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Greenhouse Gas Distribution in the Niger Delta Region

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ABSTRACT: *Increased economic activity has resulted in higher levels of greenhouse gases and carbon emissions in Nigeria, making the country more vulnerable to the effects of climate change. To investigate the distribution of greenhouse gases in the Nigerien Delta, researchers used an ex post facto approach. The information was gathered from the six Niger Delta states that comprise BRACED: Delta, Edo, Rivers, Cross Rivers, and Akwa Ibom. The study focused on twelve refineries or gas flare sites, which represented all of the areas that fit the Niger Delta profile. Starting in September 2022 and ending in February 2023, data were collected every other week using Sage thermal mass flow metres. We used ANOVA and statistical diagrams to look for regional differences in climate-GHG concentrations. Greenhouse gas emissions from the Niger Delta area fell sharply between 1993 and 2022, reaching a low of 1.38 million square metres in 2010. In 2022, the average CO_2 concentration in the area was 25.4µg/m³, and SO_2 emissions were 20.1µg/m³. Carbon dioxide far outnumbered sulphur IV oxide (SO_2) in greenhouse gas flares. Soil organic carbon concentrations averaged highest in Rivers State and lowest in Akwa Ibom. An examination of regional statistics revealed that NO_2 and SO_2 emissions varied significantly, with the greatest differences found between the states of Edo and Rivers. However, CO_2 emissions were uniform across the country. Reduce the impact by collaborating, strengthening our capabilities, conducting research, and sharing our technologies.*

KEYWORDS: greenhouse gases, carbon dioxide, Niger Delta, spatial spread, emission

INTRODUCTION

Human activity in the environment can have either beneficial or detrimental impacts. Nevertheless, the proliferation of the population and human endeavours have led to an escalation in the emission of greenhouse gases (Bello, 2010). The increase in greenhouse gas (GHG) emissions is directly correlated with population growth, economic development, and improvements in living conditions. Over the past five decades, economic activities in Nigeria have led to a rise in carbon emissions and concentrations of greenhouse gases. This has intensified the greenhouse effect and is anticipated to result in climate change, which is currently recognised as the most significant, hazardous, and intricate global environmental concern. Petroleum exploration and exploitation contribute to the escalation of gas flaring (Chijoke, 2002).

Annually, a staggering amount of 150 billion cubic metres of natural gas is burned off, resulting in the wastage of 15-20 billion dollars and the emission of 260-400 million metric tonnes of greenhouse gases (McMichael et al., 2003). According to the World Bank, approximately 110 billion cubic metres (bcm) of associated gas are burned and released into the atmosphere every year. This amount is sufficient to meet the annual natural gas consumption of both Germany and France (Ismail & Umukoro, 2012). Nigeria has the highest amount of Associated Gas (AG) flaring globally (Nkwocha & Mbano, 2010). As a result of unsustainable exploration practices and a deficiency in gas utilisation infrastructure in Nigeria. The greenhouse gases responsible for the increase in solar heat trapped in the Earth's atmosphere are carbon dioxide (CO_2), methane (CH_4), and nitrogen dioxide (N_2O) (UNFCC, 2007). In addition to increasing temperatures, gas flaring can also lead to the formation of acid rain, which has detrimental effects on agriculture, forests, and other infrastructure (Ismail & Umukoro, 2012). Acidic rainwater leads to roof erosion and contamination of soil and water.

The primary contributors to CO_2 emissions are transportation, industry, and power generation. The emission of carbon dioxide (CO_2) has the potential to increase the Earth's temperature and disrupt climate patterns (Odionkhere & Efe, 2021). The exponential expansion of the global economy has led to a surge in energy demand, consequently resulting in the escalation of greenhouse gas (GHG) emissions. Odiong et al. (2010) examine the correlation between gas flaring in the Niger Delta and the subsequent rise in greenhouse gas emissions. Nigeria's flaring activities make a substantial contribution to the overall global emissions of greenhouse gases (GHGs). According to Eronmhonsele and Norris (2021), flaring is likely the primary contributor to greenhouse gas (GHG) emissions in the Niger Delta. Due to the inefficiency of numerous flares, methane is emitted in place of carbon dioxide. The potent greenhouse gas methane has the potential to contribute to the phenomenon of global warming. The increase in temperature in the Niger Delta is primarily attributed to human activities. Greenhouse gas emissions are caused by the utilisation of automobiles, the consumption of power in residential areas, and the use of aerosol products (Okechukwu & Ukeje, 2016). Ozabor and Obisesan (2015) conducted a study on the impact of gas flaring on temperature, agriculture, and the Ebedei community in the Delta State. The findings indicate that the temperature in the Ebedei zone fluctuates in accordance with the proximity to the flare source. The study aimed at evaluating the spatial distribution of greenhouse gases in the Niger Delta region.

Study Area

The Niger Delta is in Nigeria's coastal plain between 3°N and 6°N and 5°E and 8°E. According to Odigwe, Efe, and Atubi (2020) and Emoyan et al. (2008), the area under consideration includes 8600 square kilometres of stagnant swamplands and 2,370 square kilometres of rivers, creeks, and estuaries. The area under study has many wetlands, including mangrove forests, swamps, coastal ridges, and woodlands (Eyinla & Ukpo, 2006). Giwa et al. (2019) reported that Nigeria's Niger Delta gas reserves cover 70,000 km2, with 20,000 km2 on land. Due to its large gas reserves, the Niger Delta has been gas flaring, which has harmed the environment (Okechukwu & Ukeje, 2016). More emissions raise ambient temperature, which should offset CO_2 production and absorption.

The Niger Delta Region has a semi-hot, humid equatorial climate with high internal variability. The climate is characterised by year-round high temperatures. Although all months have rain, May and September are the wettest, with double rainfall and 665.2mm of rain (Efe, 2007; Efe et al., 2013). However, August has low precipitation and frequent convectional showers. The annual rainfall ranges from 1500mm to 4300mm, with 1620mm in Ondo and 3202.52mm in Warri to 2400mm in Port Harcourt. This region also includes Yenagoa, Calabar, and Benin City. These towns receive 3000mm, 2666mm, and 2583mm of annual precipitation, according to Iwugo et al. (2003), Efe (2007), and Efe & Ojoh (2011). Due to abundant precipitation, flat terrain, and an elevated water table, flooding occurs frequently. Intense and frequent precipitation events saturate silt and clay soils, reducing infiltration rates and increasing surface runoff. The upper and middle delta back swamps receive most rainfall runoff. Runoff is hindered by the coastal zone's low topographic gradient. Flooding is common after rain. Thus, urban micro-heat islands have increased due to rising temperatures.

By 2022, the population is projected to reach 51.2 million. Rivers, Delta, Akwa Ibom, and Imo have populations over three million. Bayelsa had the lowest population in 2022, below three million. Bayelsa and Cross River States may be excluded, so population sizes are unlikely to vary much. However, population densities vary. The population density of the Niger Delta Region was 182 per square kilometre in 1991 and 265 in 2006, according to the UNDP (2010). However, Imo, Abia, Akwa Ibom, and Rivers have above-average population densities. Imo has 833.5 people per square kilometre, Abia State 760.68, Akwa Ibom 799.3, and Rivers 635.89. Population distribution is uneven, especially in core Niger Delta states. Due to the fragmented and swampy topography, human settlements are limited. Rapid global economic growth has increased energy needs and greenhouse gas (GHG) emissions, contributing to the greenhouse effect. Osita (2008) states that greenhouse gas emissions affect the population.

Conceptual Issues

In 1827, Jean-Baptiste-Joseph de Fourier discovered that the Earth's atmosphere allows solar short-wavelength radiation to pass through, resulting in the warming of the surface. The atmosphere acts as a barrier that prevents longer-wavelength radiation, which has a cooling effect on Earth, from reaching the surface. Greenhouses are structures with roofs made of glass or plastic and walls that are transparent.

Permitting sunlight to enter increases the temperature inside. The walls of the structure impede the dissipation of heat (Ejemeyovwi, 2009; Kweku et al., 2017; Ojha, 2017). The greenhouse effect elevates the Earth's temperature by trapping and preserving heat within the atmosphere. The Earth's atmosphere contains greenhouse gases that enhance its overall warmth, exceeding the warming effect caused by the sun alone (The Royal Society, 2010).

The Sun influences Earth's climate by emitting visible and near-visible energy, which encompasses ultraviolet wavelengths. Approximately one-third of solar energy reaching Earth's outermost layer is reflected into space. The Earth's surface absorbs more than one-third of the energy not absorbed by the atmosphere (IPCC, 2021). To maintain equilibrium, Earth must emit an equal amount of energy into space as it absorbs. As a result of its significantly lower temperature compared to the Sun, the Earth releases radiation with longer wavelengths, predominantly in the infrared spectrum (see Figure 1).

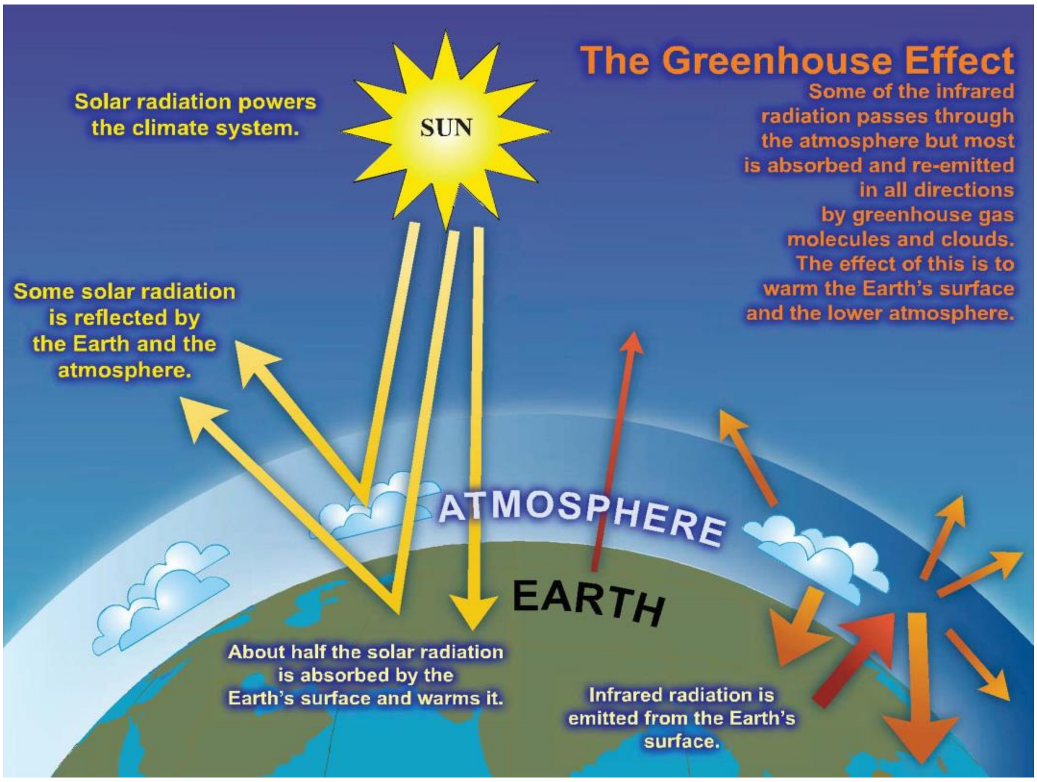

Figure 1: Model of the natural greenhouse effect
Source: Intergovernmental Panel on Climate Change (2007)

The atmosphere receives a significant amount of the heat radiation emitted by land, and clouds and subsequently re-emitted back towards Earth. The topic of discussion is the greenhouse effect. The greenhouse effect refers to the process by which Earth's atmosphere traps and preserves solar radiation. Carbon dioxide, water vapour, and methane are gases that permit sunlight to enter the Earth's atmosphere while trapping and absorbing the planet's heat. Greenhouse gases (GHGs) provide thermal insulation for the lower layers of the atmosphere. Human activities, such as the combustion of fossil fuels, amplify the greenhouse effect (Ojha, 2017). The greenhouse effect is a scientific hypothesis that elucidates the process by which carbon dioxide, ozone, and other gases amass in the Earth's atmosphere, impeding the dissipation of thermal energy into outer space.

The term "greenhouse effect" is still employed to elucidate the phenomenon of radiation-induced heat retention in the Earth's atmosphere, owing to historical circumstances. In 1859, John Tyndall conducted measurements to determine the heat-trapping abilities of water vapour, carbon dioxide, and methane. Tyndall posits that fluctuations in atmospheric gas concentrations may be a contributing factor to the occurrence of ice ages, as suggested by Wallington et al. (2004).

Similar to the greenhouse effect, the Earth's atmosphere allows solar radiation to pass through, resulting in the warming of the surface. Subsequently, the Earth emits infrared thermal energy into the atmosphere. Specific atmospheric gases selectively absorb and reroute a significant proportion of the radiation emitted by Earth. This process leads to an increase in the Earth's temperature. The Earth's atmosphere effectively retains solar heat, similar to the way greenhouse gases function.

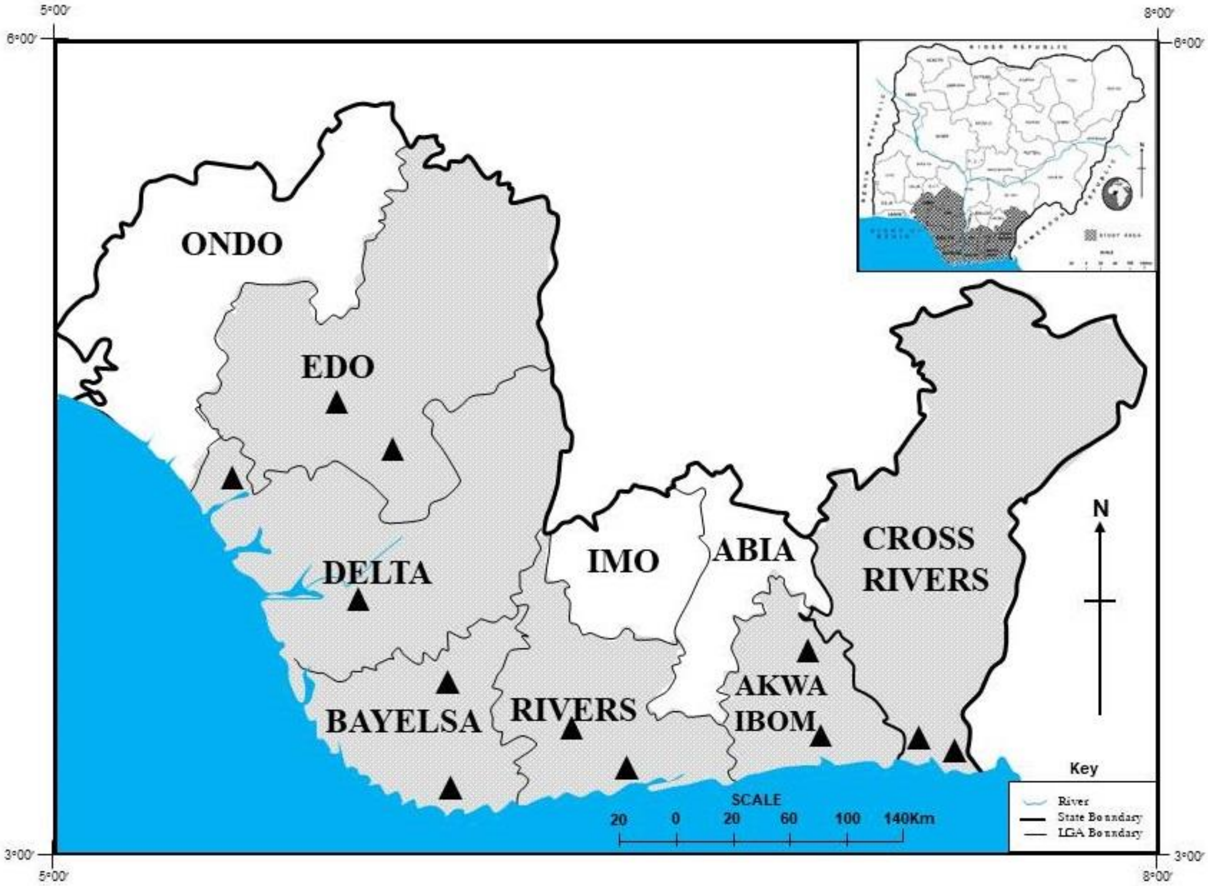

Figure 2: The sample location for greenhouse gas emissions in the BRACED state of the Niger Delta
Source: Cartography Laboratory, Department of Geography and Regional Planning, Delta State University, Abraka, 2023

METHODS AND MATERIALS

This study employed ex post facto research methodology. Okereke (2007) used this study's design. The data was derived from both primary and secondary sources. The main dataset consisted of measurements of greenhouse gases (GHGs) including CO_2, NO_2, and SO_2. The selected greenhouse gas was chosen due to its ubiquitous presence and capacity to trap heat. Efe and Mogborukor (2012) state that these gases are prevalent in the area and have a significant impact on the occurrence of acid rain. Secondary data comprises past greenhouse gas (GHG) data obtained from CRU websites.

The dataset comprises data on greenhouse gas emissions (GHGE) over 30 years. A systematic sampling technique was employed to choose samples from industrial areas in the Niger Delta, with specific consideration given to refineries and gas flaring sites. This study collected data from six states in the Niger Delta region, specifically Bayelsa, Rivers, Akwa Ibom, Cross Rivers, Edo, and Delta. The states mentioned are commonly known as BRACED, as depicted in Figure 2.

Information was gathered from two prominent petroleum facilities or refineries in the selected states. The study focused on twelve specific flare sites or refineries in the Niger Delta region, as indicated in Table 1. The utilisation of twelve flare sites/refineries is warranted to encompass all regions that satisfy the criteria of the Niger Delta area and prevent any exclusions. Ezeigbo et al. (2002) conducted a study on the tidal characteristics of rivers in the Niger Delta, focusing on the same locations.

Table 1: Sampling Areas

Sample States	Sample Areas
Delta	Forcados, and Warri
Rivers	Bonny, and Port Harcourt
Cross Rivers	Calabar, and Ikang
Akwa Ibom	Uyo, and Eket
Bayelsa	Brass, and Yenagoa
Edo	Ologbo, Okada

Fieldwork, 2023

Data archives and greenhouse gas (GHG) concentrations are collected concurrently. Data was collected from September 2022 to February 2023. The selection of the months was based on the fact that October and March exhibit the highest levels of gas concentrations, whereas September experiences the highest amount of rainfall.

Data were collected biweekly in September and February. GHG was measured using an open-air sampling method that utilised a Sage thermal mass flow metre. A total of twelve locations utilised Sage thermal mass flow metres to quantify the volume of flared gases. The instrument autonomously analysed a sample of surrounding air, utilising its physical characteristics, and transmitted a continuous signal to an analyzer. In 2022, the Sage metre exhibited measurements of carbon dioxide, nitrous oxide, and sulphur dioxide obtained from the analyzer. The gas emissions were monitored by the researcher and five highly skilled research assistants using the Sage thermal mass flow meter (Efe, 2008; Efe, 2016).

The GHG data from the archives of the National Oil Spill Detection and Response Agency (NOSDRA) in the chosen states were acquired through the following methodologies: The selection of greenhouse gas data was conducted using random sampling, focusing on measurement locations within each zone. This approach aimed to identify and analyse geographical variations in gas flares. We have also obtained a substantial collection of data on greenhouse gas (GHG) emissions. The dataset covers the periods from 1993 to 2002, 2003 to 2012, and 2013 to 2022. The source of the data is the verified records of flared gas obtained from Shell Petroleum Development Company. The selection of years was based on the reliability of the data, the continuity of records, and the diversity of data sources.

The data was analysed using ANOVA, and statistical diagrams were generated. ANOVA is employed to detect disparities in comparative analysis. In their air quality and climate studies, Odjugo and Ikhuoria (2003), Efe (2010), Ede et al. (2011), Tawari and Abowei (2012), and Efe (2013) found significant results. The data underwent a process of double-validation before being analysed using SPSS version 22. Efe et al. (2013) employed the Scheffe & Tufte post hoc test to identify the disparity in GHG concentration across the region. Repeated measure designs are constrained due to the control of type I errors by robust procedures such as Tukey or Scheffe (Caldwell & Cheuvront, 2019).

RESULTS AND DISCUSSION

Figure 3 depicts the annual emissions of greenhouse gases (GHGe) in the Niger Delta region from 1993 to 2022. In contrast, the region had its lowest annual greenhouse gas (GHG) emissions in 2010, totaling 1.38 million cubic metres, as illustrated in Figure 4.8. The initial magnitude of greenhouse gas (GHG) emissions in 1993 was approximately 164,343 cubic metres. This quantity steadily decreased over two years, reaching 154045 cubic metres in 1995. Between 2002 and 2005, greenhouse gas (GHG) levels increased significantly, from 151,307 to 171,891 m^3.

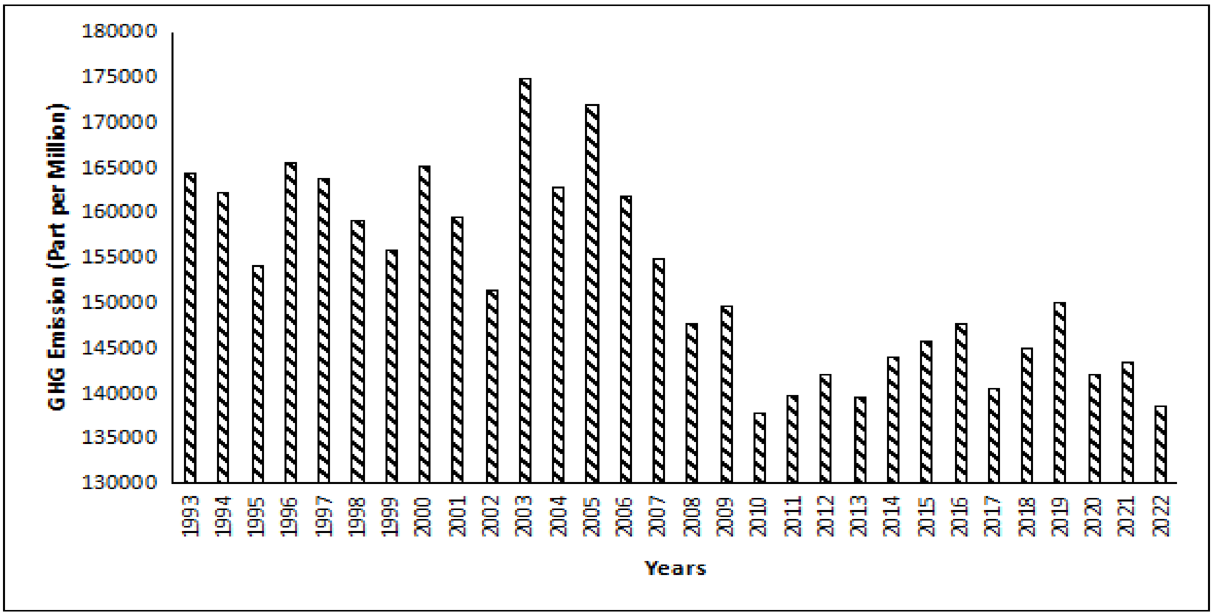

Figure 3: Greenhouse Gas Emissions from the Niger Delta
Source: Worldbank (2022)

It is worth noting that, as shown in Figure 3, 2003 was the peak year for emissions over the previous 30 years. Between 2006 and 2010, greenhouse gas emissions decreased significantly, from 161,719 m3 to 139,819 m^3. After that, there was a slight increase to 150,000 cubic metres in 2019, followed by a significant decrease to 142,000 cubic metres in 2020. During the time period studied, the average volume was determined to be 152661.3 m^3, a value that has been linked to negative environmental impacts in the Niger Delta Region.

According to Emam (2016), Giwa et al. (2017), and Fawole et al. (2017), the burning of natural gas that is connected to crude oil in the Niger Delta area presents a difficulty for the people living there due to the release of substantial quantities of carbon monoxide (CO), carbon dioxide (CO2), sulphur dioxide (SO2), nitrogen dioxide (NO2), soot containing black carbon (BC), and hydrocarbons. Human exposure to nitrogen dioxide (NO_2) has been linked to respiratory problems, increased asthma attacks, and other respiratory diseases. Approximately 4.5 million cubic metres of greenhouse gases (GHG) were released during the study's time frame. Examining the entire duration of the analysis, it is clear that 2003 had the highest level of greenhouse gas (GHG) emissions. The release of harmful gases is determined by the flare system's combustion efficiency, whereas the brightness and colour are determined by the specific composition of the gas produced (Uchegbulam et al., 2022).

Table 2: Greenhouse Gas Emissions from the Niger Delta

States	**SO_2**	**CO_2**	**NO_2**
Akwa Ibom	12.0	23.2	21.0
Bayelsa	24.5	26.8	26.0
Cross Rivers	17.5	25.4	23.2
Delta	23.3	26.3	24.6
Rivers	25.5	25.4	28.2
Edo	17.6	25.0	18.5
Average	**20.1**	**25.4**	**23.6**

Source: Authors Computation (2022)

Table 2 shows greenhouse gas emissions in the Niger Delta region. The average concentration of CO_2 emissions is 25.4µg/m³, while sulphur dioxide (SO_2) emissions have an average concentration of 20.1µg/m³. Furthermore, NO_2 emissions have an average concentration of 23.6µg/m³. The most commonly flared greenhouse gas is carbon dioxide, while the least frequently flared greenhouse gas is sulphur IV oxide (SO_2). Carbon dioxide (CO_2) concentrations in the BRACED region of the Niger Delta range from 20µg/m³ to 30µg/m³ in Akwa Ibom, Bayelsa, Cross Rivers, Delta, Edo, and Rivers states (see Figure 4).

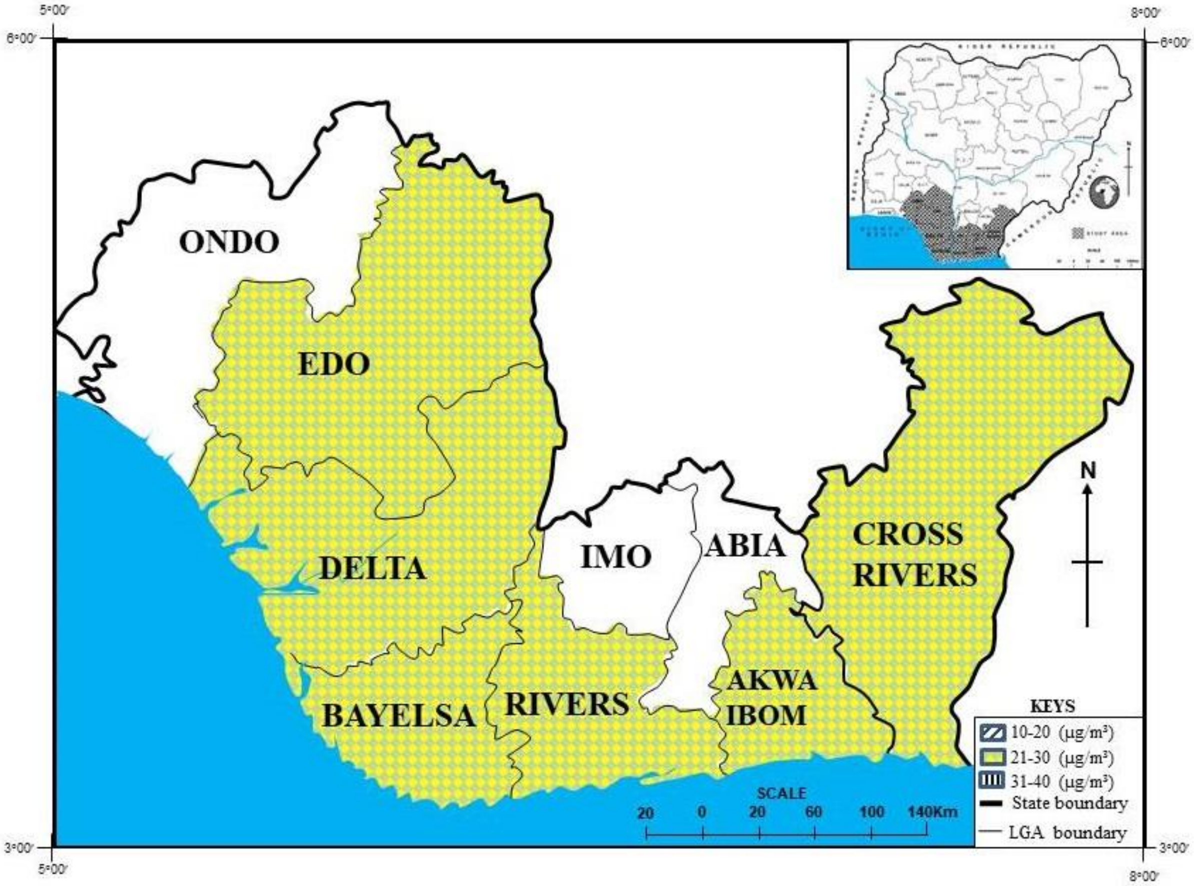

Figure 4: Geographical Dispersion of Carbon Dioxide in the BRACED region of the Niger Delta
Source: Cartography Laboratory, Department of Geography and Regional Planning, Delta State University, Abraka, 2023

This suggests that the carbon dioxide emission rate in the Niger Delta's buffered condition is nearly identical across all regions. The region's high rate of deforestation and flaring activities may be considered contributing factors. The average concentration of CO_2 emissions is highest in Bayelsa State and lowest in Akwa Ibom. However, there is little or no variation in carbon dioxide (CO_2) emissions between the states of Cross Rivers, Rivers, and Edo. Furthermore, it is worth noting that Bayelsa and Delta States have the highest carbon dioxide (CO_2) emissions. The average concentration of Sulphate (SO_2) in the BRACED region of the Niger Delta ranges from 10µg/m³ to 20µg/m³ in Akwa Ibom, Cross Rivers, and Edo states (refer to Figure 5). In Delta, Rivers, and Bayelsa states, Sulphate (SO_2) concentrations range from 20µg/m³ to 30µg/m³. This observation suggests that Sulphate emissions are higher in the states of Delta, Rivers, and Bayelsa. The high prevalence of oil corporations in these states, which engage in gas flaring, may be contributing to this trend. The average concentration of sulphate (SO_2) emissions is highest in Rivers State and lowest in Akwa Ibom. Nonetheless, there is a limited or insignificant difference in Sulphate (SO_2) emissions between Cross Rivers and Edo states. Furthermore, it is worth noting that the states of Rivers, Bayelsa, and Delta have the highest levels of sulphur (SO_2) emissions.

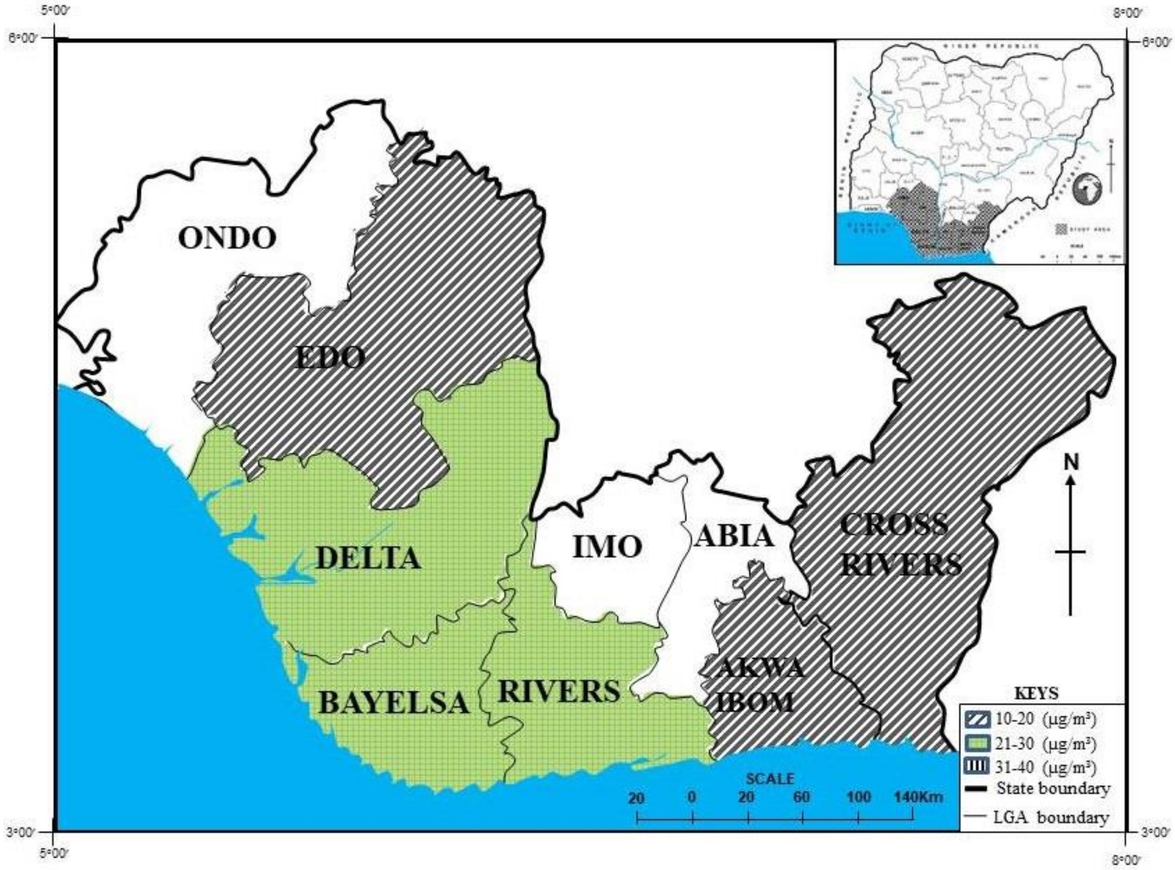

Figure 5: Distribution of SO2 in the BRACED states of the Niger Delta region
Source: Cartography Laboratory, Department of Geography and Regional Planning, Delta State University, Abraka, 2023

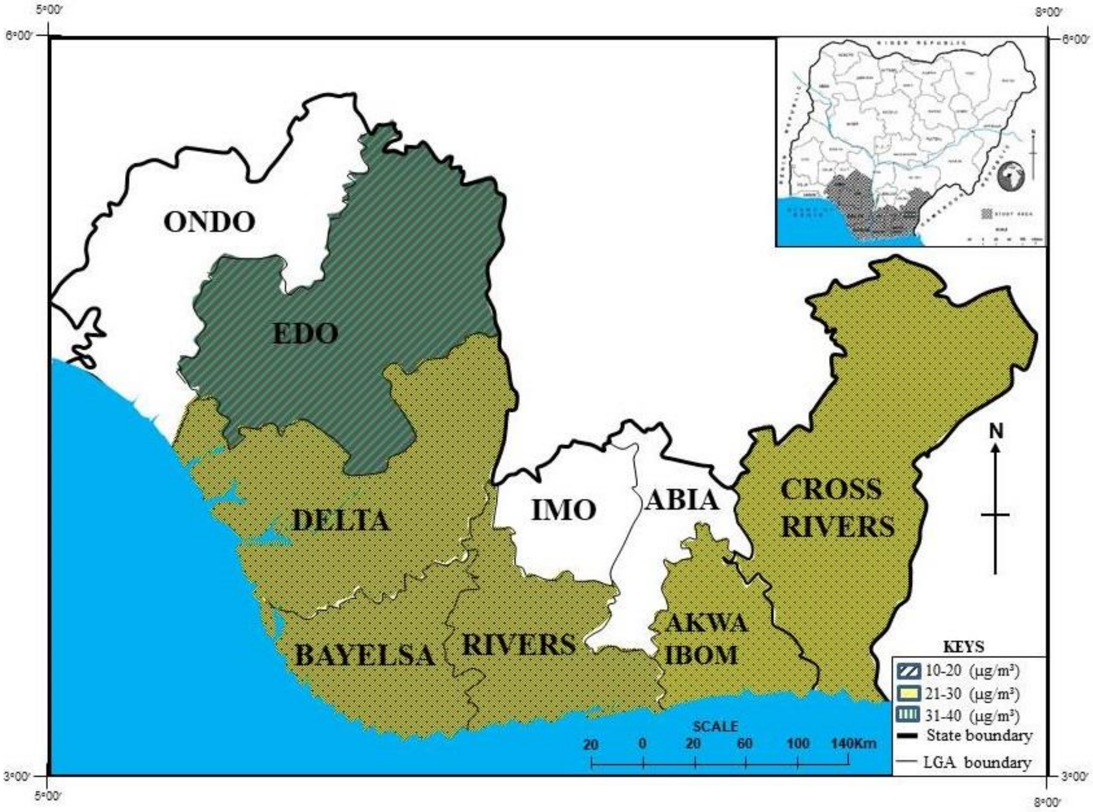

Figure 6: Distribution of NO_2 in the BRACED states of the Niger Delta
Source: Cartography Laboratory, Department of Geography and Regional Planning, Delta State University, Abraka, 2023

Figure 6 shows that concentrations range from 21µg/m³ to 30µg/m³ in Akwa Ibom, Bayelsa, Cross Rivers, Rivers, and Delta states. The concentration of nitrogen dioxide (NO_2) in Edo state ranges from 10 to 20 µg/m³. This observation suggests that the states of Akwa Ibom, Bayelsa, Cross Rivers, Rivers, and Delta have slightly higher rates of nitrogen dioxide emissions. The average rate of nitrogen dioxide (NO_2) emissions is highest in Rivers State and lowest in Akwa Ibom. However, it is important to note that there is little or no difference in nitrogen dioxide (NO_2) emissions between Cross Rivers and Delta state. Furthermore, it is worth noting that the states of Rivers and Bayelsa have the highest nitrogen dioxide (NO_2) emissions.

Table 3: ANOVA Explaining the GHGE variations in the Niger Delta

Emission		Sum of Squares	Df	Mean Square	F	Sig.
CO_2	Between Groups	31.495	5	6.299	1.384	.277
	Within Groups	81.945	18	4.552		
	Total	113.440	23			
NO_2	Between Groups	240.365	5	48.073	5.403	.003
	Within Groups	160.155	18	8.898		
	Total	400.520	23			
SO_2	Between Groups	551.487	5	110.297	12.962	.000
	Within Groups	153.172	18	8.510		
	Total	704.660	23			

Source: Fieldwork, 2023

Table 3 presents a statistical analysis of the variation in greenhouse gas emissions observed across the Niger Delta region. The statistical model shows a significant difference in greenhouse gas emissions (NO_2

and SO_2) in the Niger Delta region, with a P-value of <0.05. Nonetheless, carbon dioxide (CO_2) emissions in the Niger Delta show little or no variation. The Scheffe post hoc test yielded statistically significant results at the 0.05 level. The obtained value was 0.011 (see Table 4). This value indicates a significant difference in NO_2 emissions between Edo State and Rivers State. Similarly, the Scheffe post hoc test reveals statistically significant differences in the levels of variation in SO_2 emission among the regions of Akwa Ibom and Rivers compared to other states in the region, as indicated by the respective p-values of (0.001, 0.002, 0.00) and (0.00, 0.037, 0.041) (see Table 4). This suggests that SO_2 emissions vary significantly across these regions. To summarise, the levels of SO_2 emissions observed in Akwa Ibom and Rivers states within the Niger Delta region differ significantly from those observed in other nearby states. Rivers and Akwa Ibom states, located in the Niger Delta region, have significantly lower NO_2 and SO_2 emissions than other states in the region. Nonetheless, carbon dioxide (CO_2) emissions are consistent across all states in the Niger Delta region. The model shows a significant difference in NO_2 emission gaps between Edo and Rivers states, while SO_2 emissions vary greatly between Akwa Ibom, Bayelsa, and Delta.

Table 4: Scheffe Post Hoc

Scheffe							
Dependent Variable	(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
NO_2	6 Edo	5 Rivers	-9.6500*	2.1092	.011	-17.504	-1.796
SO_2	1 Akwa Ibom	2 Bayelsa	-12.5750*	2.0627	.001	-20.255	-4.895
		4 Delta	-11.2500*	2.0627	.002	-18.930	-3.570
		5 Rivers	-13.5250*	2.0627	.000	-21.205	-5.845
	5 Rivers	1 Akwa Ibom	13.5250*	2.0627	.000	5.845	21.205
		3 Cross Rivers	8.0250*	2.0627	.037	.345	15.705
		6 Edo	7.9000*	2.0627	.041	.220	15.580
*. The mean difference is significant at the 0.05 level.							

CONCLUSION

The study on the spatial distribution of greenhouse gases in the Niger Delta region sheds significant light on the region's environmental challenges. According to the study, GHG emissions in the Niger Delta area are associated with the greenhouse effect theory. This effect occurs when the Earth's atmosphere traps solar radiation due to the presence of gases like carbon dioxide and methane. These gases contribute to thermal insulation in the Earth's deeper layers, a phenomenon exacerbated by human activities such as fossil fuel combustion. Successful policies and initiatives aimed at reducing emissions and promoting sustainable practices require close collaboration among government agencies, local communities, and international players. Furthermore, in order to strengthen the region's ability to adapt to and mitigate the negative effects of greenhouse gas emissions, adequate resources need to be allocated to capacity building, research, and technology transfer.

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