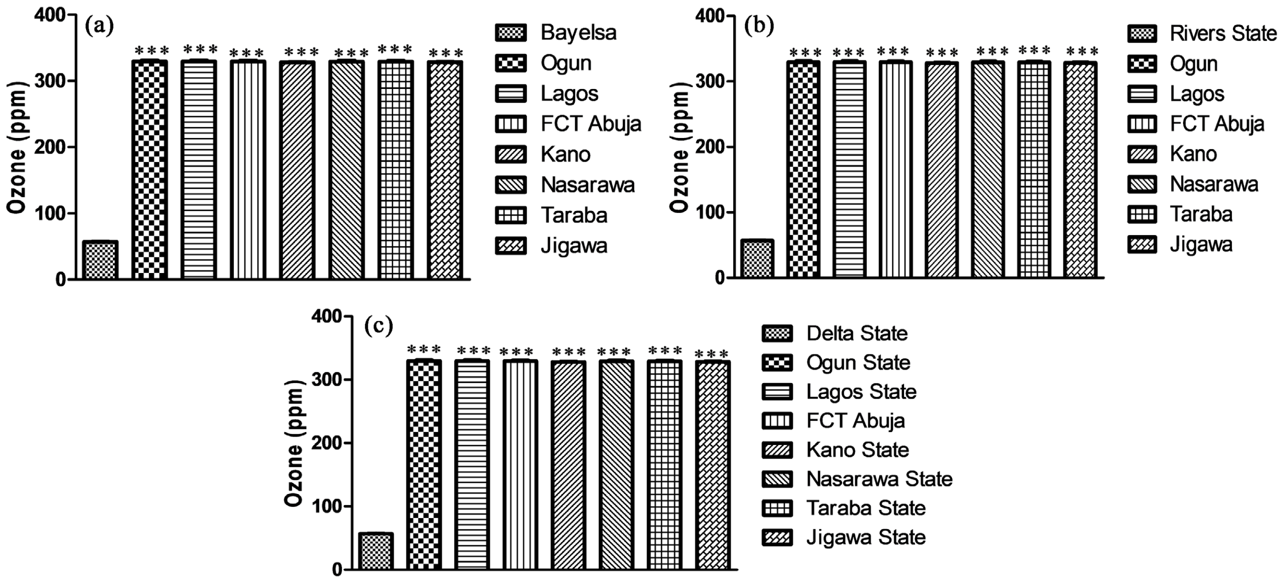


Figure 4. Comparison of ozone between the flare region and non flare region.

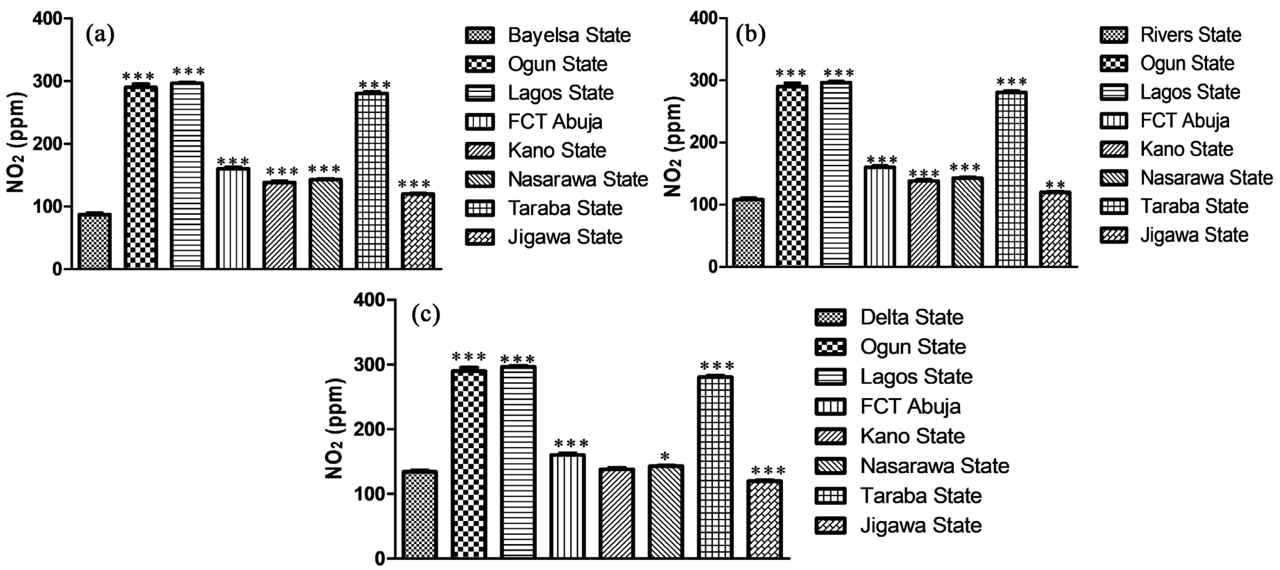


Figure 5. Comparison of NO_2 between the flare region and non flare region.

Taraba) showed high concentration index than those in the Niger Delta stations. The concentration of NO_2 in the Jigawa station showed low statistical significance when compared with the Rivers (Port Harcourt) station. Also, it was observed that NO_2 concentrations in Kano and Nasarawa stations are not statistically significant when compared with Niger Delta (Delta) stations.

Figures 6(a)-(c) show the comparative CO_2 concentration index between Niger Delta stations and non-flare stations. The result showed a strong statistical relationship in CO_2 concentration in both flare and non-flare stations as there is a homogeneous monotonic increase in the concentration index of CO_2. In all the stations considered. This result shows that CO_2 is one of the most abundant pollutants in the flare stations aside from CH_4 while for non-flare stations, CO_2

has the highest index followed by NO_2.

The result of the regression statistics (Tables 2-4) showed that gas-flaring has a greater influence on the concentration of CH_4 and CO_2 respectively. The increase in the gas-flaring activities seems to increase the concentration of the pollutants for they tend to accumulate near the source point but decrease in the non-flaring locations. However, the decreases in the concentrations of these pollutants are caused by wind, dry depositions and other mitigation processes.

The results of the statistical averages (Tables 5-7) of all the pollutants in Bayelsa state with their standard deviation and standard error showed that year

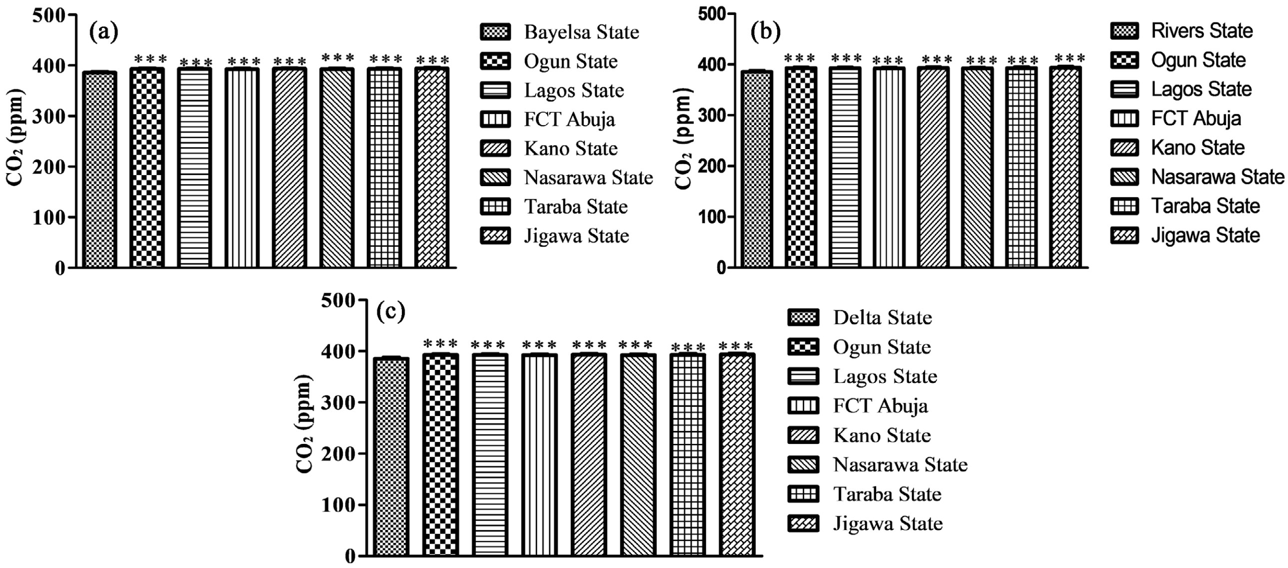


Figure 6. Comparison of CO_2 between the flare region and non flare region.

Table 5. Monthly averages of air pollutant concentrations in Bayelsa State with their standard deviation and standard error for the period 2003-2012.

YEARS	MEAN CONC of CH_4 (ppm)	Standard deviation (SD) of CH_4	Standard error (SE) of CH_4	MEAN CONC of O_3 (ppm)	Standard deviation (SD) of O_3	Standard error of O_3	MEAN CONC of NO_2 (ppm)	Standard deviation (SD) of NO_2	Standard error of NO_2
2003	1723.946	21.91	6.32	56.1647	2.06	0.59	94.12148	38.73	11.18
2004	1729.728	13.87	4.00	57.3319	2.17	0.63	92.64547	43.99	12.70
2005	1730.286	8.37	2.42	54.4281	1.27	0.37	90.64494	42.17	12.17
2006	1722.223	14.28	4.12	57.1586	3.35	0.97	91.46054	40.41	11.67
2007	1732.921	15.46	4.46	55.2187	1.42	0.41	83.15172	35.36	10.21
2008	1736.170	14.23	4.11	58.6802	2.96	0.85	83.13088	33.12	9.56
2009	1742.412	12.27	3.54	57.1286	2.12	0.61	85.11320	33.911	9.79
2010	1740.400	7.33	2.12	58.1763	3.43	0.99	76.38385	41.53	11.99
2011	1752.255	21.23	6.13	58.3196	1.61	0.46	86.42268	31.58	9.12
2012	1767.420	13.77	3.97	56.7783	1.75	0.50	78.80879	33.43	9.65

Table 6. Monthly averages of air pollutant concentrations in Rivers State with their standard deviation and standard error for the period 2003-2012.

YEARS	MEAN CONC of CH_4 (ppm)	Standard deviation (SD) of CH_4	Standard error (SE) of CH_4	MEAN CONC of O_3 (ppm)	Standard deviation (SD) of O_3	Standard error of O_3	MEAN CONC of NO_2 (ppm)	Standard deviation (SD) of NO_2	Standard error of NO_2
2003	1735.398	21.83	6.30	55.9953	2.00	0.58	110.446	48.70	14.06
2004	1730.427	13.87	4.00	57.2429	2.16	0.62	115.194	51.06	14.74
2005	1731.348	8.16	2.36	54.3009	1.22	0.35	113.295	53.17	15.35
2006	1723.773	14.90	4.30	57.0647	3.34	0.96	115.726	51.91	14.99
2007	1734.091	15.18	4.38	55.0859	1.34	0.39	95.2234	35.82	10.34
2008	1737.264	13.49	3.89	58.6348	2.91	0.84	103.759	49.51	14.29
2009	1743.735	12.19	3.52	57.0171	2.08	0.60	107.113	46.93	13.55
2010	1742.048	7.34	2.12	58.0992	3.44	0.99	105.718	48.65	14.04
2011	1752.863	21.21	6.12	58.2138	1.56	0.45	102.646	39.06	11.28
2012	1768.989	13.51	3.90	56.7082	1.68	0.48	109.667	49.98	14.43

Table 7. Monthly averages of air pollutant concentrations in Delta State with their standard deviation and standard error for the period 2003-2012.

YEARS	MEAN CONC of CH_4 (ppm)	Standard deviation (SD)of CH_4	Standard error (SE) of CH_4	MEAN CONC of O_3 (ppm)	Standard deviation (SD) of O_3	standard error of O_3	MEAN CONC of NO_2 (ppm)	Standard deviation (SD) of NO_2	Standard error of NO_2
2003	1741.028	19.21	5.55	56.26	2.25	0.65	135.0419	64.63	18.66
2004	1738.174	11.76	3.39	57.25	2.27	0.65	141.1649	75.33	21.75
2005	1737.377	6.73	1.94	54.50	1.35	0.39	134.5924	67.06	19.36
2006	1731.105	10.63	3.06	57.14	3.43	0.99	143.5328	70.38	20.32
2007	1741.013	14.28	4.12	55.27	1.52	0.44	126.8056	57.45	16.59
2008	1743.488	12.81	3.69	58.56	3.11	0.89	129.6386	60.58	17.49
2009	1750.132	8.54	2.47	57.26	2.34	0.67	135.6946	59.09	17.06
2010	1746.159	6.59	1.90	58.03	3.42	0.99	127.5164	60.59	17.49
2011	1759.879	20.25	5.85	58.32	1.78	0.51	133.9337	51.27	14.79
2012	1773.897	11.76	3.39	56.80	1.98	0.57	132.7467	54.65	15.78

2012 has the highest methane effluence (1767.42 ppm) in all the stations within the years considered, while low value of the concentration was recorded in year 2006 (1722.22 ppm).

Figures 7(a)-(c) show the non-linear trends of the pollutants in Niger Delta stations and revealed that methane has the highest uniform variations among all the pollutants considered in the region because of its abundance in the flare source point [17].

Figures 8(a)-(c) show that the concentration of methane pollutant follows a

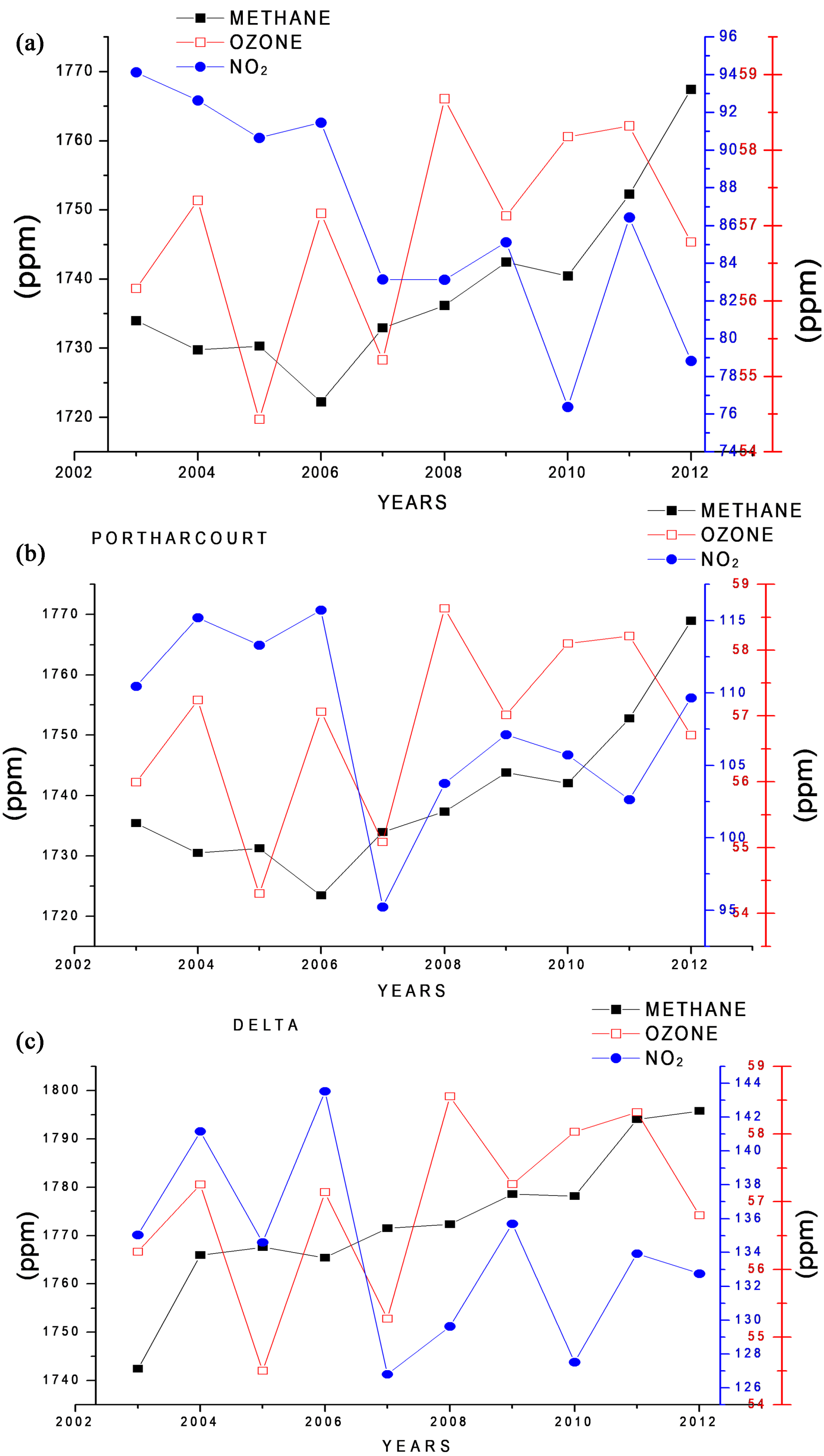
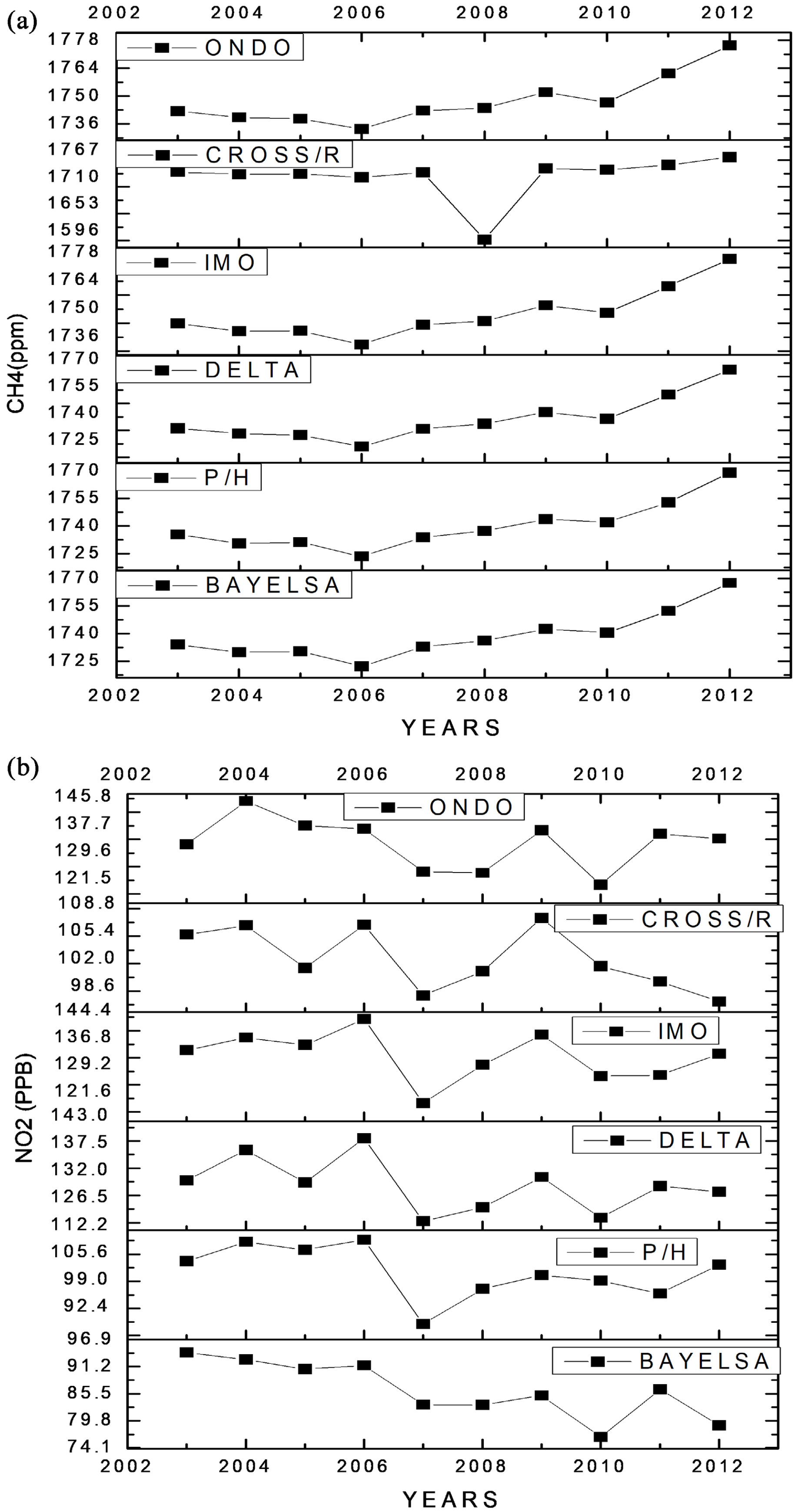


Figure 7. Average concentrations of the pollutants in Niger Delta. (a) Bayelsa State; (b) Rivers State; (c) Delta State.


(a)
CH4(ppm)
ONDO
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(c)

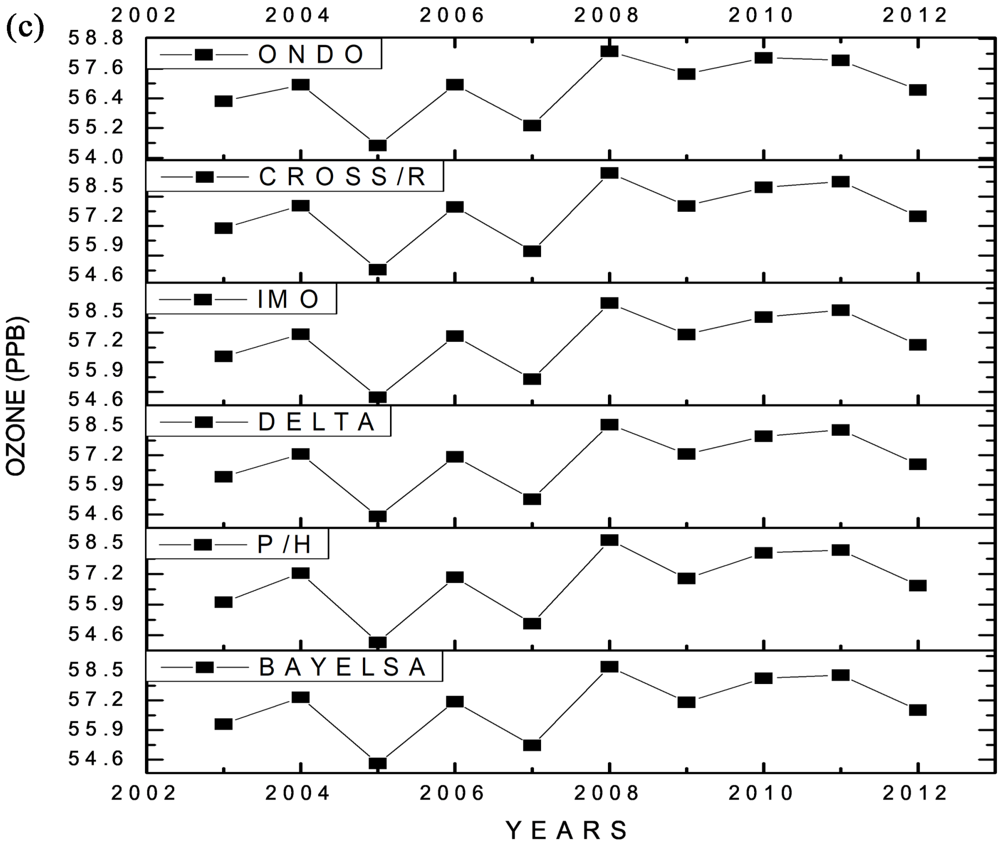

Figure 8. Trend pattern of CH_4, NO_2 and O_3 in the Niger Delta region. (a) CH_4 (ppm); (b) NO_2 (ppm); (c) O_3 (ppm).

regular increasing pattern throughout the years considered except in Cross-River state in 2008 where there is a drastic drop in the concentration, while NO_2 and O_3 followed a non-linear trend in all the stations considered.

4. Conclusion

This work utilized satellite pollution data to quantify air emissions in the Niger Delta region (flare zone) in comparison with that of the non-flared zone. The results obtained showed that gas-flaring tends to contribute significantly to air emissions in the Niger Delta region. However, it was observed that both CH_4 and CO_2 gases were the most abundant pollutants in this region due to gas-flaring. Moreover, the pollution decreases as the distance increases from the flare site. Also, O_3 increases mostly in locations with little or no gas-flaring rates than in locations that are deeply involved in the flaring cycle. It was further observed that due to vehicular emissions ozone precursors such as NO_2, carbon monoxide and volatile organic compounds are also prevalent in this region of Nigeria [18]. Likewise, NO_2 though more prevalent and dominant in the states with less flare capacity also experiences irregular patterns in concentrations. Moreover, it was observed that major cities and towns situated far away from flaring sites such as Lagos, Abuja, Kano and Ogun states are also polluted beyond the recommended limits due to pollution from diverse sources. Hence, the results of this study will further assist in the management and regulation of air pollution in Nigeria, especially in the Niger Delta region.

Conflicts of Interest

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

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