Journal of Atmospheric Science Research
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ARTICLE

Monitoring and Quantification of Carbon Dioxide Emissions and Impact of Sea Surface Temperature on Marine Ecosystems as Climate Change Indicators in the Niger Delta Using Geospatial Technology

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ABSTRACT

The Niger Delta marine environment has experienced a series of environmental disasters since the inception of oil and gas exploration, which can be attributed to climate change. Carbon dioxide (CO_2) emissions and sea surface temperature (T) ties associated with burning fossil fuels, such as gas flaring, vehicular traffic, and marine vessel movement along the sea, are increasing. Using data extracted from the NASA Giovanni satellite's Atmospheric Infrared Sounder (AIRS) and Moderate Resolution Imaging Spectroradiometer (MODIS), this study mapped the carbon footprint and T along the coastline into the deep sea from 2003 to 2011, using ArcGIS software. The spatial distribution of CO_2 and T concentrations determined by the inverse distance weighting (IDW) method reveals variations in the study area. The results show an increase in the quantity of the mean tropospheric CO_2 from July 2003 to December 2011, from 374.5129 ppm to 390.7831 ppm annual CO_2 emissions, which also reflects a continuous increase. The average Monthly sea surface temperature had a general increasing trend from 25.79 °C in July 2003 to 27.8 °C in December, with the Pearson correlation coefficient between CO_2 and T indicating 50% strongly positive, 20% strongly negative, 20% weakly positive, and 10% weakly negative. CO_2 levels, like temperature, follow a seasonal cycle, with a decrease during the wet season due to precipitation dissolving and plant uptake during the growing season, and then a rise during the dry season. Carbon capture and storage technologies must be implemented to benefit the marine ecosystem and human well-being.

Keywords: Carbon footprint; NASA Giovanni; Climate change; Coastline; Carbon capture and storage

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ARTICLE INFO
Received: 27 September 2022 | Revised: 30 November 2022 | Accepted: 05 December 2022 | Published: 30 December 2022
DOI: https://doi.org/10.30564/jasr.v6i1.5107

CITATION
Okpobiri, O., Rowland, E.D., Egobueze, F.E., et al., 2023. Monitoring and Quantification of Carbon Dioxide Emissions and Impact of Sea Surface Temperature on Marine Ecosystems as Climate Change Indicators in the Niger Delta Using Geospatial Technology. Journal of Atmospheric Science Research. 6(1): 1-20. DOI: https://doi.org/10.30564/jasr.v6i1.5107

1. Introduction

The greatest issue plaguing the 21st century on a global scale is climate change. An increase in the emission of greenhouse gas (GHG) such as methane, nitrous oxide, carbon dioxide (CO_2), and fluorinated gases [1] is the causal effect to which carbon dioxide is the greatest contributor. Though CO_2 is a naturally occurring GHG with a low global warming potential (GWP) of one [2], it is the major culprit due to its longer atmospheric lifespan of 300-1000 years [2-4]. The concentration of carbon dioxide in the atmosphere surpasses all other GHG as a result of human activities, which can be attributed to the increasing population and the consequent need for energy and change in land-use cover [5,6]. CO_2 released from burning fossil fuels can easily be detected as it has a peculiar signature wherein the amount of heavy carbon -13 isotopes in the atmosphere declines, and the ratio of oxygen to nitrogen is reduced [3,7]. This can be related to the increase in global surface temperature over the years as [8] indicates no net increase from solar input [9]. Projected a 130% increase in CO_2 emissions by 2050. The increased human-driven levels of CO_2 emission along the coastline from activities, such as onshore and offshore energy drilling, marine transportation of goods, and resource extraction have resulted in higher atmospheric temperature and consequently, heavier precipitation. The coastal areas are more vulnerable to the dangers of climate change which manifest as flooding, changes in shoreline, higher water table, saltwater intrusion in the aquifer, and oceans acidification [10]. The carbon cycle through which atmospheric carbon dioxide concentrations are regulated involves the carbon sink which includes; forests, ocean, and soil. All these are however under threat from human activities like deforestation, ocean pollution, and oil spill, limiting their ability to absorb free tropospheric CO_2. In recent times there have been frequent flooding episodes, outbreaks of water-borne diseases, and cases of massive dead fish occurring in the coastal states of Nigeria. These necessitate the need for monitoring and mapping our carbon footprint. Remote sensing as a cost-effective method allows consistent, precise, and comprehensive data collection of GHG at a regional and global scale from the Atmospheric Infrared Sounder (AIRS) on the Earth Observing System (EOS) Aqua satellite [11].

2. Study area

The study location is along the Niger Delta coastline. Spanning about 800 km, it cuts across Lagos, Ondo, Delta, Bayelsa, Rivers, and Akwa Ibom states. With a 14% surge in population to over 40 million residents according to the Niger Delta Region survey by the National Population Commission and an estimated land mass of 70,000 km^2, it is densely populated. The study area is located between longitudes 0040 00’0” and 0080 00’0” east of the first meridian and latitudes 040 00’0” and 060 00’0” north of the equator. There are 2 main seasons all year round; a lengthy rainy season which commences from March to October with precipitation of about 4000 mm [12] and the dry season from November to February. The peak of both wet and dry seasons are July and December respectively. This location was chosen because it is highly susceptible to CO_2 emission owing to the fact that the 6 major seaports and all the gas flaring points in the country are distributed within this region (**Figure 1**).

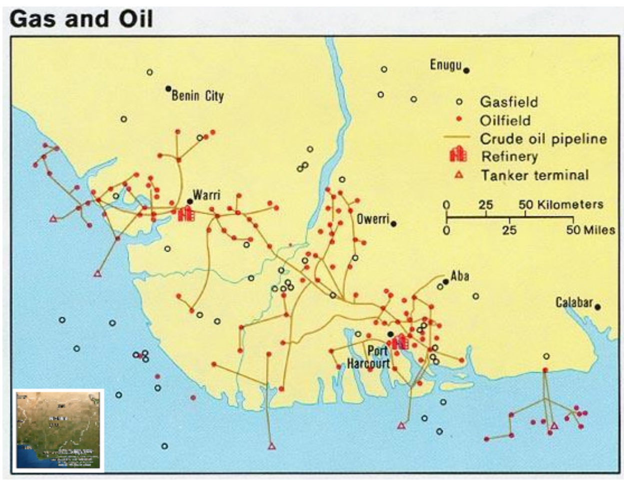


Figure 1. Niger Delta coastal area map with oil and gas fields (about 606 oilfields – 355 onshore, 251 offshore, and 178 gas flare points). Nigerian Oil and Gas Corporation (1997) and Anifowose et al. [13]

3. Materials and method

3.1 Data collection

The remote sensing data utilized in this study are the mean carbon dioxide emissions in ppm acquired from the Atmosphere Infrared Sounder on National Aeronautics and Space Administration (NASA) Giovanni Aqua Satellite and Sea Surface Temperature at 11 microns using Moderate Resolution Imaging Spectroradiometer (MODIS) R2019.0 (https://giovanni.gsfc.nasa.gov/giovanni/) with an accuracy of 20 × 2.50 for selected geophysical parameters, and the map of the Niger Delta coastal area highlighting the oil and gas fields and gas flare points from Nigerian Oil and Gas Corporation (1997) and Anifowose et al. [13]

3.2 Data processing

The monthly average CO_2 and sea surface temperature data were extracted from Giovanni and processed using ArcGIS software with the spatial interpolation method, Inverse Distance Weighting (IDW) from 42 stations from July 2003 to December 2011.

The ArcGIS software was launched and the acquired data prepared in Microsoft Excel sheets and saved in CSV format was imported. The area of interest was delineated in Google earth, saved as kml file, and imported into the ArcGIS software retaining the Projected Coordinate System using WGS UTM 1984 Zone N32 which covers the coastal region in Nigeria, and then converting it to a shapefile on ArcGIS. Google Earth image Subsetting was done using clipping tools in the Arc Toolbox. The editing tool was used to digitize the shoreline boundary creating the shapefile of the area of interest.

Step1: CO_2 processing: Arc Toolbox → Spatial Analyst Tool → Interpolation → Click on the Inverse Distance Weighting (IDW) → Import the CSV File Containing the CO_2 Result of the Area Under Review for July, 2003 → Click on Environment → Processing Extend Select the Shapefile of the Study Area →Click on Spatial Analysis →Click on the Mask and Select the Study Area → Ok. The final result was exported for further analysis. The same process was repeated in December 2003, 2005, 2007, 2009 and 2011. The same process was repeated for the sea surface temperature.

3.3 Inverse Distance Weighting (IDW) technique

Inverse distance weighting is a mathematical means of estimating an unknown value from nearby known values. Based on Toiler's law "everything is related to everything else but near things are more related than distant things", IDW uses the "weight" of the known value(s) which is a function of the inverse distance, to estimate the unknown value. Burrough and McDonnell [14] found that utilizing IDW within a squared distance yields reliable results. To estimate the CO_2 concentration across the marine environment, spatial interpolation of the CO_2 emission collected from 42 stations in the coastal environment for each sampling year is obtained and reclassified into five classes for the period under review. The Inverse Distance formula is given in equation 1:

$$x^* = \frac{w_1x_1 + w_2x_2 + w_3x_3 + \ldots + w_nx_n}{w_1 + w_2 + w_3 + \ldots + w_n} \tag{1}$$

Where x* is the unknown value at a location to be estimated, w is the weight, x is the known point value, and n, is the total number of x.

The weight formula is given in equation 2 as:

$$wi = \frac{1}{d_{lx*}^{P}} \tag{2}$$

Where di is the distance from the known point, P a variable that stands for Power.

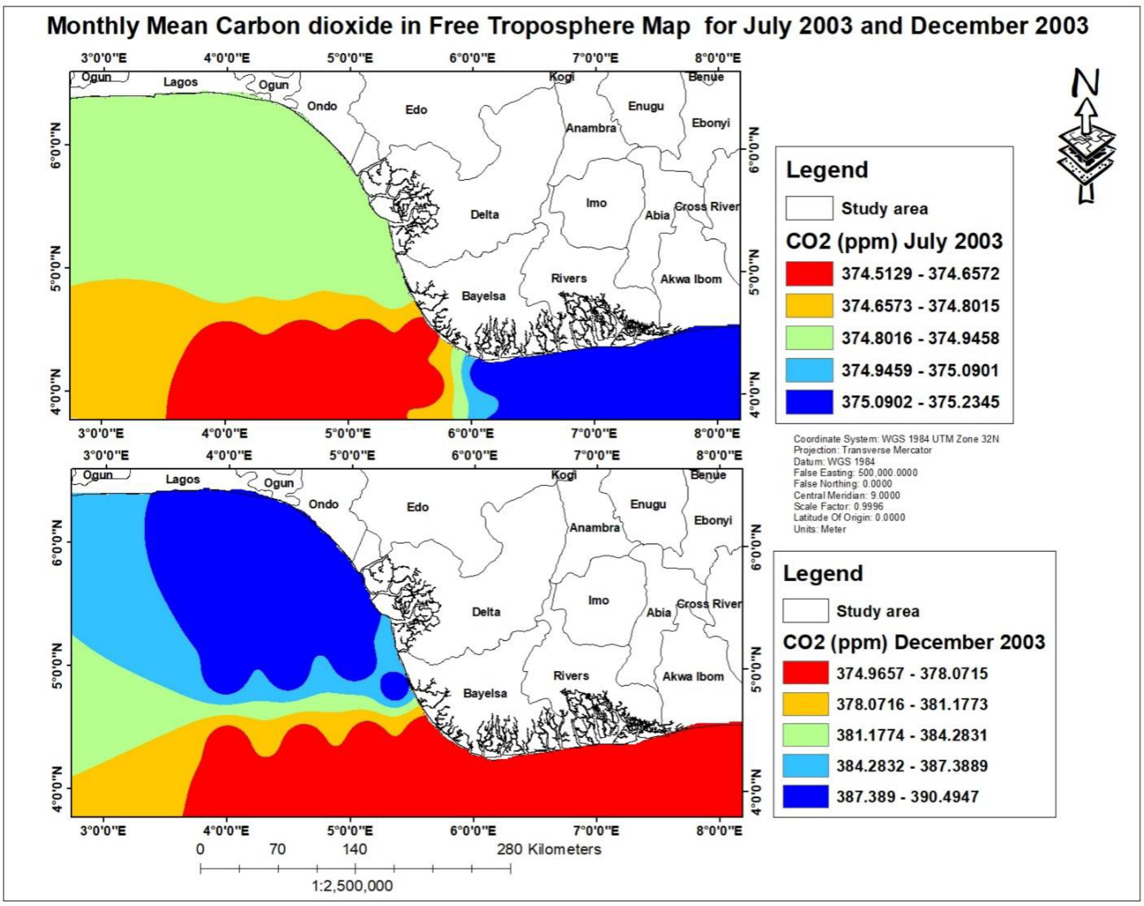
3.4 Data analysis

Step 2: Plotting histogram and line chart with the analyzed statistical data such as mean, minimum, maximum, and percentage of CO_2 using Microsoft excel to estimate the quantity of carbon dioxide emitted each year for both wet and dry seasons and identify the trend. Finally, the relationship between CO_2 and sea surface temperature was established using the Pearson correlation coefficient.

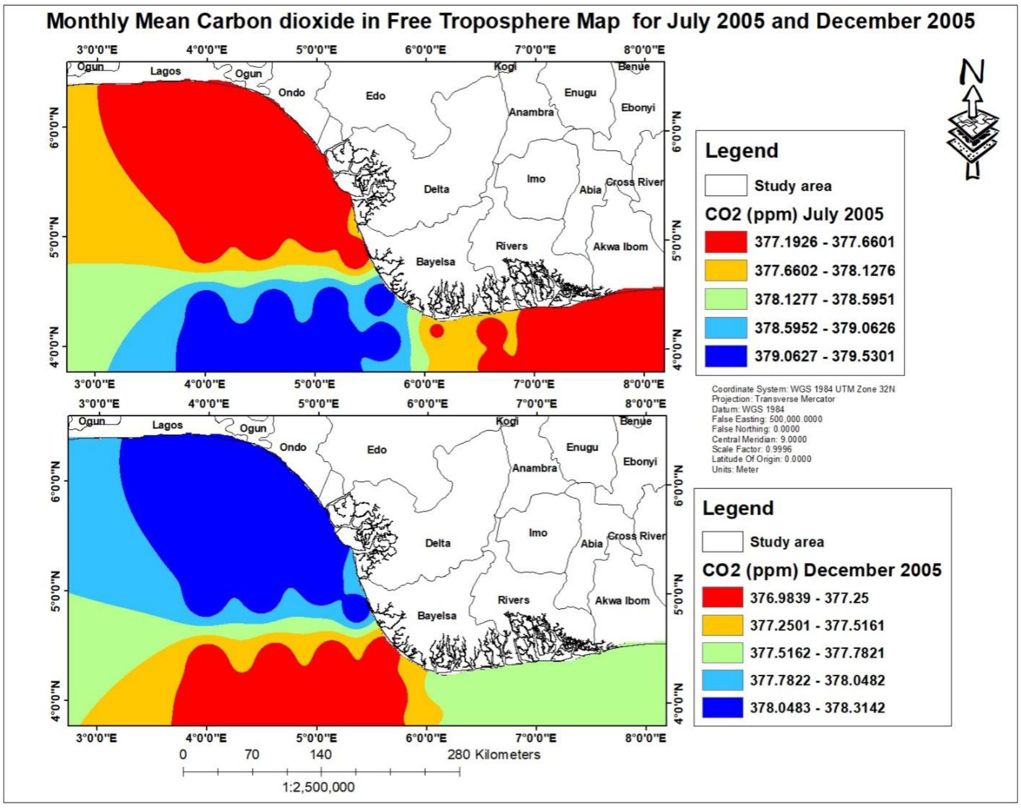
4. Results and discussion

4.1 Monitoring and quantifying carbon footprint

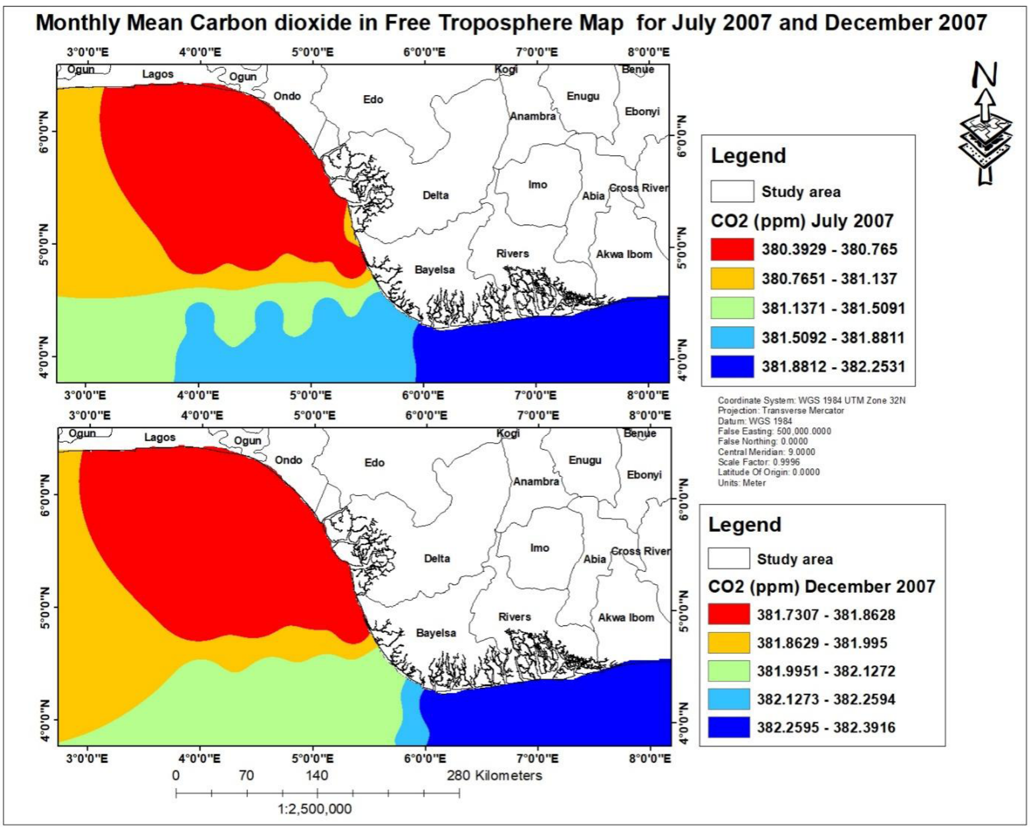
The monthly average CO_2 spatial distribution as seen in **Figures 2a to 2e** and their estimated CO_2 in **Table 1**, is constantly increasing annually for both July and December. This reflects an increase in the amount of carbon dioxide emitted from burning fossil fuels in electric power generating sets, marine vessels, and vehicles associated with the increasing populace. Deforestation for industrial and residential needs as well as agricultural degradation resulting from oil spills typical of the Niger Delta is another likely factor. Most important is the fact that the continuous exploration of fossil fuels and the increasing spate of illegal refineries in the region in response to the ever-increasing need for energy is not abating. December has the highest mean CO_2 concentrations increasing from 376.5186 ppm in 2003 to 390.5302 ppm in 2011. Whereas in July, the lowest values ranging from 374.8737 ppm in 2003 with a continuous increase to 390.1123 ppm are recorded. This contrast represents the different seasons and can be attributed to various factors. Firstly, July is the peak of the rainy season when carbon dioxide is dissolved into carbonic acid during precipitation. Also, December is characterized by hot, dry spells which are grounds for cooling thereby increasing electrical energy consumption and inadvertently increasing the carbon dioxide concentration in the atmosphere. Another vital factor is that the consumption of CO_2 gas by plants for photosynthesis is low in December, thus reducing the use of carbon dioxide.



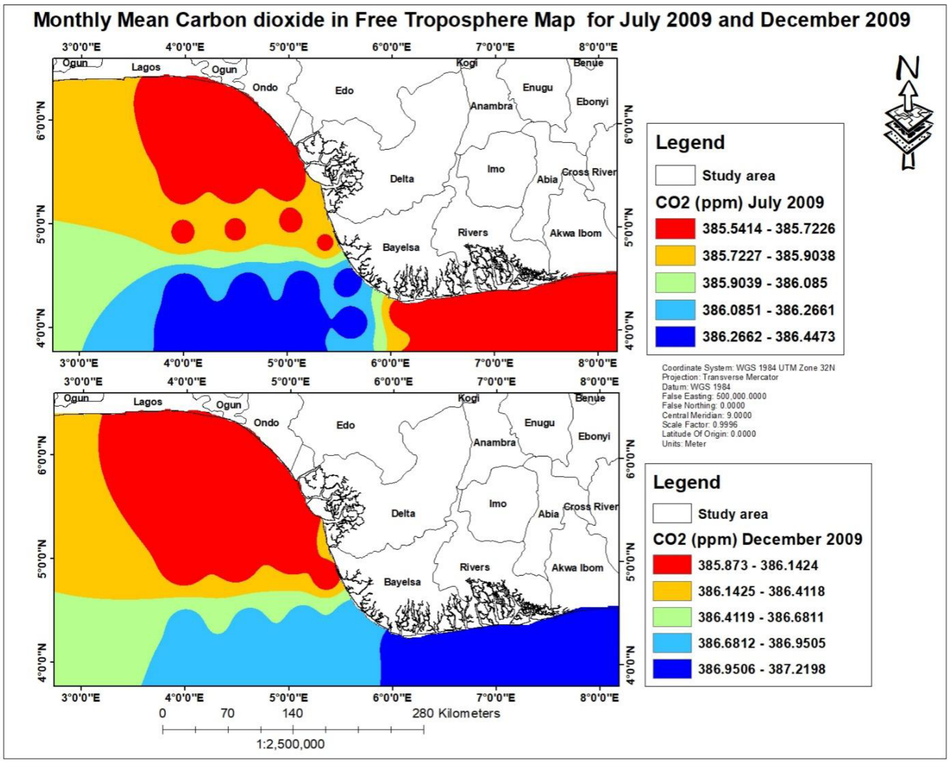
(a)


Monthly Mean Carbon dioxide in Free Troposphere Map for July 2005 and December 2005
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Benue
Enugu
Anambra
Ebonyi
Delta
Imo
Abia
Cross River
Bayelsa
Rivers
Akwa Ibom
N
Legend
Study area
CO2 (ppm) July 2005
377.1926 - 377.6601
377.6602 - 378.1276
378.1277 - 378.5951
378.5952 - 379.0626
379.0627 - 379.5301
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
CO2 (ppm) December 2005
376.9839 - 377.25
377.2501 - 377.5161
377.5162 - 377.7821
377.7822 - 378.0482
378.0483 - 378.3142
0
70
140
280 Kilometers
1:2,500,000

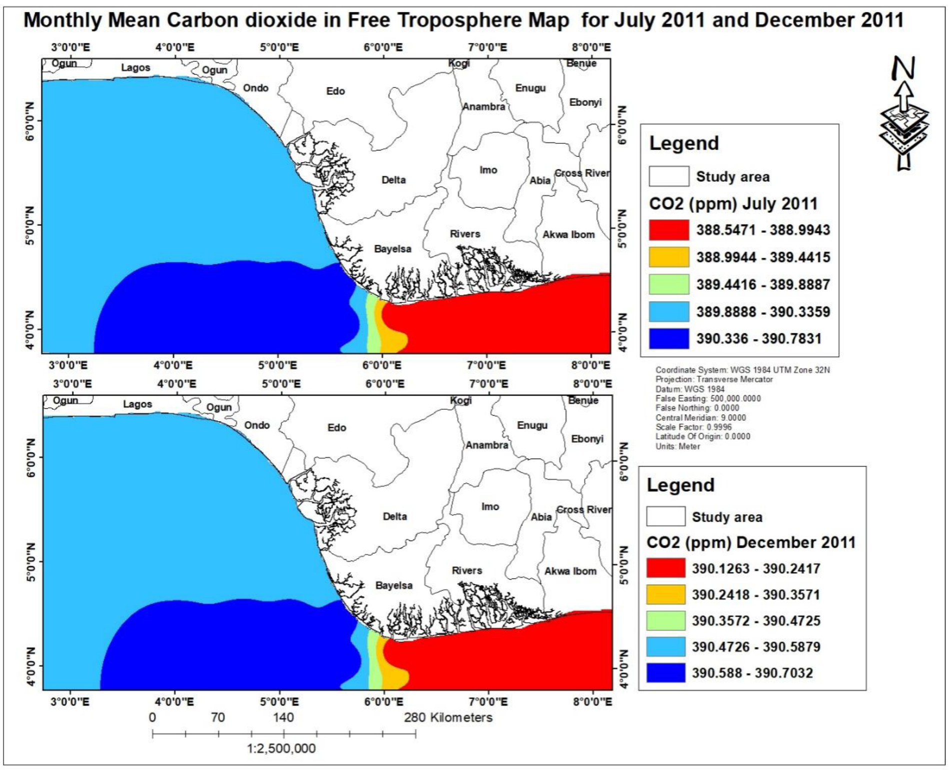
(b)


Monthly Mean Carbon dioxide in Free Troposphere Map for July 2007 and December 2007
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Benue
Enugu
Anambra
Ebonyi
Delta
Imo
Abia
Cross River
Bayelsa
Rivers
Akwa Ibom
N
Legend
Study area
CO2 (ppm) July 2007
380.3929 - 380.765
380.7651 - 381.137
381.1371 - 381.5091
381.5092 - 381.8811
381.8812 - 382.2531
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
CO2 (ppm) December 2007
381.7307 - 381.8628
381.8629 - 381.995
381.9951 - 382.1272
382.1273 - 382.2594
382.2595 - 382.3916
0
70
140
280 Kilometers
1:2,500,000

(c)



(d)



(e)

Figure 2. Monthly mean Tropospheric CO_2 in the marine environment in Nigeria. (a)July 2003 and December 2003, (b) July 2005 and December 2005, (c) July 2007 and December 2007, (d) July 2009 and December 2009, (e) July 2011 and December 2011.

Table 1. Average tropospheric carbon dioxide for the wet and dry seasons from 2003-2011.

YEAR	July Minimum	July Maximum	Mean CO_2	December Minimum	December Maximum	Mean CO_2
2003	374.5129	375.2345	374.8737	374.9657	390.4947	382.73
2005	377.1926	379.5301	378.3614	376.9839	378.3142	377.649
2007	380.3929	382.2531	381.323	381.7307	382.3916	382.061
2009	385.5414	386.4473	385.9944	385.873	387.2198	386.546
2011	388.5471	390.7831	389.6651	390.1263	390.7032	390.415

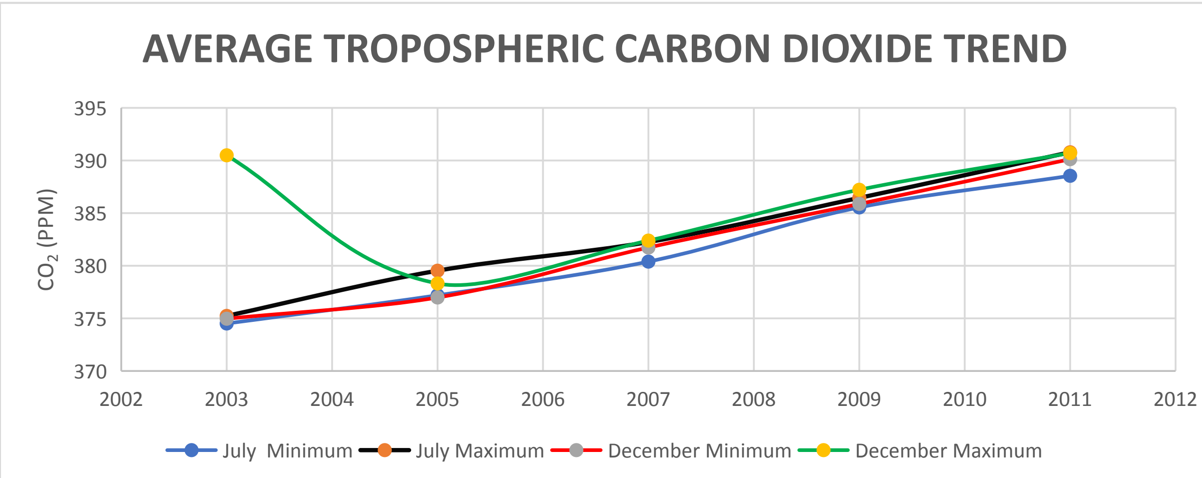


Figure 3. Minimum and Maximum carbon dioxide levels for July and December 2003–2011.

Ideally, higher CO_2 levels are expected in December and lower values in July. However, the trend in **Figure 3** shows a dip in the maximum amount of CO_2 emitted in December 2005 which gradually built up in 2007 corresponding to the drop in the average carbon dioxide level recorded for that month in **Table 1** and **Figures 2a to 2e**. This anomaly could result from wind action or low CO_2 absorption by carbon sink within that period.

Although the mean CO_2 values for December were only lower than that of July in the year 2005 see **Table 1**. The relative frequency of the maximum CO_2 levels between December and July in **Table 2** and **Figure 4** shows a plunge in 2005 from a 0.64% increase in 2003. This dip continually plunges till 2011 when it slowly builds up. In the case of the minimum values, **Table 3** and **Figure 5** indicate a 0.03% increase in December 2007 over July 2007 and a 0.05% increase in December 2011 over July of the same year. Whereas in 2003, 2005, and 2009, the percentage decreased in December and increased in July.

4.2 Comparative analysis of the spatial variation

Figure 2a to 2e a pictorial of the spatial distribution of the monthly carbon dioxide concentrations was derived using the Inverse Distance Weighting (IDW) method. It can be observed that the values show a spatial difference between two major parts of the region; the Northeast (NE) and the Southwest (SW), with variations in the spatial patterns for each season. The highest and lowest monthly average values of 390.5302 ppm in December 2011 and 374.8737 in July 2003 were both recorded in the NE. The significant dip from 380.7649 ppm in July 2007 to 371.8493 ppm in December of the same

Table 2. Percentage change in the maximum carbon dioxide levels for July and December 2003-2011.

YEAR	% July Maximum	% December Maximum	% +/- in Mean CO_2 December from July	Interpretation
2003	19.60	20.24	0.64	Higher in December than July
2005	19.83	19.61	-0.22	Higher in July than December
2007	19.97	19.82	-0.15	Higher in July than December
2009	20.19	20.07	-0.12	Higher in July than December
2011	20.41	20.25	-0.16	Higher in July than December

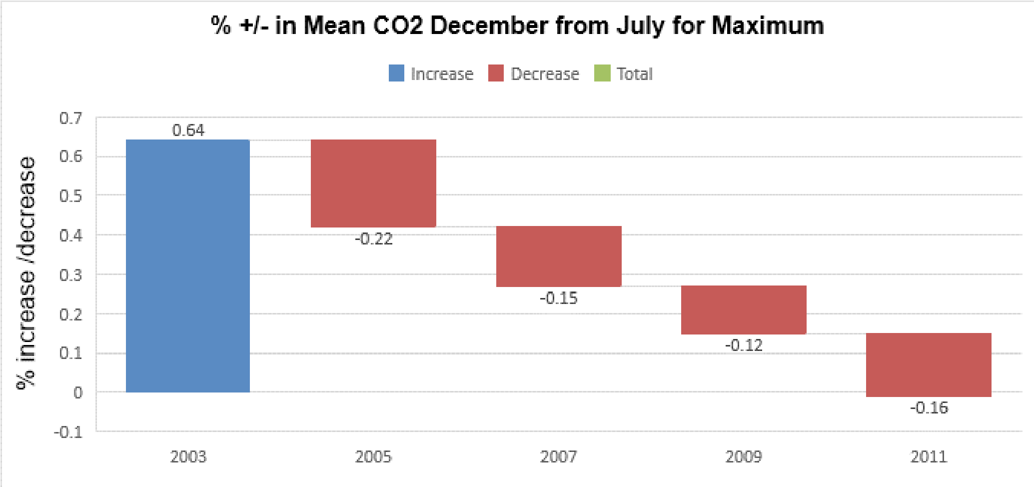


Figure 4. Percentage increase and decrease in the mean maximum carbon dioxide between December and July.

Table 3. Percentage change in the minimum carbon dioxide levels for July and December 2003-2011.

YEAR	% July Minimum	% December Minimum	% +/- in Mean CO_2 December from July	Interpretation
2003	19.65	19.64	-0.01	Higher in July than December
2005	19.79	19.74	-0.05	Higher in July than December
2007	19.96	19.99	0.03	Higher in December than July
2009	20.23	20.21	-0.02	Higher in July than December
2011	20.38	20.43	0.05	Higher in December than July

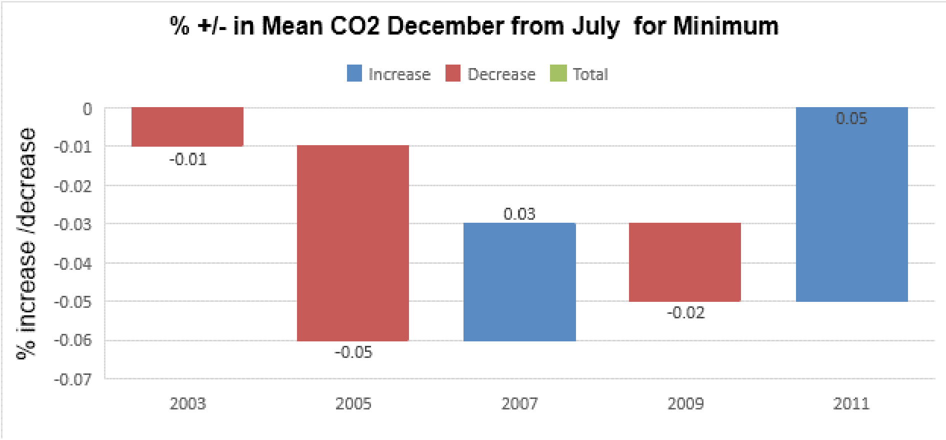


Figure 5. Percentage increase and decrease in the mean minimum carbon dioxide between December and July.

year not with standing, the NE experienced the most elevated concentrations over time with an overall mean CO_2 value of 3823.0911ppm. While the SW with fairly consistent increasing CO_2 values and a negligible drop in rates between July and December 2005 recorded 3823.0596ppm. This is a function of the population, the level of industrialization, urban expansion, and the number of gas flaring points.

The Spatio-temporal carbon dioxide values, for July in **Table 4** and **Figure 6** show that in 2003 and 2007, the NE was lower than the SW by 0.01%. In 2005 and 2009, the percentage of CO_2 across the NE and SW was the same, whereas in 2011, the NE is 0.07% higher than the SW. As a result, the South West emitted more CO_2 than the North East. Factors that could influence CO_2 in the marine environment during the wet season include rainfall and temperature differences, gas flaring activities, marine vessels, and illegal oil bunkering.

For the months of December as shown in **Table 5** and **Figure 7**, in 2003, 2005, and 2011, the NE surpassed the SW by 0.57%, 0.02%, and 0.02% respectively. While in 2007 and 2009, the percentage of CO_2 in the NE decreased by 0.55%, and 0.05%, respectively, implying that CO_2 was higher in the South West than in the North East. This could be a function of temperature and rainfall differences, gas flaring activities, marine vessels, urban expansion, and the level of industrialization.

Table 4. Percentage change in carbon dioxide levels for July 2003-2011 in the NE and SW.

Period	% Northeast Mean CO_2	% Southwest Mean CO_2	% +/- in Mean CO_2 North East from South west	Interpretation
2003 July	19.64	19.65	-0.01	Higher in South West than North East
2005 July	19.78	19.78	0.00	Equal
2007 July	19.94	20.01	-0.07	Higher in South West than North East
2009 July	20.20	20.20	0.00	Equal
2011 July	20.43	20.36	0.07	Higher in North East than South West

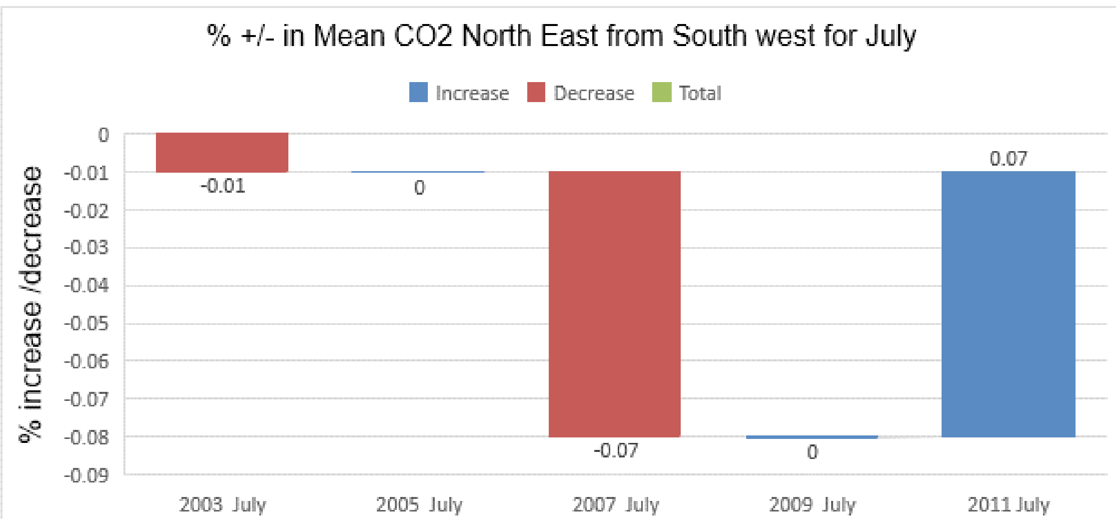


Figure 6. Percentage increase/decrease in Mean CO_2 NE from SW for July.

Table 5. Percentage change in carbon dioxide levels for December 2003-2011 in the NE and SW.

Period	% Northeast mean CO_2	% Southwest mean CO_2	% +/- in Mean CO_2 North East from South west	Interpretation
2003 December	20.24	19.67	0.57	Higher in North East than South West
2005 December	19.76	19.73	0.02	Higher in North East than South West
2007 December	19.43	19.98	-0.55	Higher in South West than North East
2009 December	20.18	20.23	-0.05	Higher in South West than North East
2011 December	20.41	20.39	0.02	Higher in North East than South West

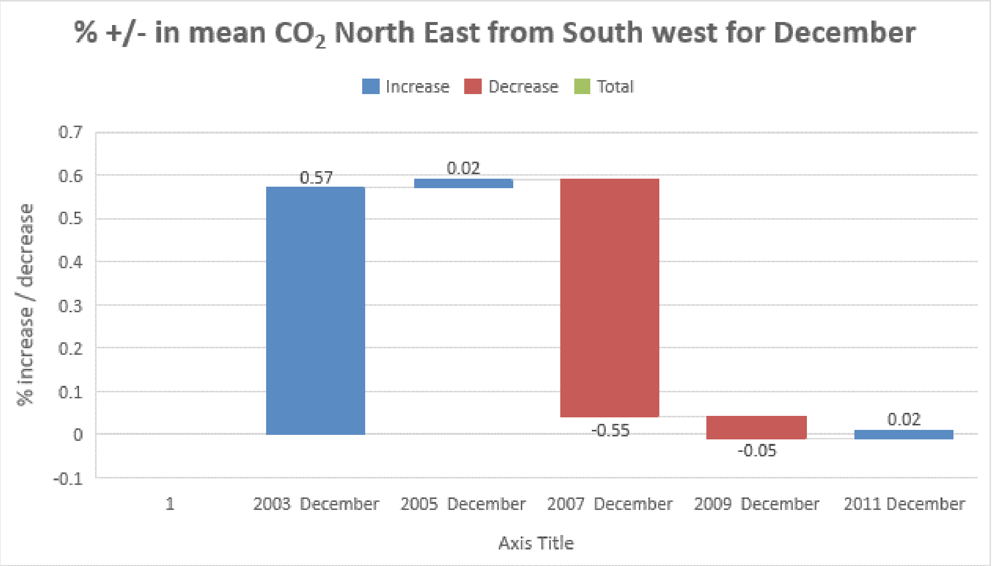


Figure 7. Percentage increase/decrease in Mean CO_2 NE from SW for December.

4.3 Predictions

From the projections made using Microsoft excel, **Figure 8** shows a steep linear trend in the minimum emission for both July and December with higher values in December. While the maximum values show a gradual trend in December, and a steep trend line to about 398ppm in July see **Figure 9**. In July, **Figure 10** and **Table 6** projects a uniform steep trend in the NE and SW whereas there is a variation in December, where the NE has a gradual trend and the SW, has a steep trend in **Figure 11**.

x

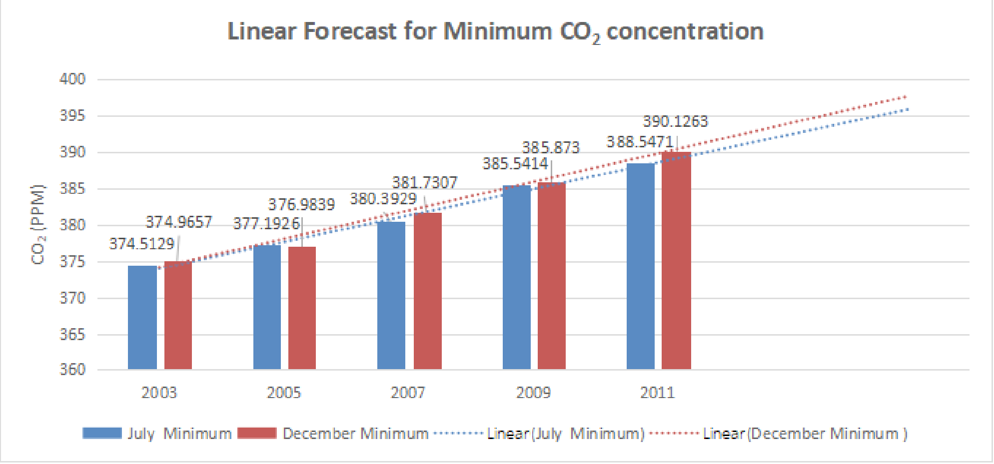


Figure 8. Trend line for the minimum CO_2 concentration.

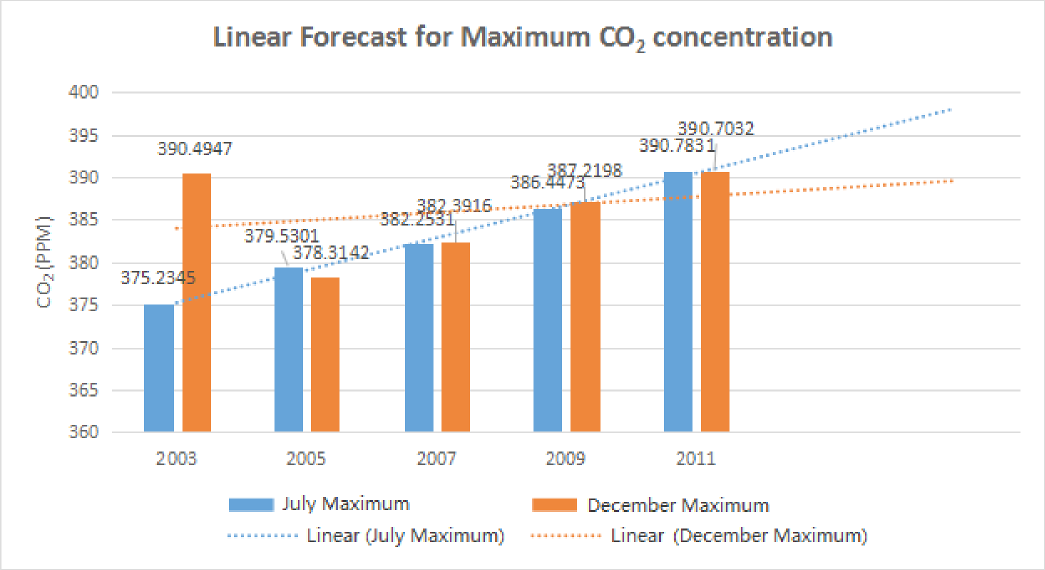


Figure 9. Trend line for the Maximum CO_2 concentration.

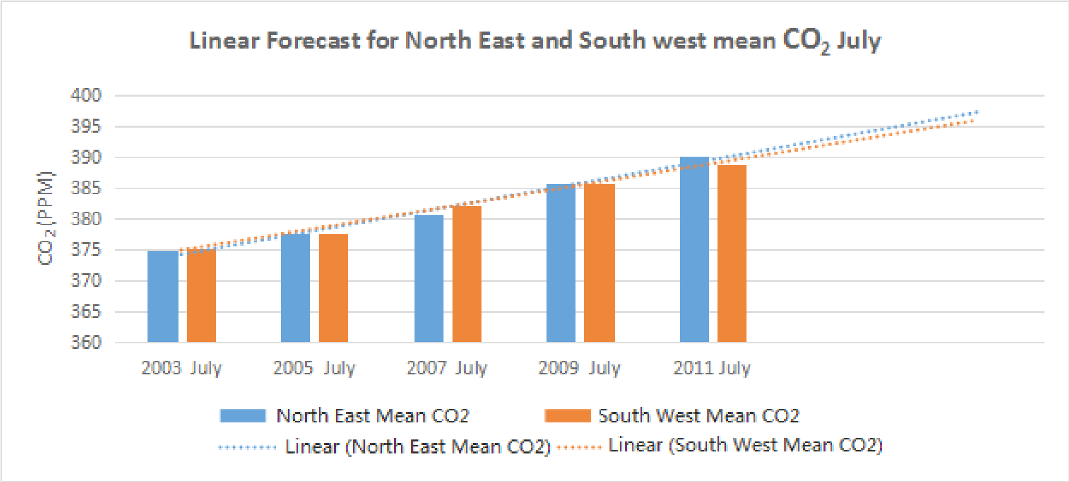


Figure 10. Trend line for the mean CO_2 concentration in the NE and SW for July.

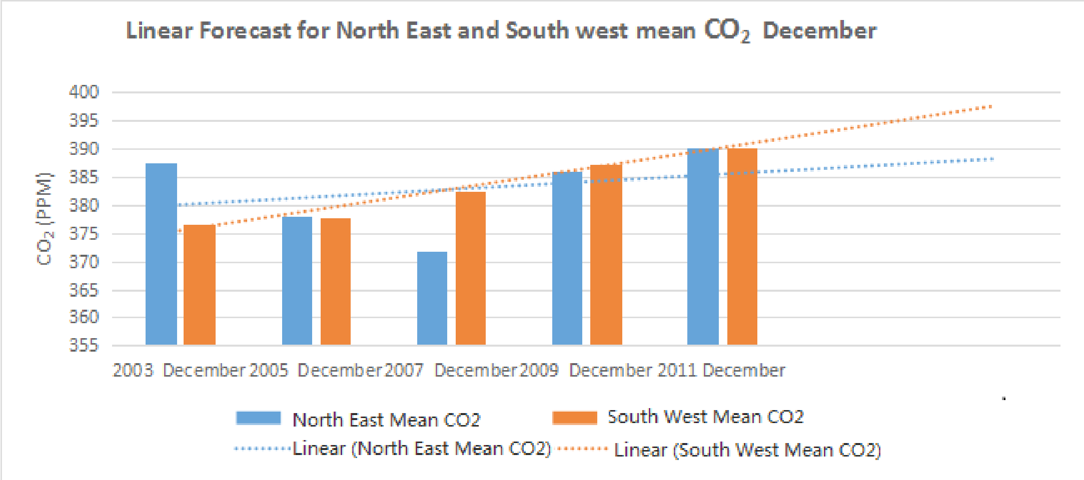


Figure 11. Trend line for the mean CO_2 concentration in the NE and SW for December.

Table 6. Monthly average tropospheric carbon dioxide for the peak wet and dry seasons from 2003-2011 for NE and SW.

Period	North East		South West	
	CO_2 Range	Mean CO_2	CO_2 Range	Mean CO_2
July 2003	374.8016-374.9458	374.8737	375.0902-375.2345	375.1623
December 2003	384.2832- 390.4947	387.3889	374.9657-378.0175	376.5186
July 2005	377.1926-378.1276	377.6586	377.1926-378.1276	377.6601
December 2005	377.7822-378.3142	378.0482	377.5162-377.7821	377.6491
July 2007	380.3929-381.137	380.7649	381.8812-382.2531	382.0671
December 2007	361.7037-381.995	371.8493	382.2595-382.3916	382.3255
July 2009	395.5414-385.9038	385.7226	385.5414-385.7226	385.632
December 2009	385.873-386.4118	386.1424	386.9506-387.2198	387.0852
July 2011	389.8888-390.3359	390.1123	388.5471-388.9943	388.7707
December 2011	390.4726-390.5879	390.5302	390.1263-390.2417	390.1840

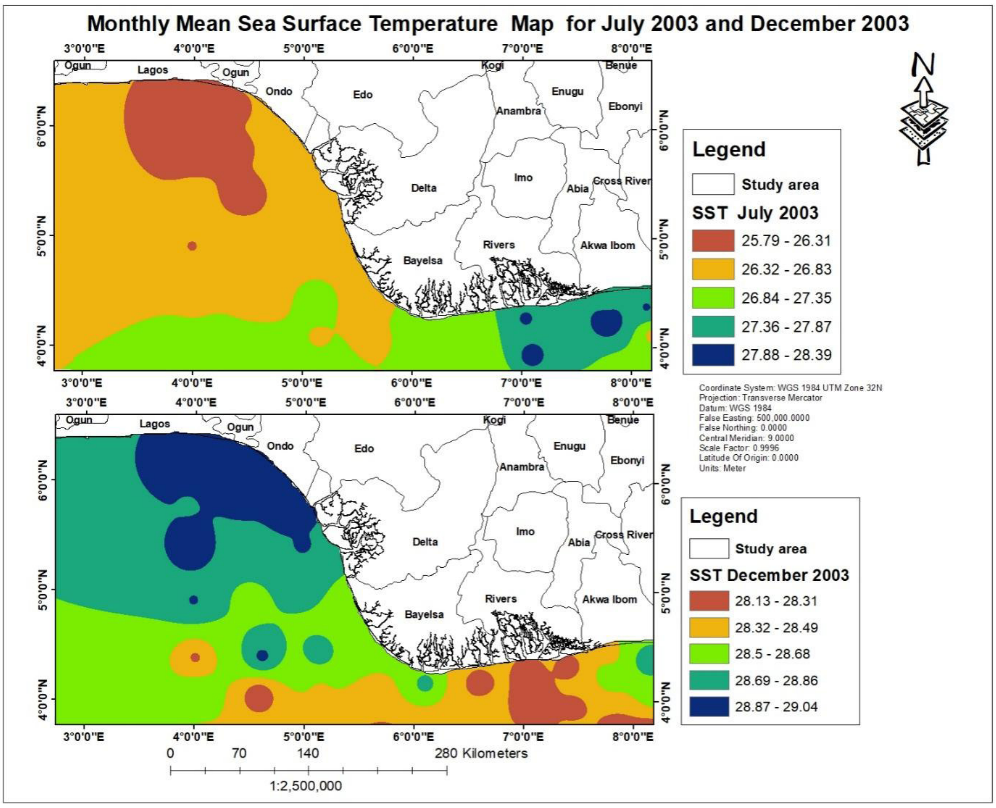
The overall investigation predicts increasing CO_2 emissions in both seasons over the years with higher concentrations in the Southwest if adequate measures are not taken to reduce carbon footprint.

4.4 Sea surface temperature

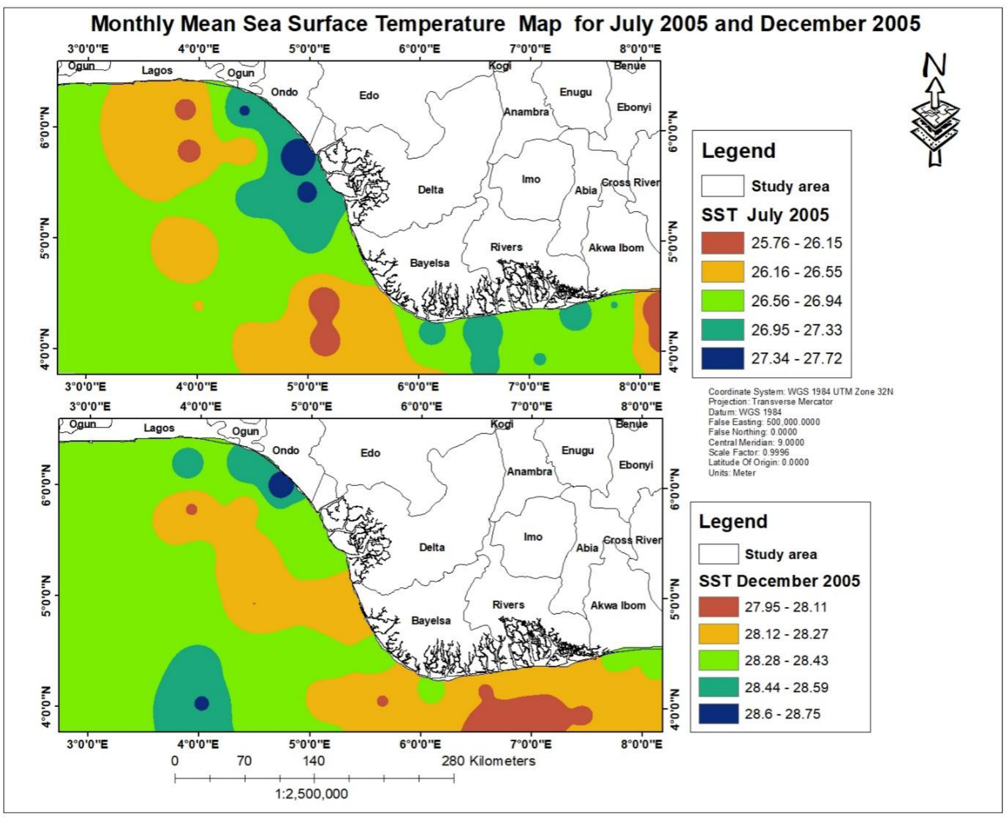
The temperature of the ocean's surface water is an important physical property of the world's oceans. As the oceans absorb more heat, sea surface temperatures rise, and the ocean circulation patterns that transport warm and cold water around the world change [15]. A change in sea surface temperature, according to Ostrander, G. K., Armstrong, K. M., Knobbe, E. T., et al. [16], can affect the marine ecosystem in a variety of ways, including how variations in ocean temperature can affect what species of plants, animals, and microbes are present in a location, alter migration and breeding patterns, endanger sensitive ocean life such as corals, and change the frequency and intensity of harmful algal blooms such as red tide. Long-term increases in sea surface temperature may also reduce circulation patterns that transport nutrients from the deep sea to the surface. Changes in reef habitat and nutrient supply could drastically alter ocean ecosystems and lead to fish population declines, affecting people who rely on fishing for food or a living [17, 18].

The results in **Figure 12**, show that the sea surface temperature was consistently low during the wet season and high during the dry season from 2003 to 2011 and also indicate a spatial variability in the monthly average sea surface temperature across the region.

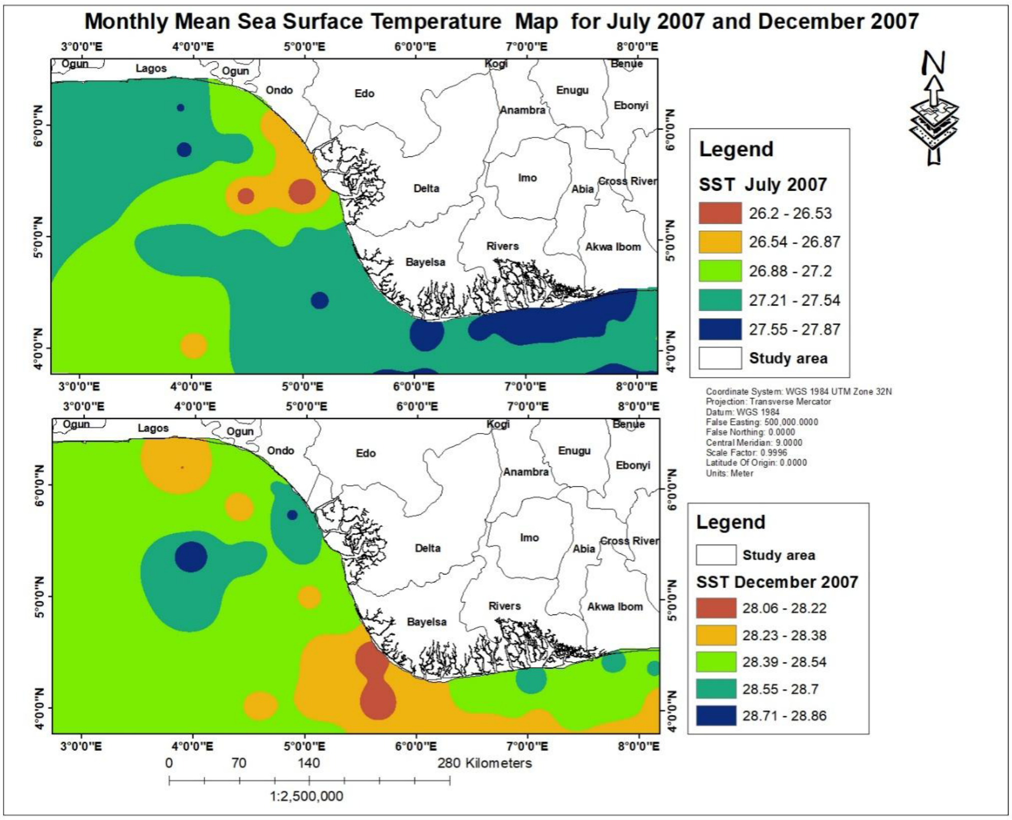
According to Tables 7 and 8, the lowest minimum temperatures for both seasons were recorded in July 2011; 25.7 °C and in December 2011; 27.8 °C. While the highest maximum temperatures of 28.39 °C and 29.27 °C were recorded in July 2003 and December 2009 respectively. The minimum temperature values show a linear trend gradually increasing in July and fairly constant in December in **Figure 13**. While **Figure 14** indicates a reduction in the maximum temperature in July and a fairly constant trend in December. However, the spatial distributions show a general increase in sea surface temperature from 2003 to 2011, and factors that could influence the rise in temperature include oil and gas operations such as gas flaring activities as shown in **Figure 1**, as well as the movement of marine vessels, and bunkering activities.


Monthly Mean Sea Surface Temperature Map for July 2003 and December 2003
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Enugu
Benue
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Rivers
Akwa Ibom
Bayelsa
Legend
Study area
SST July 2003
25.79 - 26.31
26.32 - 26.83
26.84 - 27.35
27.36 - 27.87
27.88 - 28.39
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
SST December 2003
28.13 - 28.31
28.32 - 28.49
28.5 - 28.68
28.69 - 28.86
28.87 - 29.04
0
70
140
280 Kilometers
1:2,500,000

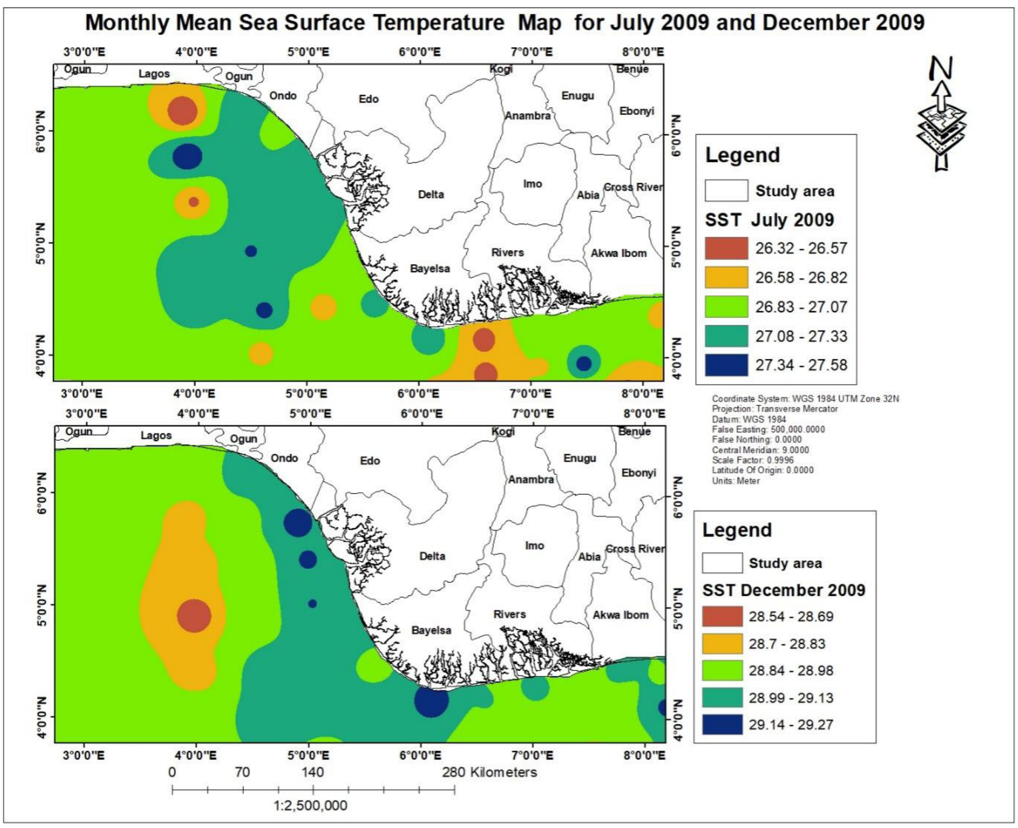
(a)


Monthly Mean Sea Surface Temperature Map for July 2005 and December 2005
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
6°0'0"N
5°0'0"N
4°0'0"N
Ogun
Lagos
Ondo
Edo
Kogi
Enugu
Benue
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Rivers
Akwa Ibom
Bayelsa
Legend
Study area
SST July 2005
25.76 - 26.15
26.16 - 26.55
26.56 - 26.94
26.95 - 27.33
27.34 - 27.72
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
SST December 2005
27.95 - 28.11
28.12 - 28.27
28.28 - 28.43
28.44 - 28.59
28.6 - 28.75
0
70
140
280 Kilometers
1:2,500,000

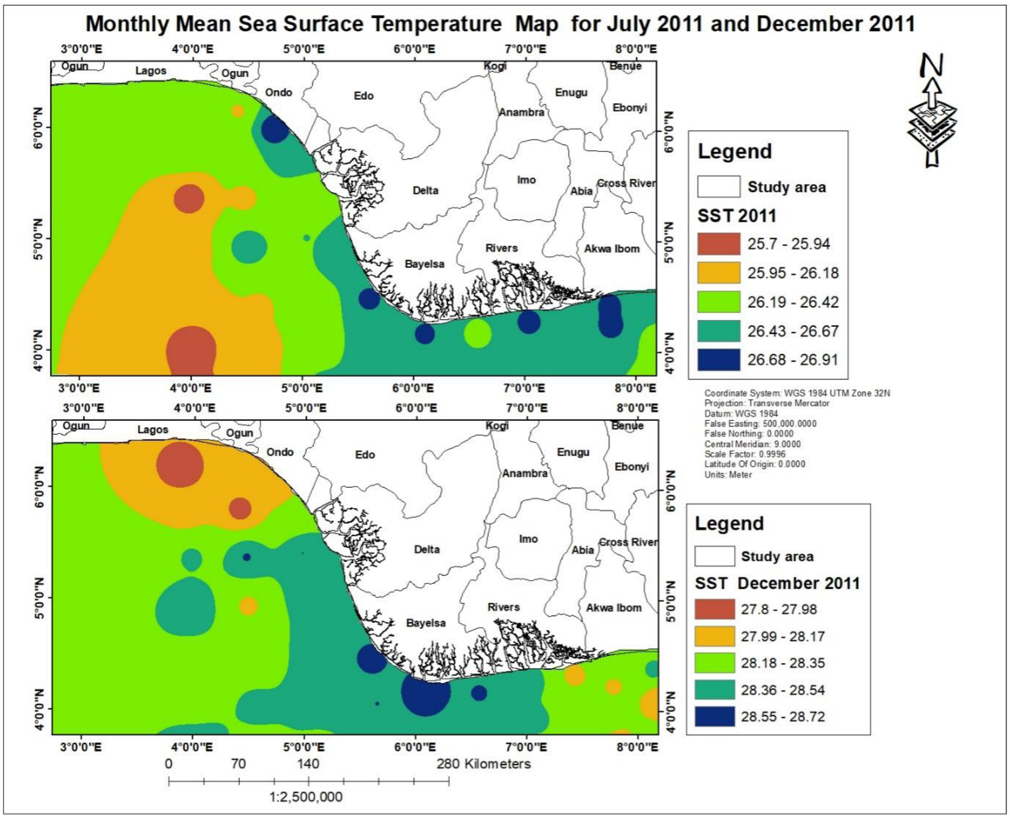
(b)


Monthly Mean Sea Surface Temperature Map for July 2007 and December 2007
Ogun
Lagos
Ogun
Ondo
Edo
Kogi
Enugu
Benue
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Rivers
Akwa Ibom
Bayelsa
Legend
SST July 2007
26.2 - 26.53
26.54 - 26.87
26.88 - 27.2
27.21 - 27.54
27.55 - 27.87
Study area
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
SST December 2007
28.06 - 28.22
28.23 - 28.38
28.39 - 28.54
28.55 - 28.7
28.71 - 28.86
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
4°0'0"N
5°0'0"N
6°0'0"N
0
70
140
280 Kilometers
1:2,500,000

(c)


Monthly Mean Sea Surface Temperature Map for July 2009 and December 2009
Ogun
Lagos
Ogun
Ondo
Edo
Kogi
Enugu
Benue
Ebonyi
Anambra
Delta
Imo
Abia
Cross River
Rivers
Akwa Ibom
Bayelsa
Legend
Study area
SST July 2009
26.32 - 26.57
26.58 - 26.82
26.83 - 27.07
27.08 - 27.33
27.34 - 27.58
Coordinate System: WGS 1984 UTM Zone 32N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 9.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Study area
SST December 2009
28.54 - 28.69
28.7 - 28.83
28.84 - 28.98
28.99 - 29.13
29.14 - 29.27
3°0'0"E
4°0'0"E
5°0'0"E
6°0'0"E
7°0'0"E
8°0'0"E
4°0'0"N
5°0'0"N
6°0'0"N
0
70
140
280 Kilometers
1:2,500,000

(d)



(e)

Figure 12. Monthly mean Sea Surface Temperature in the marine environment in Nigeria. (a)July 2003 and December 2003, (b) July 2005 and December 2005, (c) July 2007 and December 2007, (d) July 2009 and December 2009, (e) July 2011 and December 2011.

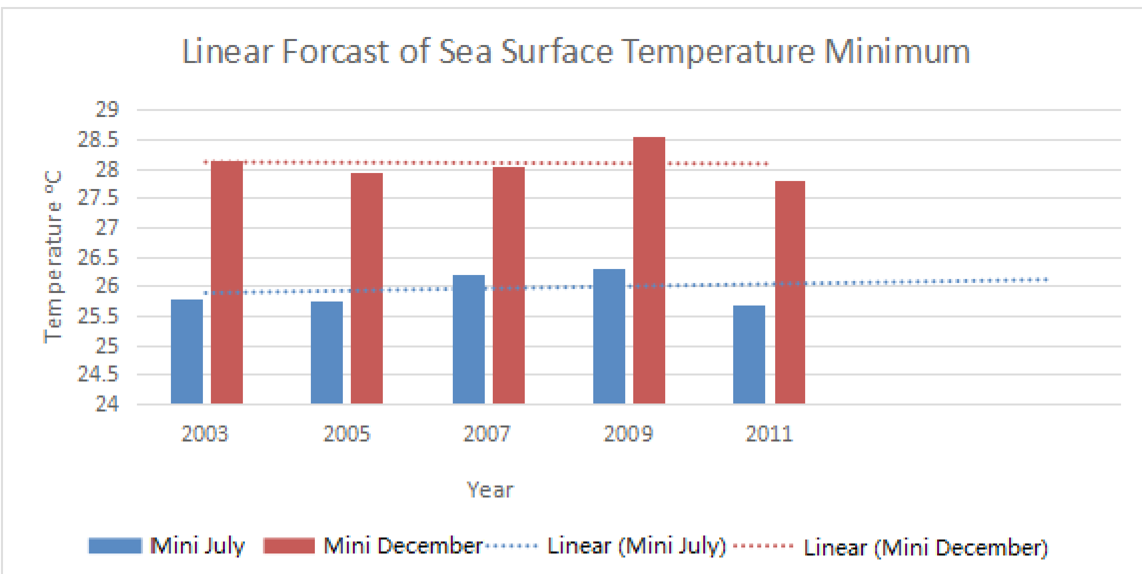


Figure 13. Trend line for the Minimum Sea surface temperature.

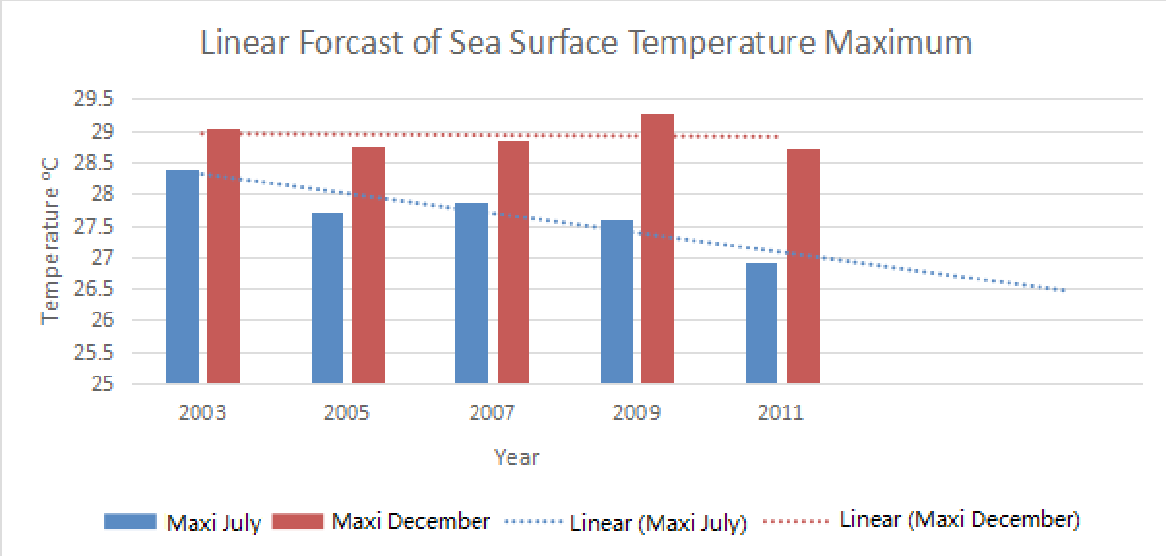


Figure 14. Trend line for the Maximum Sea surface temperature.

Table 7. Sea Surface Temperature for Minimum from 2003-2011.

Year	2003	2005	2007	2009	2011
Mini July	25.79	25.76	26.2	26.32	25.7
Mini December	28.13	27.95	28.06	28.54	27.8

Table 8. Sea Surface Temperature for Maximum from 2003-2011

Year	2003	2005	2007	2009	2011
Maxi July	28.39	27.72	27.87	27.58	26.91
Maxi December	29.04	28.75	28.86	29.27	28.72

4.5 Correlation between carbon dioxide and sea surface temperature

The regional distribution of carbon dioxide revealed that carbon dioxide is continuously increasing as a result of increased combustion of fossil fuels in oil and gas exploration, marine vessel movement, and population density in coastal communities. Consequently, the study area was classified into two: NE and SW for CO_2, based on these activities. The Pearson correlation coefficient was utilized to determine the relationship between the carbon dioxide concentrations and the sea surface temperatures (**Table 9**). The correlation coefficient revealed that 50% of the study stations showed a strong positive relationship between increased carbon dioxide concentrations and high temperatures during both the dry and wet seasons, 20% showed a strong negative relationship, 20% showed a weak positive relationship, and 10% showed a weak negative relationship. As earlier observed, the CO_2 levels are low in July and higher in December. This corresponds with lower sea surface temperatures in July and higher values in December. A scatter plot of correlation coefficients between temperature and carbon dioxide concentrations for July and December from 2003 to 2001 is shown in **Figure 15**.

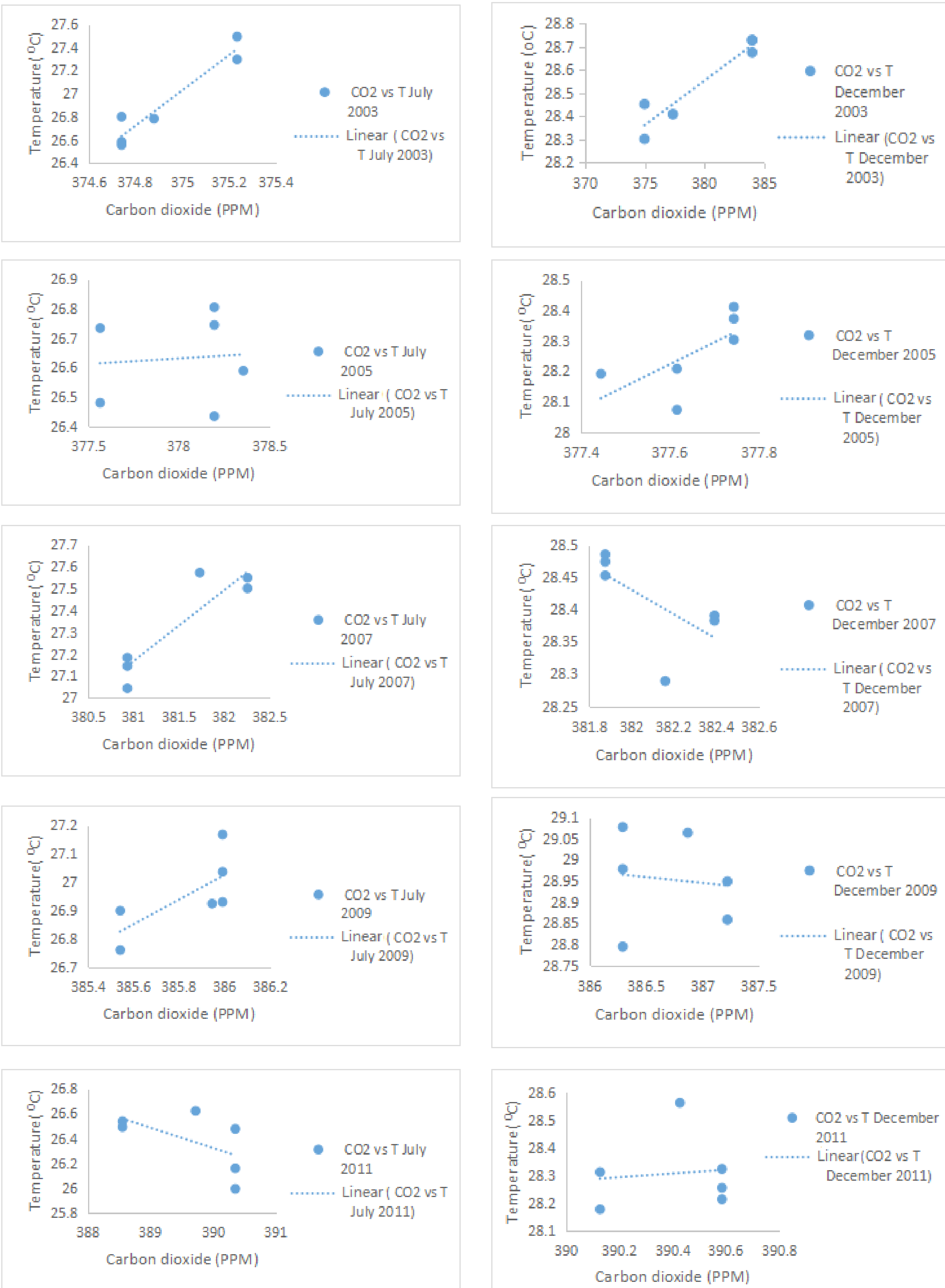


Figure 15. Pearson Correlation coefficient between CO_2 and Sea surface temperature.

Table 9. Pearson correlation coefficient between CO_2 and sea surface temperature.

Year	r (CO_2 vs T July)	Strength	Direction	r (CO_2 vs T December)	Strength	Direction
2003	.96	Strong	positive	0.95	Strong	positive
2005	.09	Weak	positive	0.68	Strong	positive
2007	.91	Strong	positive	-0.65	Strong	Negative
2009	.72	Strong	positive	-0.11	Weak	Negative
2011	-.59	Strong	Negative	0.11	Weak	positive

4.6 Environmental implications

An increase in the levels of carbon dioxide emitted and sea surface temperature leads to Global warming which results in climate change with serious repercussions on the environment. The principal consequence being higher temperatures has a ripple effect beginning with frequent torrential precipitation due to increased evaporation rate and higher water vapour retaining capacity of a warm atmosphere. In addition, sea level rise according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was expected to rise by 18 to 59 centimeters globally by the end of the 20th century. The Niger Delta coastline is categorized as an extreme hotspot of climate vulnerability by the IPCC and has in recent years experienced a series of coastal inundations, which increased annually during the period under review [19,20], erosion, and increased soil salinity induced by saltwater intrusion depleting the mangrove reserves [21]. Furthermore, the effects include changes in the circulation pattern of coastal waters [22] and warmer ocean water. Warm water holds less oxygen, and CO_2 depletion occurs in the upper 1km where most species live, inducing hypoxia in some species and increasing ocean acidity creating an imbalanced marine ecosystem [23]. In response, marine life either dies or migrate to more conducive waters.

Public health is not spared either, as warm humid climates encourage the breeding of vector-borne diseases like yellow fever and waterlogged areas for breeding mosquitos, carriers of malaria. Hot weather reduces the size of water bodies like lakes. The dry beds resulting from this shrinkage can be sources of air pollution with high levels of arsenic and other toxins which are poisonous to inhale leading to respiratory problems [24]. Poor nutrition of the population, another effect, is a function of poor crop yield and consuming mutated aquatic organisms from the acidic ocean.

5. Conclusions and recommendation

Geospatial Technology has demonstrated that the continuous increase in carbon dioxide concentration in the atmosphere caused by human activities heats up the atmosphere, resulting in heavier precipitation, which exacerbates coastal flooding. Climate change is also causing ocean acidification, shoreline erosion, and saltwater intrusion along the Niger Delta marine environment. Variations in CO_2 concentration and sea surface temperature across the region reflect differences in seasons, weather, and rates of human-driven carbon emissions. The observed trend indicates that carbon dioxide levels will rise with sea surface temperature serving as climate change indicators. It is in man's best interest to mitigate this by reducing our carbon footprint and protecting our carbon sink.

GIS and remote sensing technology should be used to regularly monitor carbon dioxide levels, and all illegal crude oil refineries in the Niger Delta should be decimated. Environmental friendly policies, such as carbon capture and storage, should be developed and implemented to improve the marine ecosystem and residents' quality of life, and thus boost economic activity.

Conflict of Interest

There is no conflict of interest.

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Appendix 1

Carbon dioxide (PPM) July					Sea Surface Temperature (°C) July				
2003	**2005**	**2007**	**2009**	**2011**	**2003**	**2005**	**2007**	**2009**	**2011**
374.7397	378.1945	380.9311	385.9913	390.3538	26.555	26.435	27.18357	26.92857	25.99571
374.7397	378.1945	380.9311	385.9913	390.3538	26.58214	26.74429	27.145	27.16643	26.16
374.7397	378.1945	380.9311	385.9913	390.3538	26.79929	26.80428	27.04357	27.035	26.47643
374.8788	378.3543	381.7284	385.9451	389.7175	26.78214	26.58929	27.57143	26.92286	26.62071
375.2345	377.5654	382.2531	385.5414	388.5471	27.49286	26.73386	27.5	26.89786	26.53714
375.2345	377.5654	382.2531	385.5414	388.5471	27.29571	26.48071	27.54857	26.75929	26.49143

Appendix 2

Carbon dioxide (PPM) December					Sea Surface Temperature (°C) December				
2003	**2005**	**2007**	**2009**	**2011**	**2003**	**2005**	**2007**	**2009**	**2011**
384.0065	377.7441	381.8758	386.2906	390.5842	28.72786	28.41071	28.47429	28.79429	28.25571
384.0065	377.7441	381.8758	386.2906	390.5842	28.67429	28.30286	28.45286	28.97786	28.21429
384.0065	377.7441	381.8758	386.2906	390.5842	28.72643	28.37214	28.48571	29.07714	28.32357
377.3511	377.4448	382.1591	386.8678	390.4262	28.40714	28.19143	28.28929	29.06357	28.56286
374.9657	377.616	382.3916	387.2199	390.1263	28.3	28.07357	28.38286	28.85786	28.31243
374.9657	377.616	382.3916	387.2199	390.1263	28.45071	28.20786	28.39071	28.94857	28.17786