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Impact of Concentration Levels of Atmospheric Pollutants on Local Climate of Delta State, Nigeria

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Abstract

Studies in various regions of the world have revealed that air pollution can have a significant influence on local climate. This study therefore considers the impact of concentration levels of atmospheric pollutants on local climate of Delta state, Nigeria. Monthly and annual averaging of the daily pollutant concentrations and meteorological parameters within the period of investigation was carried out. Descriptive Statistics, correlation analysis, coefficient of determination (R^2) analysis and least squares regression analysis of the selected meteorological parameters with CH_4 and O_3 concentrations for the period of 2003 to 2012 and NO_2 and CO_2 concentrations for the period of 2011 to 2014 were carried out. The regression relationship was then used to obtain predicted values for the meteorological parameters within the period of investigation. The results of the descriptive statistics of annual averages of CH_4, O_3, NO_2 and CO_2 concentrations within the period of investigation revealed that the emission levels breached FEPA and EGASPIN limits. The results of the correlation analysis indicated that CO_2 had a strong significant positive correlation with temperature with a correlation coefficient of 0.962, while a moderate negative correlation coefficient of 0.549 was obtained for CH_4, and very weak correlation coefficients of -0.167 and 0.077 were obtained for O_3 and NO_2 respectively. CH_4, O_3 and CO_2 had a moderately significant positive correlation with solar radiation with correlation coefficients of 0.661, 0.571 and 0.656 respectively, while a weak negative correlation coefficient of 0.106 was obtained for NO_2. CH_4 had a strong significant positive correlation with relative humidity with a correlation coefficient of 0.859, while moderate correlation coefficients of -0.516 and 0.646 were obtained for NO_2 and CO_2 respectively, and a weak correlation coefficient of 0.345 was obtained for O_3. CO_2 and CH_4 had a strong significant correlation with wind speed with correlation coefficients of 0.951 and -0.906 respectively, while a moderate nega-

tive correlation coefficient of 0.518 was obtained for O_3, and a weak negative correlation coefficient of 0.317 was obtained for NO_2. The predicted values of the meteorological parameters showed a significant level of agreement with their measured values. Therefore, among the atmospheric pollutants postulated as influencing meteorological parameters, CO_2 appears to be the most strongly significant in explaining temperature variations in this region of Niger Delta, with correlation coefficient of 96.2% and coefficient of determination (R^2) of 0.926, implying that CO_2 influenced 92.6% variation in temperature in this part of Niger Delta within the period of investigation.

Keywords

Air Pollution, Atmospheric Pollutants, Local Climate, Meteorological Parameters

1. Introduction

Air pollution is a major environmental problem facing the Niger Delta region [1]. Air pollution is the contamination of the atmosphere by noxious gases and particulates.

Studies have revealed that air pollution can have a major effect on local climate [1]. Due to the spatial distributions of atmospheric pollutants with higher concentration levels mostly found near emission sources, variations in emission and concentration levels of air pollutants can cause a significant influence on local climate [2] [3] and in some situations regional climate by means of teleconnections in the atmosphere [4].

About 8 billion cubic meters of gas is flared yearly at various oil production sites in Nigeria [1]. It has been reported that the Niger Delta region of Nigeria has more than 123 gas flaring sites making Nigeria one of the major emitters of greenhouse gases in Africa [5]. Nigeria is accountable for almost one-sixth of the gas flared worldwide [6]. Nearly 75% of Nigeria's natural gas is being flared and all occur in the Niger Delta region. The flares have contributed more greenhouse gases thereby causing climate change which could possibly lead to increased occurrence of flooding in the region [7].

There have been occurrences of acidified rain in the Niger Delta region due to the introduction of a high concentration of sulphur and oxides of nitrogen into the atmosphere [8] [9]. Combustion processes in gas flaring sites give rise to the emission of lower fractions of hydrocarbons and oxides of nitrogen and the presence of ultraviolet radiation produces smog which could cause a reduction in visibility [10].

About 45.8 billion kilowatts of heat are released into the atmosphere of the Niger-Delta from 1.8 billion ft^3 of gas daily [11]. Heat production destroys vegetation in the vicinity of the heat source [12]. [13] undertook a study on the analysis of carbon monoxide concentration levels with some selected meteorological

parameters such as wind speed, relative humidity and temperature in ten major cities in the south eastern part of Nigeria. The result of the correlation analysis showed that out of all the meteorological parameters studied, only wind speed showed a strong correlation with carbon monoxide.

[14] undertook a study on the use of greenhouse gases as climate proxy data in explaining variability in climate. The standard deviation of CH_4 and CO_2 concentrations showed good correlations with the years associated with warming and can be used as good climate proxies. Furthermore, [15] carried out a study on the effect of meteorological parameters on distribution of atmospheric pollutants in Bayelsa State, Nigeria. The results revealed that wind speed showed a strong correlation with O_3 and CH_4 concentration levels.

Even though some amount of work has been done on the sources and distribution of air pollutants, so far, no major study has been undertaken on the effect of atmospheric pollutants on local climate in the Niger Delta. This work is aimed at increasing research efforts on understanding the association of atmospheric pollutants and related climate and environmental impacts in the Niger Delta Area.

2. Study Station, Materials and Method

2.1. Study Station

Figure 1 is the map showing gas flaring sites and highlighting study station (Warri). The city of Warri (5.52°N, 5.75°E) is a major center of petroleum activities in

Figure 1. Map of delta state showing gas flaring sites and highlighting study station: Warri. Source: NASRDA.

southern Nigeria. It has a population of over 311,970 (2006 census) [16]. The climate is marked by two different seasons: the rainy season (May to October) and the dry season (November to April). Over the course of the year, temperature typically varies from 20.56°C to 31.11°C and is rarely below 16.11°C or above 33.33°C. Rainfall periods vary from January to December with annual rainfall amount of about 2768.8 mm.

2.2. Materials

Data description

The data on daily methane (CH_4) with tropospheric ozone (O_3) concentration levels (for the period of 2003 to 2012) and daily nitrogen dioxide (NO_2) with carbon dioxide (CO_2) concentration levels (for the period of 2011 to 2014) used in this study were obtained from the National Aeronautics and Space Administration (NASA). The data on meteorological parameters (wind speed, solar radiation, temperature and relative humidity) for the period of 2003 to 2014 were acquired from the Nigerian Meteorological Agency (NIMET), Lagos.

2.3. Method

Monthly and annual averaging of the daily pollutant concentrations (NASA data) and meteorological parameters (NIMET data) within the period of investigation was carried out. The statistical analysis of weather parameters in this region of the Niger Delta with CH_4 and O_3 concentrations for the period of 2003 to 2012 and with NO_2 and CO_2 concentrations for the period of 2011 to 2014 were carried out. The regression relationship:

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

was used to obtain predicted values for the meteorological parameters within the period of investigation, so that by comparing the level of agreement between the predicted and measured values, we could ascertain the reliability of the model in this part of Niger Delta. Where:

Y = meteorological parameter (predicted);

X = atmospheric pollutant concentration;

b and a are the slope and intercept respectively and are given as:

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

$$a = \frac{\Sigma y}{n} - b\frac{\Sigma x}{n} \tag{3}$$

3. Results and Discussion

3.1. Average Annual Concentration Levels of the Atmospheric Pollutants and Meteorological Parameters

Table 1 shows the values of average annual concentration levels of CH_4 with O_3 for the period of 2003 to 2012 and selected meteorological parameters for the period of 2003 to 2014, while Table 2 shows the values of average annual concentration

Table 1. Values of average annual concentration levels of CH_4 and O_3 for the period of 2003 to 2012 and selected meteorological parameters for the period of 2003 to 2014.

Year	Mean CH_4 (ppmv)	Mean O_3 (ppmv)	Solar radiation (MJ/m^2)	Relative humidity (%)	Temperature (°C)	Wind speed (m/s)
2003	1740.994	56.262	22.973	81.567	23.361	2.327
2004	1738.120	57.253	22.723	81.207	23.215	2.329
2005	1737.331	54.501	21.970	79.705	23.381	2.415
2006	1730.918	57.139	23.072	80.560	23.229	2.346
2007	1740.740	55.272	22.791	79.938	23.037	2.341
2008	1743.628	58.556	23.062	78.871	22.977	2.324
2009	1750.178	57.259	22.251	84.289	23.536	2.235
2010	1746.312	58.033	23.548	84.700	23.693	2.242
2011	1759.923	58.319	23.921	85.781	22.669	2.068
2012	1773.787	56.800	24.012	87.538	22.724	2.093
2013			23.582	87.920	22.898	2.092
2014			24.963	87.388	23.315	2.122

Table 2. Values of average annual concentration levels of NO_2 and CO_2 for the period of 2011 to 2014.

Year	Mean NO_2 (ppmv)	Mean CO_2 (ppmv)
2011	135.695	382.370
2012	127.516	385.108
2013	133.934	388.111
2014	132.747	392.186

levels of NO_2 and CO_2 with selected meteorological parameters for the period of 2011 to 2014.

3.2. Descriptive Statistics of the Atmospheric Pollutants and Selected Meteorological Parameters

Table 3 shows the descriptive statistics of annual averages of CH_4, O_3, NO_2 and CO_2 concentrations, while Table 4 shows the descriptive statistics of annual averages of selected meteorological parameters.

3.3. Impact of the Atmospheric Pollutants Concentration on Meteorological Parameters

The impact of the concentration of atmospheric pollutants on selected meteorological parameters was determined using correlation analysis, coefficient of determination (R^2) analysis and least squares regression analysis.

3.3.1. Correlation Analysis

Table 5 shows the correlation coefficients between selected meteorological parameters and CH_4, O_3, NO_2 and CO_2 concentrations.

Figures 2(a)-(d) show temperature correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively, Figures 3(a)-(d) show solar radiation correlation

Table 3. Descriptive statistics of annual averages of CH_4, O_3, NO_2 and CO_2 concentrations within the period of investigation.

	Mean	Standard Deviation	Minimum	Maximum
CH_4 (ppmv)	1746.193	12.500	1730.918	1773.787
O_3 (ppmv)	56.939	1.300	54.501	58.556
NO_2 (ppmv)	132.473	3.519	127.516	135.695
CO_2 (ppmv)	386.944	4.208	380.139	392.186

Table 4. Descriptive statistics of annual averages of selected meteorological parameters within the period of 2003 to 2014.

	Mean	Standard Deviation	Minimum	Maximum
Solar radiation (MJ/m^2)	23.239	0.822	21.970	24.963
Relative humidity (%)	83.289	3.355	78.871	87.920
Temperature (°C)	23.170	0.315	22.669	23.693
Wind speed (m/s)	2.245	0.121	2.068	2.415
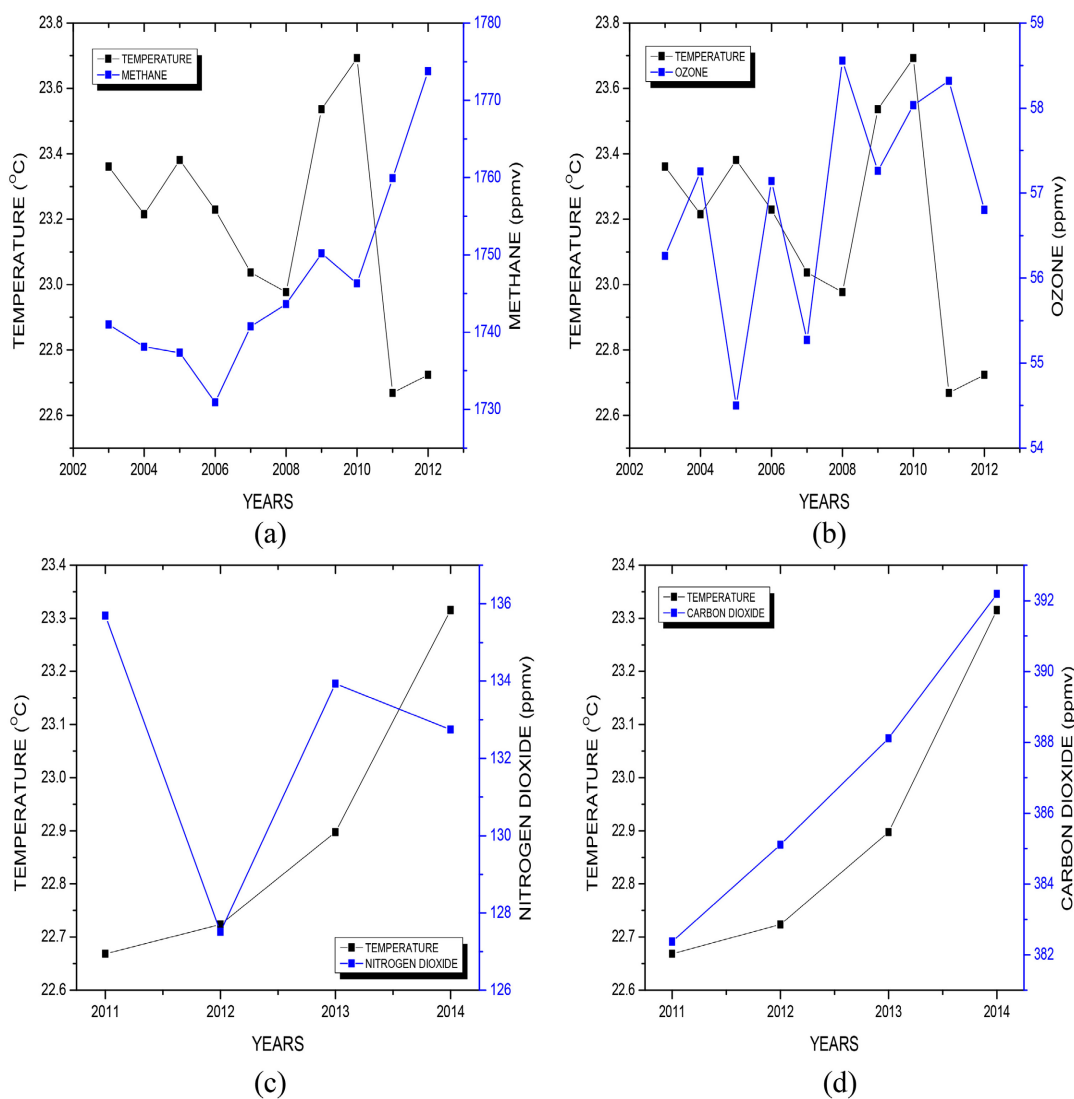
Figure 2. (a)-(d) Temperature correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

Table 5. Correlation coefficients between selected meteorological parameters (dependent variables) and CH_4, O_3, NO_2 and CO_2 concentrations (independent variables) within the period of investigation.

	CH_4 (ppmv)	O_3 (ppmv)	NO_2 (ppmv)	CO_2 (ppmv)
Solar radiation (MJ/m²)	0.661*	0.571	−0.106	0.656
Relative humidity (%)	0.859*	0.345	−0.516	0.646
Temperature (°C)	−0.549	−0.167	0.077	0.962*
Wind speed (m/s)	−0.906	−0.518	−0.317	0.951*
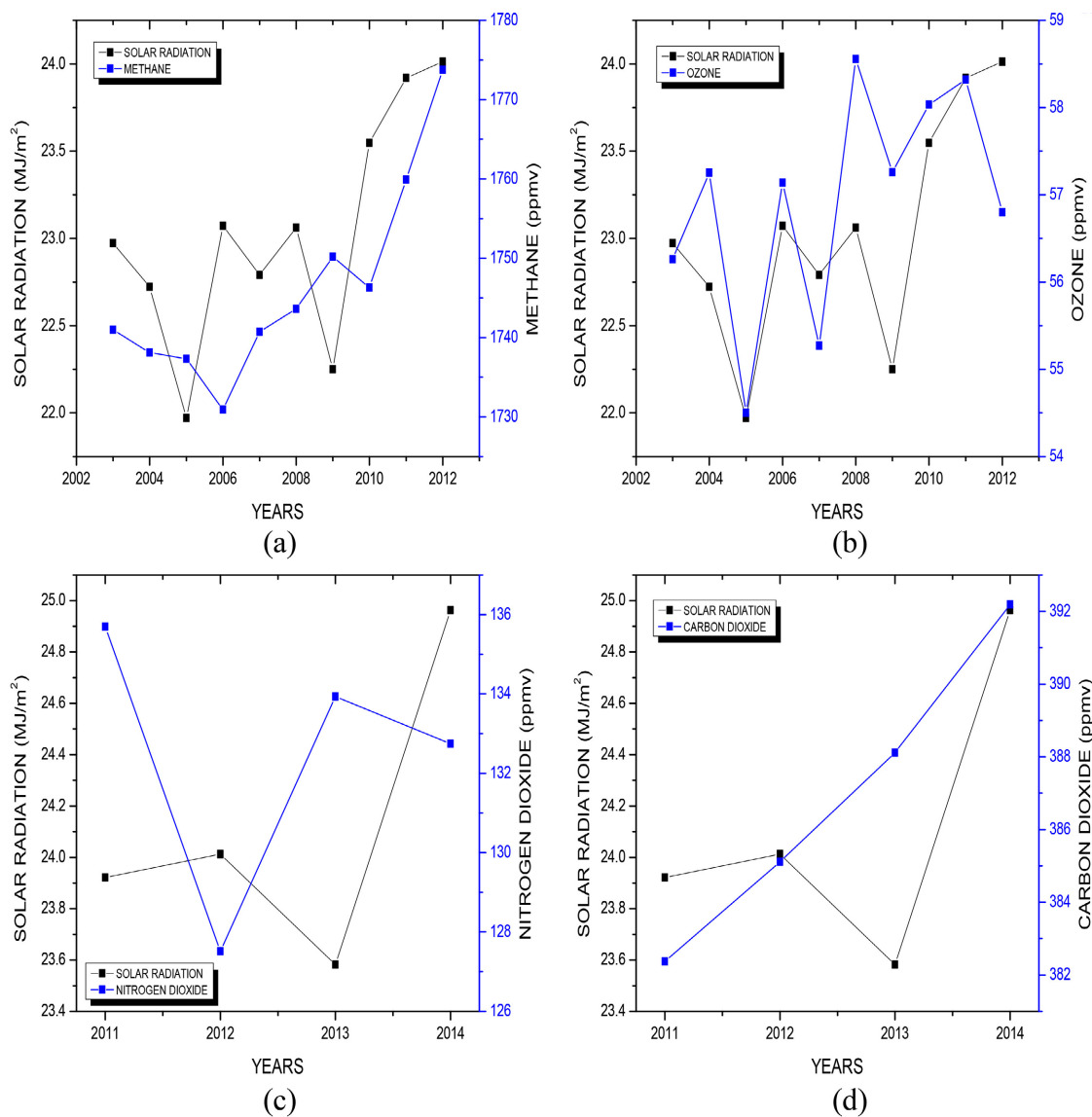
Figure 3. (a)-(d) Solar radiation correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

with CH_4, O_3, NO_2 and CO_2 concentrations respectively, **Figures 4(a)-(d)** show relative humidity correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively, while **Figures 5(a)-(d)** show wind speed correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.
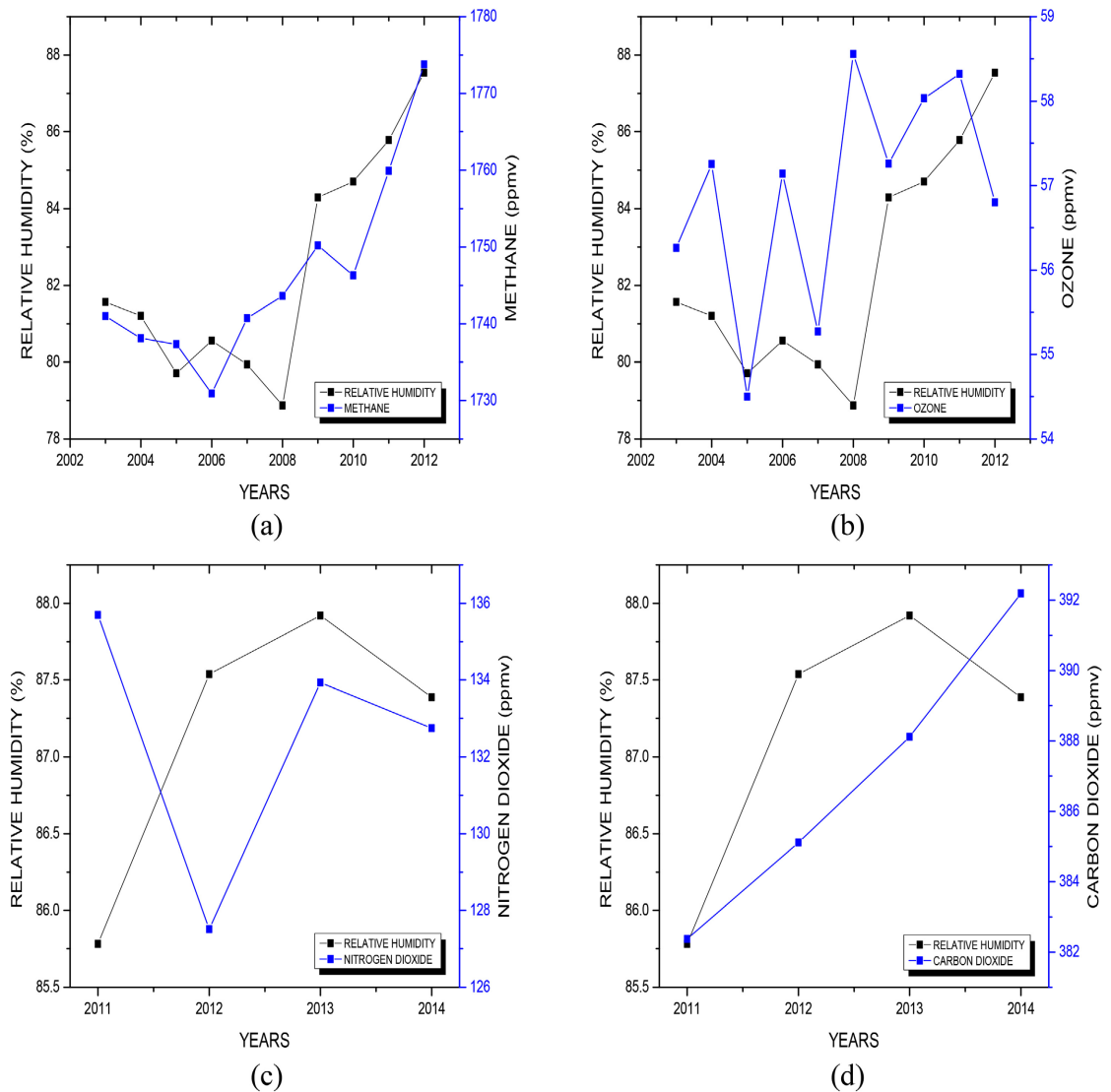
Figure 4. (a)-(d) Relative humidity correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

$$(c) \qquad\qquad\qquad\qquad\qquad (d)$$
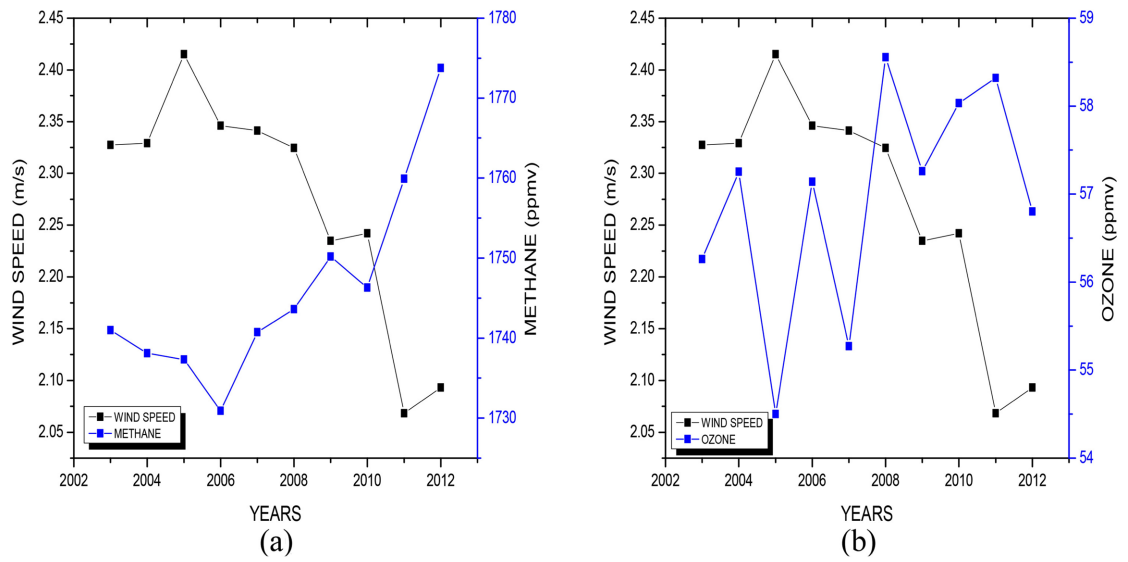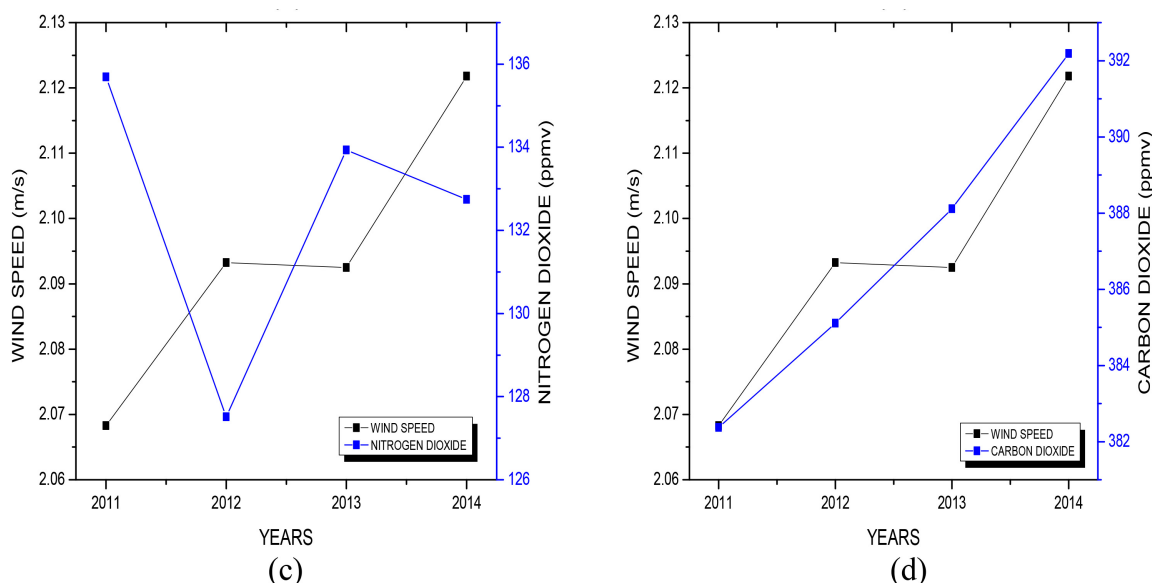
Figure 5. (a)-(d) Wind speed correlation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

3.3.2. Coefficient of Determination (R^2) and Least Squares Regression Analysis

Figures 6(a)-(d) to **Figures 9(a)-(d)** show the coefficient of determination (R^2) of the selected meteorological parameters with the concentration of atmospheric pollutants.

1) Coefficient of determination (R^2) analysis

The coefficient of determination analysis gives us the measure of the variation in the meteorological parameters (dependent variable) that is predictable from the atmospheric pollutants (independent variable).

Methane (CH_4) had coefficients of determination (R^2) of 0.820, 0.738, 0.437 and 0.302 with wind speed, relative humidity, solar radiation and temperature respectively. Tropospheric ozone (O_3) had coefficients of determination (R^2) of 0.326, 0.268, 0.119 and 0.028 with solar radiation, wind speed, relative humidity and temperature respectively. Nitrogen dioxide (NO_2) had coefficients of determination (R^2) of 0.266, 0.101, 0.011 and 0.006 with relative humidity, wind speed, solar radiation and temperature respectively. Carbon dioxide (CO_2) had coefficients of determination (R^2) of 0.926, 0.904, 0.430 and 0.417 with temperature, wind speed, solar radiation and relative humidity respectively.

2) Least squares regression analysis

The Least squares regression analysis gives us the line of best fit enabling us to predict the behavior of the meteorological parameters.

CO_2 had the highest R^2 of 0.926 with temperature, as shown in **Figure 6(d)**. To obtain predicted values for temperature, we substitute the values of a (intercept) and b (slope) from **Figure 6(d)** into the regression relationship $Y = a + bX$, where Y is temperature (predicted) and X is CO_2 concentration to obtain Equation (4) as:

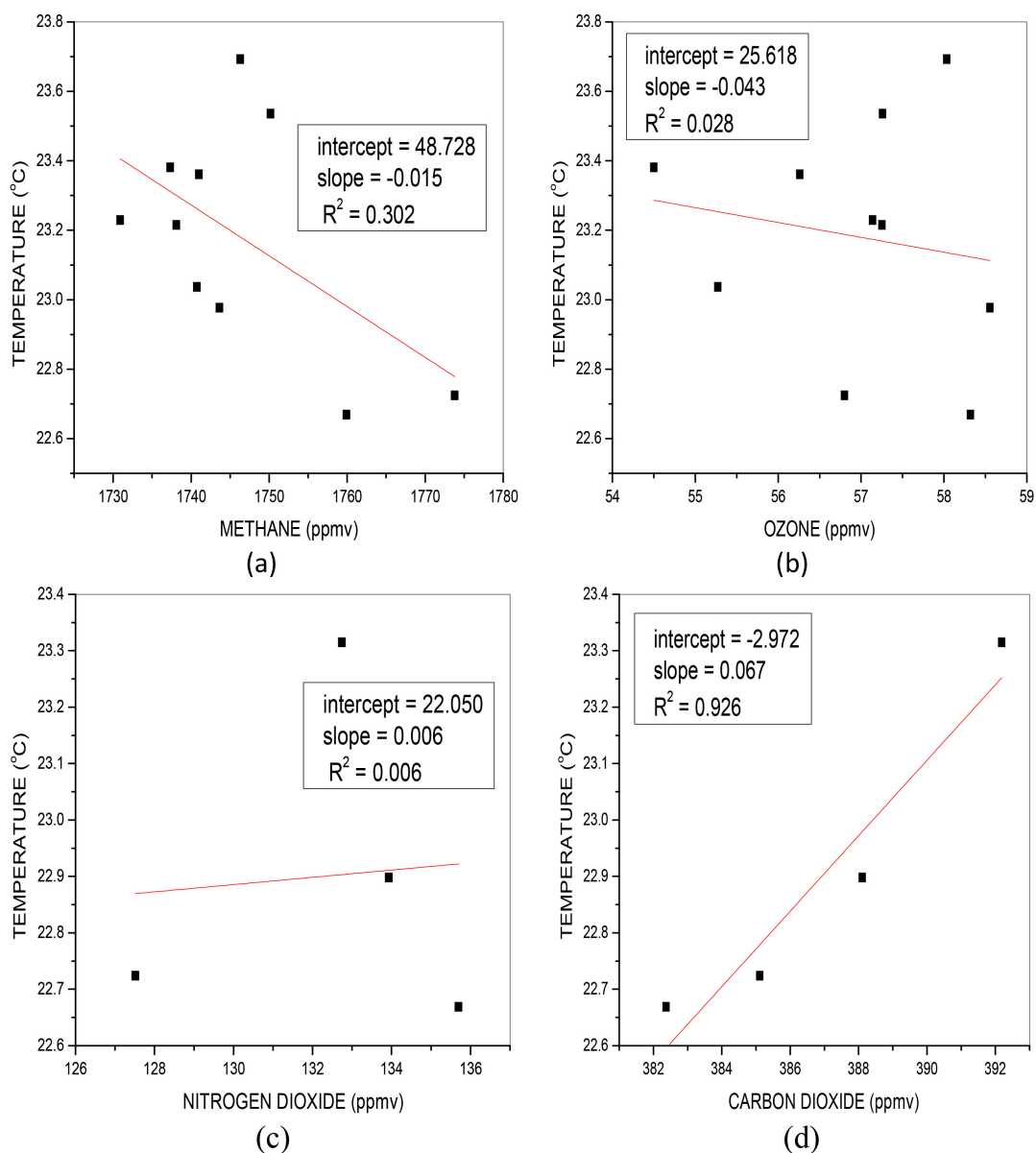$$\text{Temperature} = -2.972 + 0.067(CO_2) \qquad\qquad (4)$$

Figure 6. (a)-(d) Linear fit of temperature with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

Therefore by substituting the values of CO_2 concentration into Equation (4), we obtain predicted values for temperature within the period of investigation. **Table 6** shows predicted and measured values of temperature, while **Figure 10** shows the graph of predicted and measured values of temperature.

CH_4 had the highest R^2 of 0.437 with solar radiation, as shown in **Figure 7(a)**. To obtain predicted values for solar radiation, we substitute the values of a (intercept) and b (slope) from **Figure 7(a)** into the regression relationship $Y = a + bX$, where Y is solar radiation (predicted) and X is CH_4 concentration to obtain Equation (5) as:

$$\text{Solar radiation} = -37.859 + 0.035\left(CH_4\right) \tag{5}$$

Therefore by substituting the values of CH_4 concentration into Equation (5),

Table 6. Predicted and measured values of temperature.

Year	Mean CO_2 (ppmv)	Temperature ˚C (measured)	Temperature ˚C (predicted)
2011	382.370	22.669	22.647
2012	385.108	22.724	22.830
2013	388.111	22.898	23.031
2014	392.186	23.315	23.304
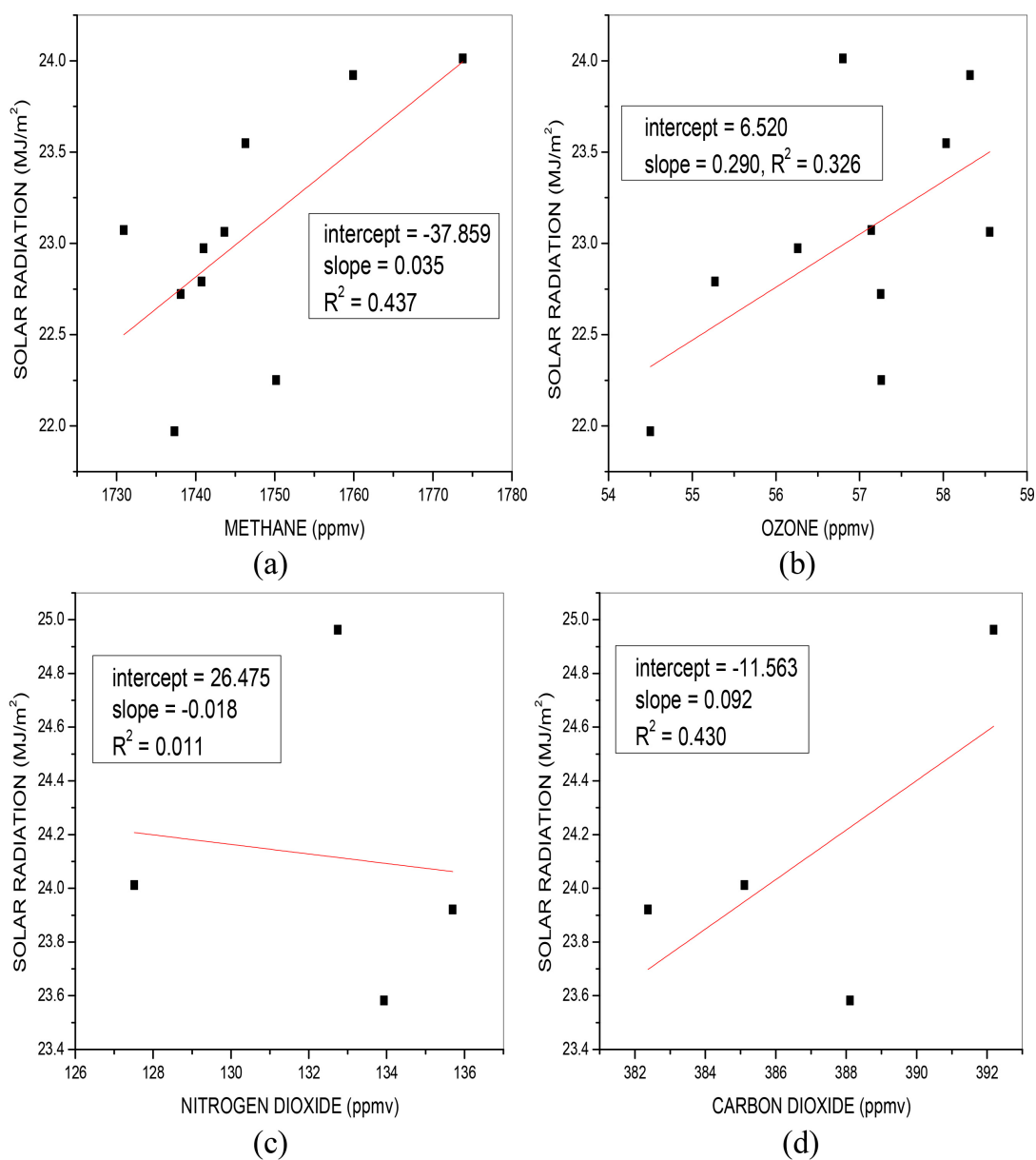
Figure 7. (a)-(d) Linear fit of solar radiation with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

we obtain predicted values for solar radiation within the period of investigation. **Table 7** shows predicted and measured values of solar radiation, while **Figure 11** shows the graph of predicted and measured values of solar radiation.
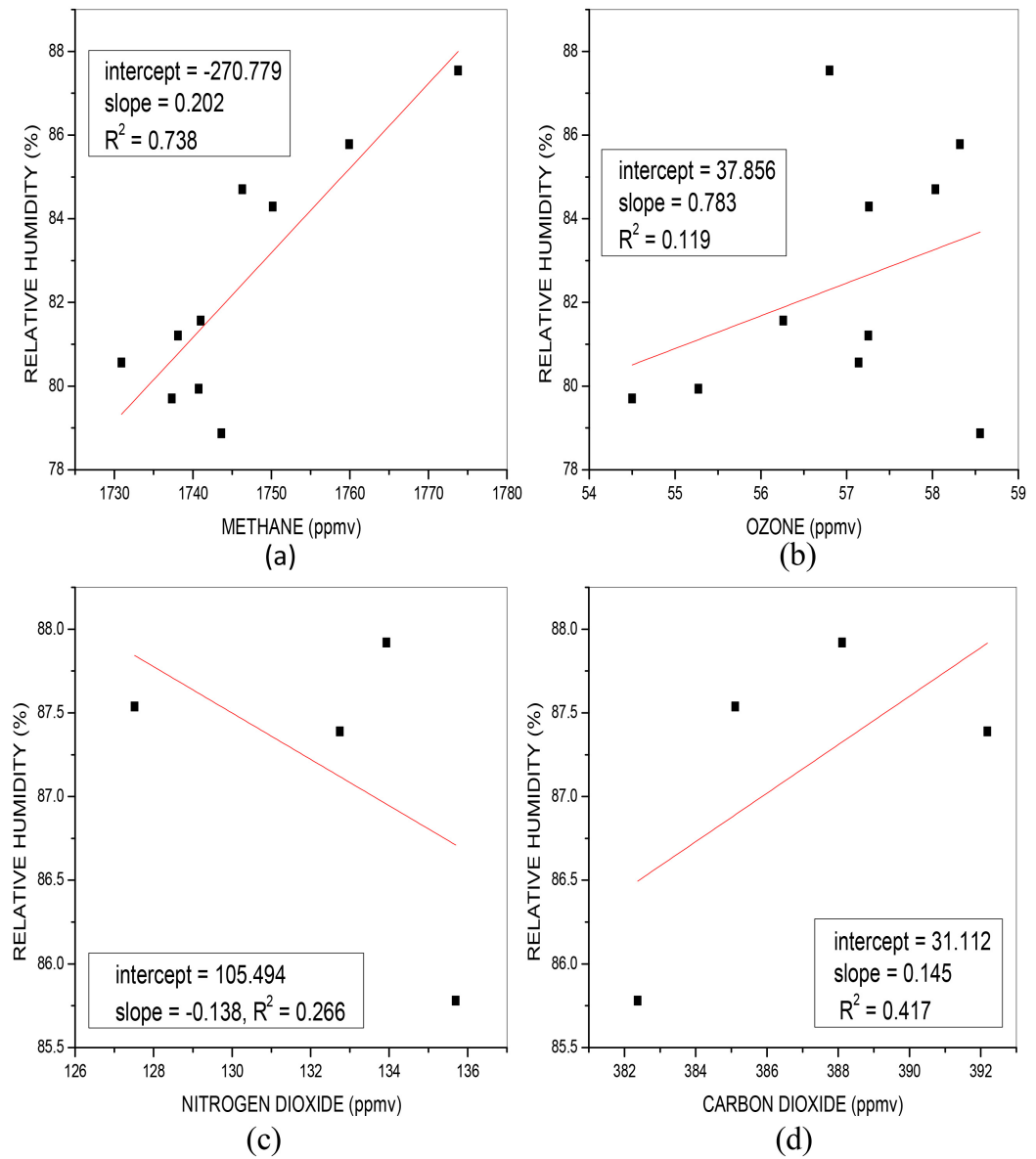
Figure 8. (a)-(d) Linear fit of relative humidity with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

Table 7. Predicted and measured values of solar radiation.

Year	Mean CH_4 (ppmv)	Solar radiation MJ/m^2 (measured)	Solar radiation MJ/m^2 (predicted)
2003	1740.994	22.973	23.076
2004	1738.120	22.723	22.975
2005	1737.331	21.970	22.948
2006	1730.918	23.072	22.723
2007	1740.740	22.791	23.069
2008	1743.628	23.062	23.168
2009	1750.178	22.251	23.397
2010	1746.312	23.548	23.262
2011	1759.923	23.921	23.738
2012	1773.787	24.012	24.224
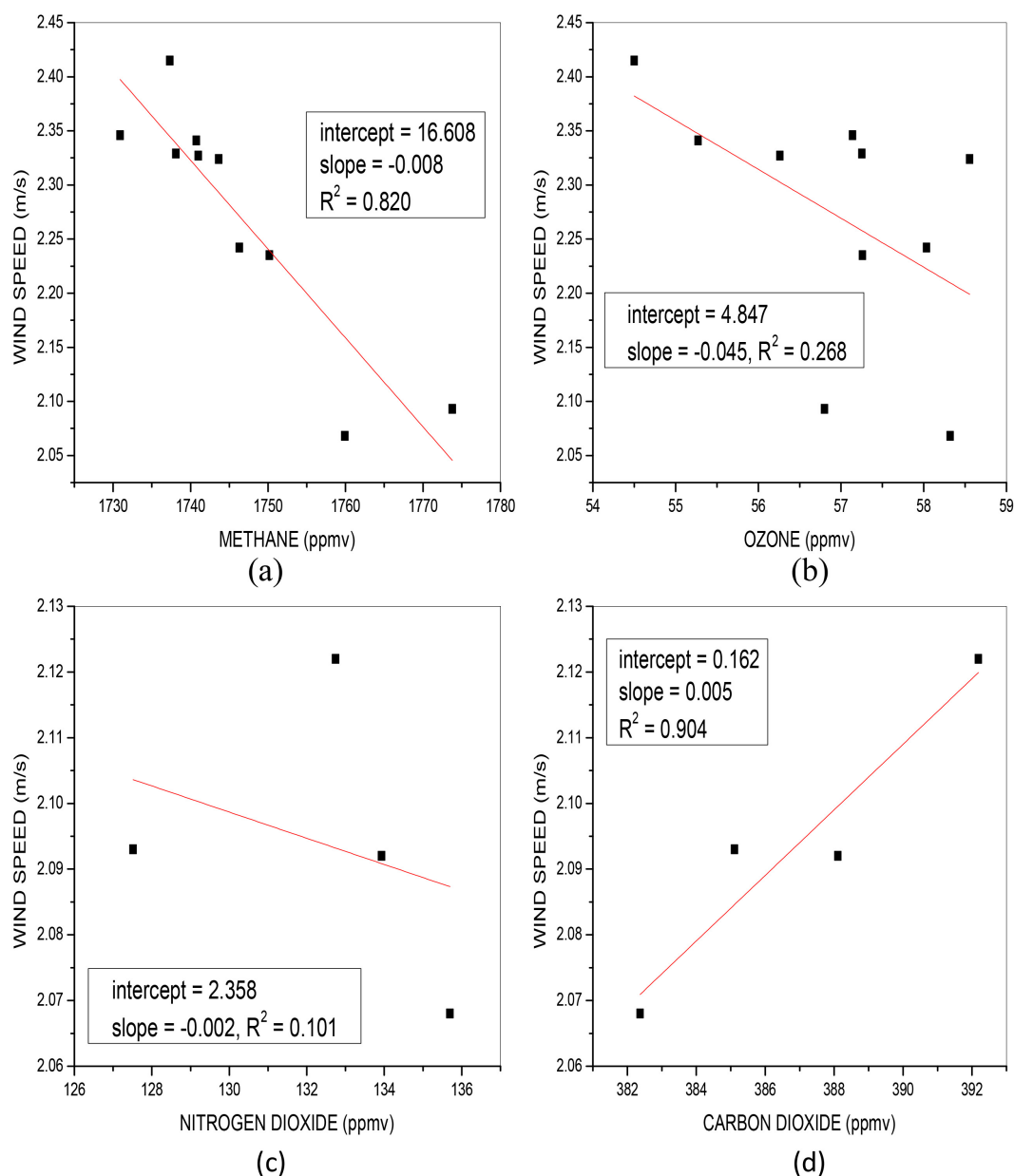
Figure 9. (a)-(d) Linear fit of wind speed with CH_4, O_3, NO_2 and CO_2 concentrations respectively.

CH_4 had the highest R^2 of 0.738 with relative humidity, as shown in **Figure 8(a)**. To obtain predicted values for relative humidity, we substitute the values of a (intercept) and b (slope) from **Figure 8(a)** into the regression relationship $Y = a + bX$, where Y is relative humidity (predicted) and X is CH_4 concentration to obtain Equation (6) as:

$$\text{Relative humidity} = -270.779 + 0.202 \left(CH_4 \right) \qquad (6)$$

Therefore by substituting the values of CH_4 concentration into Equation (6), we obtain predicted values for relative humidity within the period of investigation. **Table 8** shows predicted and measured values of relative humidity, while **Figure 12** shows the graph of predicted and measured values of relative humidity.
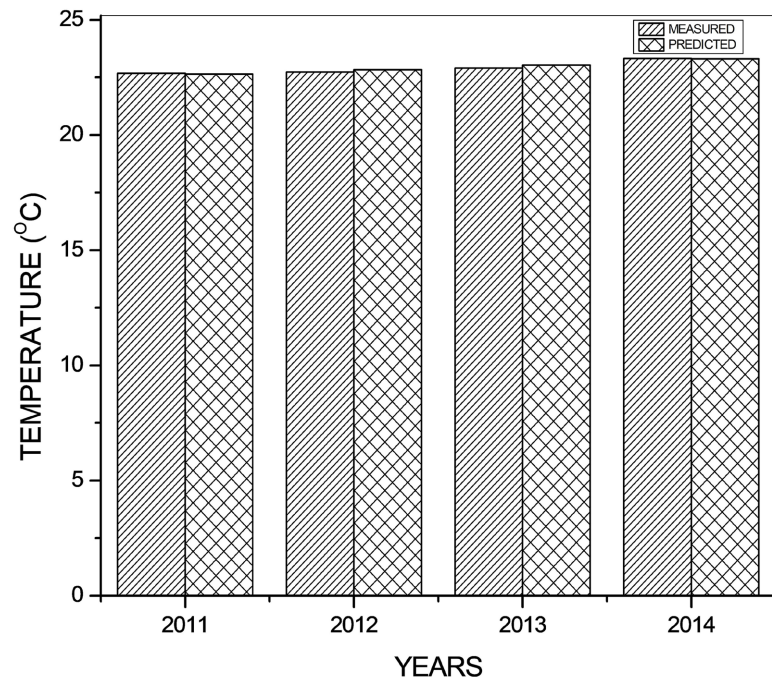
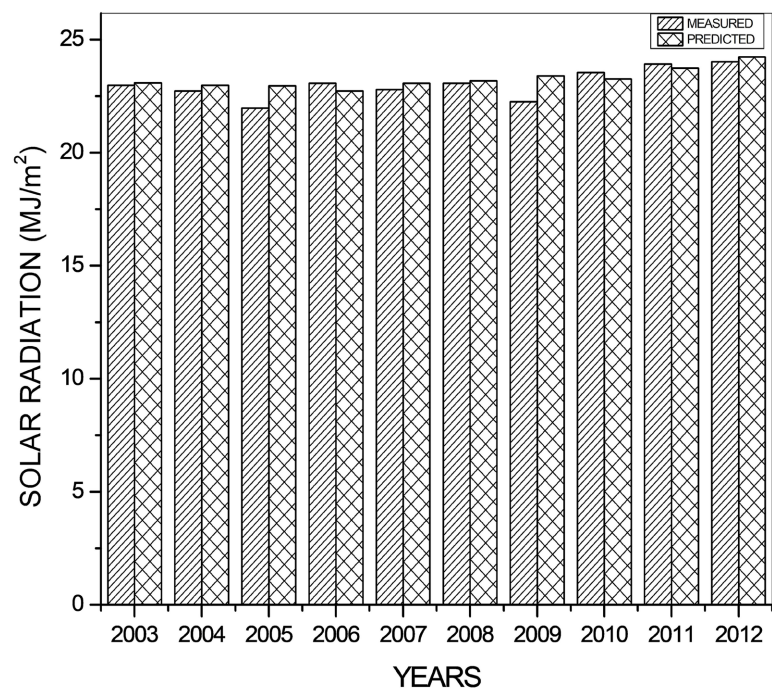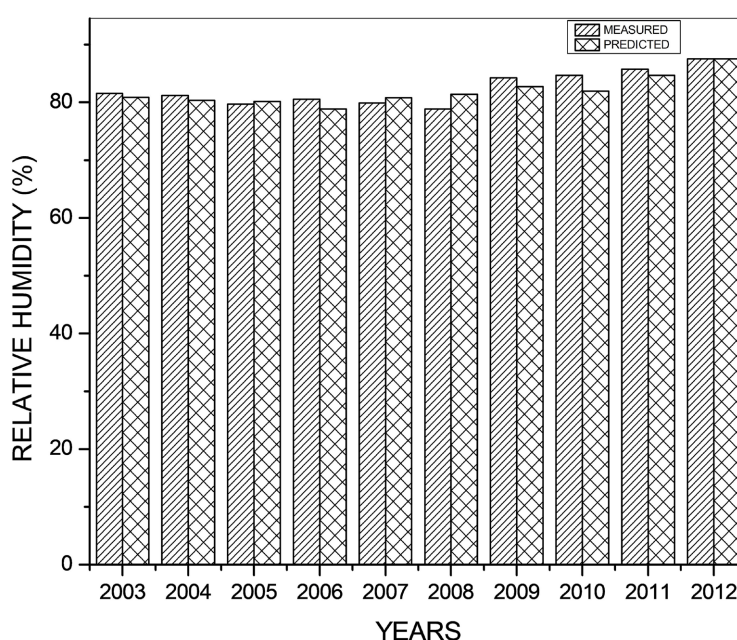**Figure 10.** Graph of predicted and measured values of temperature.

Figure 11. Graph of predicted and measured values of solar radiation.

CO_2 had the highest R^2 of 0.904 with wind speed, as shown in **Figure 9(d)**. To obtain predicted values for wind speed, we substitute the values of a (intercept) and b (slope) from **Figure 9(d)** into the regression relationship $Y = a + bX$, where Y is wind speed (predicted) and X is CO_2 concentration to obtain equation (7) as:

Table 8. Predicted and measured values of relative humidity.

Year	Mean CH_4 (ppmv)	Relative humidity % (measured)	Relative humidity % (predicted)
2003	1740.994	81.567	80.902
2004	1738.120	81.207	80.321
2005	1737.331	79.705	80.162
2006	1730.918	80.560	78.866
2007	1740.740	79.938	80.850
2008	1743.628	78.871	81.434
2009	1750.178	84.289	82.757
2010	1746.312	84.700	81.976
2011	1759.923	85.781	84.725
2012	1773.787	87.538	87.526

Figure 12. Graph of predicted and measured values of relative humidity.

$$\text{Wind speed} = 0.162 + 0.005(CO_2) \tag{7}$$

Therefore by substituting the values of CO_2 concentration into Equation (7), we obtain predicted values for wind speed within the period of investigation. Table 9 shows predicted and measured values of wind speed, while Figure 13 shows the graph of predicted and measured values of wind speed.

3.4. Discussion

The results of the descriptive statistics of annual averages of selected meteorological parameters within the period of investigation showed that relative humidity had the highest standard deviation value of 3.355%, while wind speed had the lowest standard deviation value of 0.121 m/s. Solar radiation and temperature had standard deviation values of 0.822 MJ/m^2 and 0.315˚C respectively.

Table 9. Predicted and measured values of wind speed.

Year	Mean CO_2 (ppmv)	Wind speed m/s (measured)	Wind speed m/s (predicted)
2011	382.370	2.068	2.074
2012	385.108	2.093	2.088
2013	388.111	2.092	2.103
2014	392.186	2.122	2.123
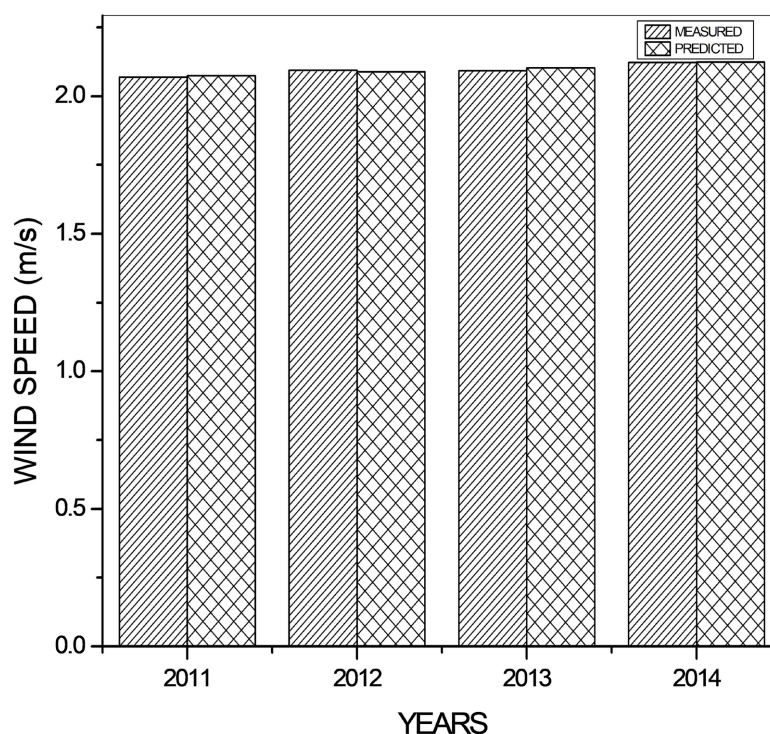
Figure 13. Graph of predicted and measured values of wind speed.

Therefore relative humidity values were the most dispersed or spread out around the mean of 83.289%, while wind speed values were the least dispersed around the mean of 2.245 m/s.

The results of the descriptive statistics of annual averages of CH_4, O_3, NO_2 and CO_2 concentrations within the period of investigation revealed that the mean values were higher than the acceptable ambient values [17]. The continuous increase in concentration level of these pollutants is due to the activities of the artisanal petroleum refineries in the Niger Delta region. The emission levels of these pollutants breached FEPA and EGASPIN limits [18] [19] [20]. The results also showed that CH_4 had the highest standard deviation value of 12.500 ppmv while O_3 had the lowest standard deviation value of 1.300 ppmv. NO_2 and CO_2 had standard deviation values of 3.519 ppmv and 4.208 ppmv respectively. Therefore CH_4 concentration values were the most dispersed or spread out around the mean of 1746.193 ppmv, while O_3 concentration values were the least dispersed around the mean of 56.939 ppmv. Methane (CH_4) had higher standard deviation

(S.D) values than carbon dioxide (CO_2), showing that on a per molecule basis, proportional rise in CH_4 concentration is much more efficient as a greenhouse gas than a comparable rise in CO_2 concentration [14]. However, CO_2 has a greater influence than CH_4 on climate change due to its higher atmospheric concentration.

The results of the correlation analysis between the selected meteorological parameters (dependent variables) and CH_4, O_3, NO_2 and CO_2 concentrations (independent variables) within the period of investigation as shown in Table 5, indicated that CO_2 had a strong significant positive correlation with temperature with a correlation coefficient of 0.962, while a moderate negative correlation coefficient of 0.549 was obtained for CH_4, and very weak correlation coefficients of −0.167 and 0.077 were obtained for O_3 and NO_2 respectively. Therefore, among the atmospheric pollutants postulated as influencing temperature, CO_2 appears to be the most strongly significant ($P < 0.05$) in explaining temperature variations in this region of Niger Delta, with a correlation coefficient of 96.2%. CH_4, O_3 and CO_2 had a moderately significant positive correlation with solar radiation with correlation coefficients of 0.661, 0.571 and 0.656 respectively, while a weak negative correlation coefficient of 0.106 was obtained for NO_2. Therefore, among the atmospheric pollutants postulated as influencing solar radiation, CH_4 appears to be the most strongly significant ($P < 0.05$) in explaining variations in solar radiation in this region of Niger Delta, with a correlation coefficient of 66.1%. CH_4 had a strong significant positive correlation with relative humidity with a correlation coefficient of 0.859, while moderate correlation coefficients of −0.516 and 0.646 were obtained for NO_2 and CO_2 respectively, and a weak correlation coefficient of 0.345 was obtained for O_3. Therefore, among the atmospheric pollutants postulated as influencing relative humidity, CH_4 appears to be the most strongly significant ($P < 0.01$) in explaining variations in relative humidity in this region of Niger Delta, with a correlation coefficient of 85.9%. CO_2 and CH_4 had a strong significant correlation with wind speed with correlation coefficients of 0.951 and −0.906 respectively, while a moderate negative correlation coefficient of 0.518 was obtained for O_3, and a weak negative correlation coefficient of 0.317 was obtained for NO_2. Therefore, among the atmospheric pollutants postulated as influencing wind speed, CO_2 appears to be the most strongly significant ($P < 0.05$) in explaining variations in wind speed in this region of Niger Delta, with a correlation coefficient of 95.1%.

The results of the coefficient of determination (R^2) analysis revealed that Methane (CH_4) had coefficients of determination (R^2) of 0.820, 0.738, 0.437 and 0.302 with wind speed, relative humidity, solar radiation and temperature respectively. This implies that CH_4 influenced 82.0% variation in wind speed, 73.8% variation in relative humidity, 43.7% variation in solar radiation and 30.2% variation in temperature in this region of Niger Delta within the period of investigation. Tropospheric ozone (O_3) had coefficients of determination (R^2) of 0.326, 0.268, 0.119 and 0.028 with solar radiation, wind speed, relative humidity and

temperature respectively. This implies that O_3 influenced 32.6% variation in solar radiation, 26.8% variation in wind speed, 11.9% variation in relative humidity and 2.8% variation in temperature in this part of Niger Delta within the period of investigation. Nitrogen dioxide (NO_2) had coefficients of determination (R^2) of 0.266, 0.101, 0.011 and 0.006 with relative humidity, wind speed, solar radiation and temperature respectively. This implies that NO_2 influenced 26.6% variation in relative humidity, 10.1% variation in wind speed, 1.1% variation in solar radiation and 0.6% variation in temperature in this region of Niger Delta within the period of investigation. Carbon dioxide (CO_2) had coefficients of determination (R^2) of 0.926, 0.904, 0.430 and 0.417 with temperature, wind speed, solar radiation and relative humidity respectively. This implies that CO_2 influenced 92.6% variation in temperature, 90.4% variation in wind speed, 43.0% variation in solar radiation and 41.7% variation in relative humidity in this part of Niger Delta within the period of investigation.

The predicted values of the meteorological parameters showed a significant level of agreement with their measured values as shown in **Figures 10-13**.

4. Conclusion

Changes in emission and concentration levels of atmospheric pollutants can significantly affect local climate and in some situations regional climate by means of teleconnections in the atmosphere. Among the atmospheric pollutants postulated as influencing meteorological parameters, CO_2 appears to be the most strongly significant in explaining temperature variations in this region of Niger Delta, with a correlation coefficient of 96.2% and a coefficient of determination (R^2) of 0.926, implying that CO_2 influenced 92.6% variation in temperature in this part of Niger Delta within the period of investigation. The emission levels of the atmospheric pollutants breached FEPA and EGASPIN limits.

Acknowledgements

Conflicts of Interest

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

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