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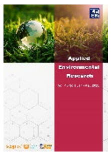

Research Article

# Effects of COVID-19 Policy on Air Quality in Lagos State, Nigeria

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## Abstract

The decrease in air quality has been a major concern in the world for decades, and it has continued to worsen with toxic gases accumulating at exponential rates. The atmosphere has been heavily polluted as a result of anthropogenic activities, and these activities were greatly reduced during the COVID-19 pandemic when a lockdown policy was imposed. The study area, Lagos, is the state in Nigeria with the highest population count, making it most susceptible to the spread of the coronavirus and, as such, having the strictest policy regulations. This study seeks to evaluate the effects of the COVID-19 lockdown policy on air quality in Lagos State. The study adopted geographic information systems (GIS) and remote sensing techniques. Goggle Earth Engine (GEE) and Sentinel 5P (S5P) TROPOMI dataset were used to obtain results for carbon monoxide (CO), sulphur dioxide ($SO_2$), aerosols (particulate matter), and nitrogen dioxide ($NO_2$) through JavaScript coding for the year before the lockdown (2019), the year of the lockdown (2020), and the year after the lockdown (2021). Results from the study revealed that the year 2020 had lower concentrations of aerosols and $NO_2$, which increased in 2021 when human and vehicular activities were back to normal. $SO_2$ and CO concentrations were higher in the year 2020 than in year 2019 and 2021, suggesting that the COVID-19 lockdown was loosely implemented. It is recommended that policymakers invest in green technologies such as solar systems to minimize emissions, enforce strict emission standards for industries and vehicles to limit the release of air pollutants.

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## Introduction

Air pollution is a significant problem in contemporary society, as it has detrimental impacts on both the environment and human health. This is evidenced by the increased rates of morbidity and mortality associated with air pollution [1]. The phenomenon of air pollution has increased exponentially due to the processes of urbanization and industrialization, and it has now acquired a global impact on human health [2]. The threat of CO from automotive exhaust, $SO_2$ released from factories, aerosols from vehicular emission [3] and $NO_2$ from the combustion of fossil fuels [4] to both human health and the environment is expanding [5].

Environmental researchers clamor for an environment with a reduction in gaseous pollutant [6–7], and to completely achieve this require going back to the preindustrial era when man was in oblivion of industrial machinery or vehicular emission. Just recently, it became clear that the best way to reduce air pollution would be to create policies that restrict certain human activities that pollute the environment. For example, Behera et al. and Kazemi-Karyani et al. [8-9] discovered improved air quality due to a reduction in anthropogenic activities as a result of the COVID-19 lockdown. In the same way, Ameachi et al. [10] in their study on the effect of fuel subsidy removal on air quality, discovered that there was a significant decline in $SO_2$, $NO_2$, and

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CO due to the fact that the majority of Lagos State residents could no longer afford fuel due to the hike in price, which in turn led to improved air quality.

The global pandemic of COVID-19 was declared by the World Health Organization (WHO) on March 11, 2020 [11]. As a result of its high transmissibility and rapid global dissemination, numerous governments implemented stringent measures on both social interactions and economic operations, such as the implementation of lockdown policies. The imposition of restrictions in late March 2020 resulted in a general lockdown for a significant portion of the global population [12]. This led to a temporary reduction in major anthropogenic sources of air pollution, resulting in significant improvements in air quality across the globe [4]. Several scholarly articles have been published on the subject of air quality enhancement as a result of the lockdown measures [8–9, 13–14]. Consequently, it can be inferred that the improvement of air quality was an advantageous unintended consequence of the pandemic. Not much has been done with the use of Sentinel 5P to investigate trends in air pollutants prior to the COVID-19 era in Nigeria [15]. To address this gap, this study was conducted to investigate the effect of the COVID-19 policy on air quality in Lagos State, Nigeria.

This study employs remote sensing techniques with JavaScript coding on Google Earth Engine with the Sentinel 5P dataset to investigate the effect of COVID-19 policy on air quality in Lagos State, Nigeria, for the year 2019, 2020 and 2021. The objective was to determine the changes in air quality before, during, and after the COVID-19 era.

## Materials and methods

### 1) Study area

Lagos State, Nigeria, is the study area for this research. The State is located in the southwestern region of Nigeria, on the Gulf of Guinea coast. Because it is the most populated state in the country, it is an excellent example for comparing air quality before, during, and after the COVID-19 lockdown policy. The research area is located on latitude 6.465422E and longitude 3.406448N. The state has a tropical climate that is hot all year, with a dry season from November to March and a rainy season from April to October. The humidity level is high all year, but especially during the rainy season. Rainfall is abundant, particularly from May to July. The dry season sees the highest temperatures. Lagos is the country's financial center; it is also the most populous city in Nigeria and on the African continent, with a current population of about 17 million people, and it covers a vast area of 1,171.28 km$^2$ (452.23 mile$^2$). Lagos state comprises of 20 local government areas (LGAs), which include: Agege, Alimosho, Apapa, Ifako-Ijaye, Ikeja, Kosofe, Mushin, Oshodi-Isolo, Somolu, Eti-Osa, Lagos Island, Lagos Mainland, Surulere, Ojo, Ajeromi-Ifelodun, Amuwo-Odofin, Badagry, Ikorodu, Ibeju-Lekki, and Epe.

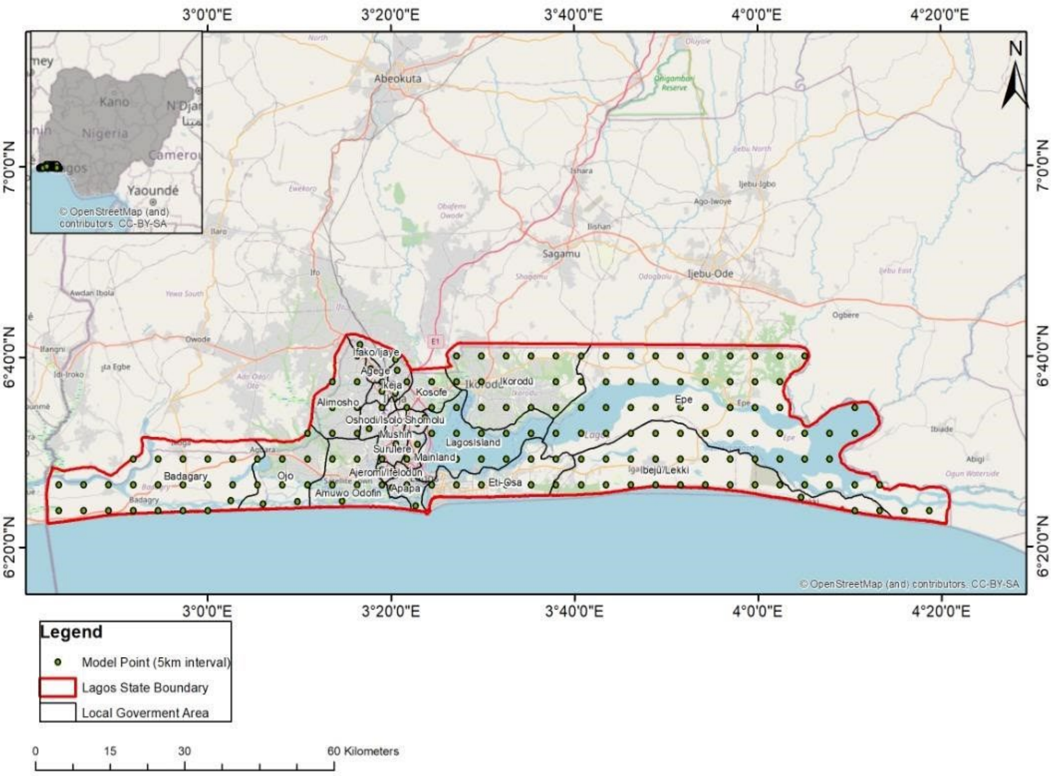


**Figure 1** Map of Lagos state showing sample points.

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### 2) Data type and data source

The study predominantly utilized secondary data obtained through the implementation of air quality technology, specifically the utilization of Sentinel-5P. The secondary data for the months March through September for the years 2019, 2020 and 2021 was obtained from Sentinel-5 Precursor (Sentinel-5P), a mission instrument that collects useful data for assessing air quality. The Sentinel-5P satellite mission is part of the Global Monitoring for Environmental and Security (GMES/Copernicus) program [16]. Copernicus Sentinel-5 P is the first Copernicus mission dedicated to monitoring the Earth's atmosphere. The mission is made up of one satellite that carries the Tropospheric Monitoring Instrument (TROPOMI) [17]. The TROPOMI instrument is a multispectral sensor that captures reflectance of wavelengths crucial for quantifying atmospheric concentrations of ozone, methane, formaldehyde, aerosol (particulate matter), carbon monoxide, nitrogen oxide, and sulfur dioxide, in addition to cloud characteristics. Its spatial resolution is 0.01 arc degrees. The TROPOMI is a passive sun backscatter imaging spectrometer that can acquire 8-band imagery in multiple spectral domains ranging from UV to visible to near-infrared (NIR) and shortwave infrared (SWIR) [18]. It has a higher spatial resolution than its predecessors, measuring 7 x 3.5 kmI (along and across track), and Sentinel5P offers a new potential for air quality research, making it suitable for polluting emission source monitoring [1]. Recent research carried out by Manisalidis et al. [1] has found a positive correlation between data obtained from Sentinel-5P and ground-truth data, giving validation to the data obtained.

### 3) Method of data collection

The Sentinel 5P pollutant dataset used for this study are achieved on Goggle Earth Engine Catalog. The first step was to create sample points along the LGAs of Lagos State. The Fishnet tool in ArcMap was used to generate stratified sampling points and intervals was set to 5 km. The points were saved into a shape file from ArcGIS and imported into Google Earth Engine to be processed in order to generate results for the three years (2019, 2020, and 2021) under review for air quality analysis at all sample points.

### 4) Method of analysis

The procedure entails the systematic arrangement and organization of data in preparation for analysis. The data processing and analysis were conducted using ArcGIS 10.5 and Google Earth Engine (GEE). Google Earth Engine provides a database of petabytes of satellite imagery taken in near real time (NRTI). Sentinel 5P houses the TROPOMI sensor, which observes pollutants and gives results for their concentration in mol/mI, with the exception of aerosol, which have no measurement unit. The result can then be assessed using GEE by scripts of codes run on the editor. After importing the sentinel 5P dataset of interest into GEE, spatial filters (filteBounds, band selection, filterData, mean, and clip) were applied. The image generated was downloaded as a Geotiff file and imported into ArcGIS 10.5 for visualization. The lack of a ground-truth measuring system in Nigeria makes it difficult to monitor air quality over a vast area [15]. As a result, this study relied entirely on data acquired from S5P. However, Kazemi-Karyani et al. [9] and Lorente et al. [18] discovered a positive correlation between S5P results and ground-truth monitoring station results. The dataset for analysis of the atmospheric pollutants using Google Earth Engine is shown in Table 1.

**Table 1** Dataset for analysis of $NO_2$, $SO_2$, CO and Aerosols

| Parameter analyzed | Image collection | Minimum | Maximum | Band used | Unit |
|---|---|---|---|---|---|
| Nitrogen dioxide ($NO_2$) | COPERNICUS/S5P/NRTI/L3_NO2 | 0.0000552 | 0.000101 | $NO_2$ column number density | mol $mI^{-1}$ |
| Sulphur dioxide ($SO_2$) | COPERNICUS/S5P/NRTI/L3_SO2 | 0.540 | 1.0606 | $SO_2$ column number density | mol $mI^{-1}$ |
| Carbon monoxide (CO) | COPERNICUS/S5P/NRTI/L3_CO | 0.039 | 0.07706 | CO column number density | mol $mI^{-1}$ |
| Aerosols (Particulate matter) | COPERNICUS/S5P/OFFL/L3_AER_AI | -1.219 | 0.20007 | Absorbing aerosol index | - |

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## Results and discussion

The concentration of CO increased in the year 2020 and decreased back in 2021 (Figure 2). Motor vehicles represent the primary contributor of CO emissions [16]. It can be anticipated that a decrease in traffic volume would result in a reduction of CO concentration. Nonetheless, indoor fuel-burning appliances represent an additional category of sources for CO [4]. With the increase in the number of individuals staying at home, there existed a possibility of heightened utilization of various household appliances such as gas space heaters, leaking chimneys, kerosene stoves, and furnaces. Practically every home in Lagos State has a generator and uses fuel or diesel on a regular basis [19], which may have contributed to the increase in CO levels in the atmosphere during the COVID-19 lockdown period. This result is in line with the results of Okoduwa and Amaechi [15] who in their studies, reported that year 2020 recorded the highest amount of CO during the COVID-19 lockdown. The concentration of $SO_2$ was observed to be higher in the year 2020 as compared to years 2019 and 2021 (Figure 3). This can be attributed to the indoor source of $SO_2$, resulting from increased individual usage of fossil fuel generators to provide power for electric utilities by individuals locked down at homes; as well as industrial activities suggestive of the fact that factories activities where at optimum levels providing utilities for individuals at home. The year 2020 witnessed a surge in electricity consumption in numerous households due to prolonged lockdown policy, resulting in a corresponding rise in the concentration of $SO_2$ during the lockdown. Thus, it can be observed that in the year 2021, the concentration decreased because the same electrical appliances were now used in the same place by multiple people. On the contrary, the study conducted by Gautam [20] has reported noteworthy declines in the levels of $SO_2$ and CO in India during the COVID-19 lockdown because strict measures were implemented effectively.

CO concentration obtained from all sampling locations for each sample point, along with the calculated average concentration for the years 2019, 2020, and 2021.

**Table 2** CO concentrations (mol $ml^{-1}$) for sampling years

| Sample months | 2019 | 2020 | 2021 |
|---|---|---|---|
| March | 0.05761 | 0.065959 | 0.063594 |
| April | 0.051372 | 0.050011 | 0.071866 |
| May | 0.04362 | 0.044078 | 0.041461 |
| June | 0.04228 | 0.08038 | 0.042464 |
| July | 0.046138 | 0.043429 | 0.043295 |
| August | 0.044766 | 0.048293 | 0.014273 |
| September | 0.039966 | 0.042843 | 0.041132 |
| Average mean | 0.004546 | 0.01324 | 0.012737 |

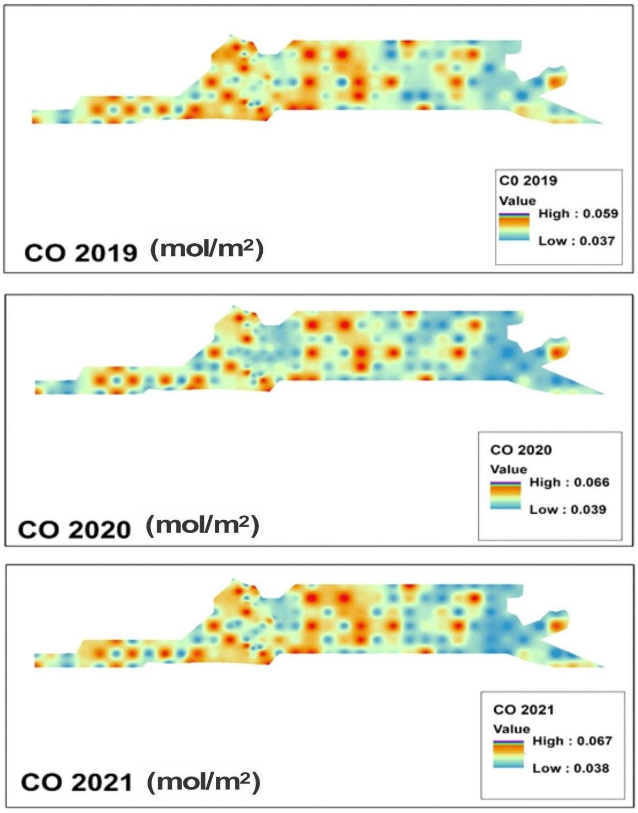


**Figure 2** CO air pollution maps for sample years.

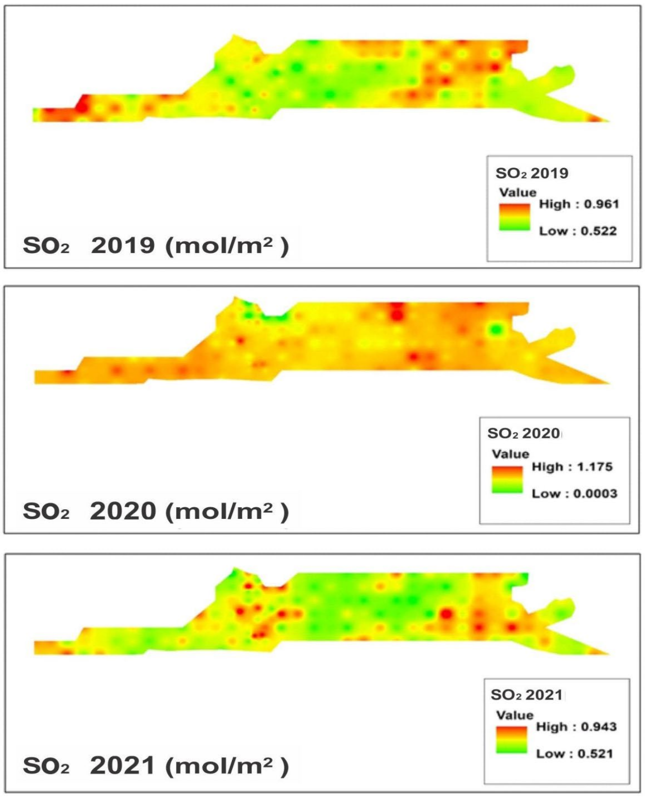


**Figure 3** $SO_2$ air pollution maps for sample years.

$SO_2$ concentration obtained from all sampling locations for each sample point, along with the calculated average concentration for the years 2019, 2020, and 2021.

**Table 3** $SO_2$ concentrations (mol $mI^{-1}$) for sampling years

| Sample months | 2019 | 2020 | 2021 |
|---|---|---|---|
| March | 0.706945 | 0.64175 | 0.67941 |
| April | 0.660605 | 0.663859 | 0.647331 |
| May | 0.574061 | 0.489058 | 0.699359 |
| June | 0.736237 | 0.658117 | 0.686589 |
| July | 0.758125 | 0.707382 | 0.735666 |
| August | 0.765165 | 0.679998 | 0.747275 |
| September | 0.724396 | 0.892511 | 0.850516 |
| Average mean | 0.049323 | 0.071886 | 0.048807 |

The findings of the study indicate that the concentration of aerosols during the lockdown period was comparatively lower than that of the years 2019 and 2021, as evidenced by the data presented in Table 4. Aerosols are suspended solid or liquid particles [21] with sizes ranging from 0.001 to 100 μm [22]. The findings suggest that the COVID-19 pandemic year led to a reduction in aerosols concentrations compared to the preceding and succeeding years. Following the period after the lockdown, there was a notable rise in the levels of aerosols concentrations. The observed increase in aerosols concentration subsequent to the reopening in 2021 may be attributed to heightened human activities, as the concentration surpassed that of the preceding year.

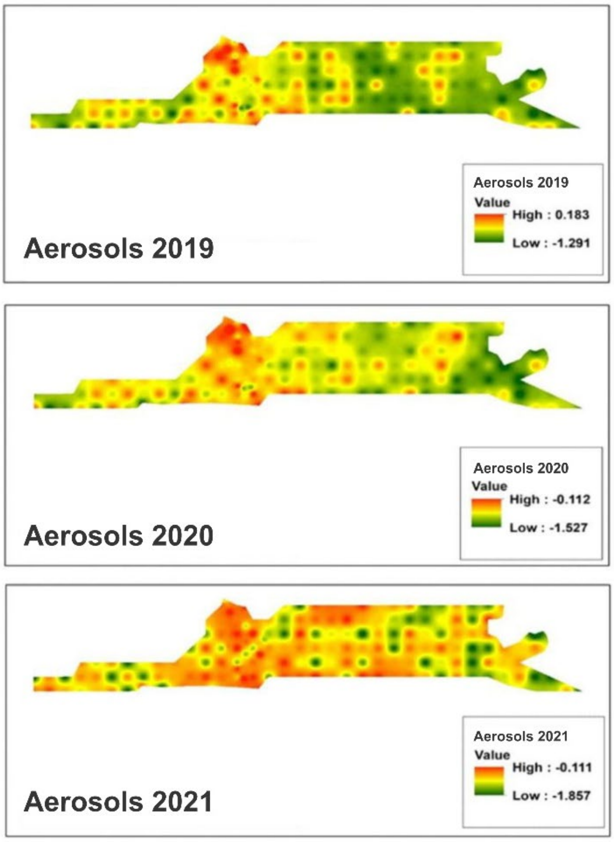


**Figure 4** Aerosols air pollution maps for sample years.

Aerosols concentration obtained from all sampling locations for each sample point, along with the calculated average concentration for the years 2019, 2020, and 2021.

**Table 4** Aerosols concentrations for sampling years

| Sample months | 2019 | 2020 | 2021 |
|---|---|---|---|
| March | 0.015021 | -0.3375 | -0.38511 |
| April | -0.19399 | -0.59577 | -0.82904 |
| May | -0.80021 | -0.91236 | -1.4133 |
| June | -0.81002 | -0.86665 | -1.37496 |
| July | -0.87608 | -0.91225 | -0.02791 |
| August | -0.67903 | -0.83679 | -0.54274 |
| September | -0.99655 | -1.11167 | -0.60896 |
| Average mean | 0.303221 | 0.188288 | 0.398984 |

Upon comparing the $NO_2$ concentration during three distinct periods, it is evident that prior to the implementation of the lockdown measures, the concentration of $NO_2$ was considerably high (Figure 5). However, during the lockdown period, there was a marked reduction in the $NO_2$ concentration. Subsequently, after the lockdown period, the concentration of $NO_2$ was observed to be higher. On the other hand, the levels of CO and $SO_2$ increased during the implementation of the lockdown policy, although not substantially. The disparity in the concentration of gaseous pollutants during the COVID-19 pandemic can be attributed to their respective sources. $NO_2$ is a byproduct of combustion processes associated with the burning of fossil fuels, including emissions from transportation vehicles, power generation facilities, and industrial operations [4, 23]. The decrease in road traffic must have resulted in a reduction of $NO_2$ levels.

$NO_2$ concentration obtained from all sampling locations for each sample point, along with the calculated average concentration for the years 2019, 2020, and 2021.

**Table 5** $NO_2$ concentrations (mol $mI^{-1}$) for sampling years

| Sample months | 2019 | 2020 | 2021 |
|---|---|---|---|
| March | 9.08E-05 | 7.75E-05 | 0.000101 |
| April | 7.84E-05 | 6.77E-05 | 9.15E-05 |
| May | 7.38E-05 | 0.000074 | 8.21E-05 |
| June | 6.33E-05 | 7.71E-05 | 9.93E-05 |
| July | 5.79E-05 | 5.78E-05 | 6.68E-05 |
| August | 5.52E-05 | 0.000065 | 6.47E-05 |
| September | 6.93E-05 | 6.49E-05 | 7.54E-05 |
| Average Mean | 9.59E-06 | 6.05E-06 | 1.23E-05 |

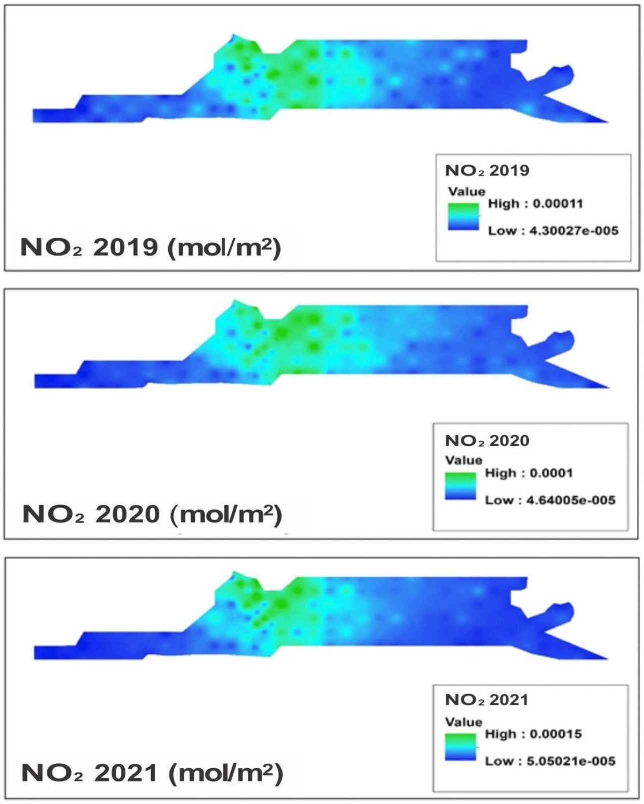


**Figure 5** $NO_2$ air pollution maps for sample years.

According to Glorennec et al. [24], research findings indicate a note-worthy reduction in the average $NO_2$ concentrations in the primary urban regions of Europe by 18–40% in 2020 as a result of the lockdown. Elshorbany et al. [25] conducted research in the United States to examine the impact of COVID-19 lockdown measures on air quality. Their findings revealed a decrease in the concentrations of $NO_2$ and CO. Research analyses conducted in the United States show a statistically significant decrease in the concentration of particulate matter in the majority of regions during the COVID-19 lockdown [26]. A noteworthy reduction in $NO_2$ and $PM_{2.5}$ levels have been observed in New York City [27]. A significant reduction in $NO_2$ levels of about 70% in India and Spain have also been reported [28]. This study yielded similar results, as we observed a decrease in $NO_2$ levels during the COVID-19 lockdown in 2020 compared to the year 2021.

This study has finds that there was a significant improvement in air quality in Lagos State as a result of the decrease in aerosols and $NO_2$ concentrations during the lockdown period. However, this is not the case for CO and $SO_2$ as the study finds an increase in the concentration of these air quality parameters. This is in line with findings of Okoduwa and Amaechi, [15] suggesting a loosely implemented COVID 19 lockdown.

## Conclusion

Research findings indicate that the COVID-19 lockdown policy had a positive impact on reducing the emission of air pollutant gases that contribute to the degradation of air quality in Lagos State. This was attributed to the decrease in anthropogenic activities during the lockdown period. Results shows that in the year 2020, a significant enhancement in air quality was observed across the majority of sampled regions. The study area exhibited a reduction in the concentration of air pollutant, such as aerosols and $NO_2$. The implementation of Covid-19 lockdown policies resulted in favorable outcomes with regards to air quality, thereby facilitating a healthier environment for the inhabitants of the research location. The enhancements observed in air quality during the period of lockdown serve as an indication of the substantial level of exertion that is necessary to attain air quality levels within the permissible limit.

## Recommendation

It is therefore recommended that policymakers invest in green technologies such as solar systems to minimize emissions, enforce strict emission standards for industries and vehicles to limit the release of air pollutants, and maintain public awareness that educates the population about the link between individual behaviors, industrial activities, and air quality, which will encourage citizens to reduce air pollution.

## Limitations of the study

While Sentinel-5P is a trustworthy instrument, ground-based measurements could provide further validation and a more complete picture of the differences in air quality. To make this a reality, the Nigerian government and relevant agencies should work towards providing ground-based monitoring instruments for air pollution monitoring. In addition, while the COVID-19 lockdown undoubtedly led to lower anthropogenic activity that improved air quality, other factors, such as meteorological variables, may also have an impact on air quality. Therefore, future research should incorporate meteorological parameters in monitoring variation in atmospheric pollution.

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