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Evaluation of Nigeria's Air Quality and COVID-19 Cases, Recovery, and Mortality Rates

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Abstract

COVID-19 pandemic in 2020 led to lockdown in Nigeria for months, halting many commercial activities, and had implications on air quality. This study investigated the relationships between COVID-19 cases and air quality, and air quality (AQ) and COVID-19 mortality and recovery in Nigerian cities during the pre-lockdown and lockdown periods. Remote sensing and GIS were employed to collect AQ data, while COVID-19 data were obtained from the Nigerian Centre for Disease Control database. Images were analyzed using Panoply and ArcGIS softwares. Datasets were analyzed on SPSS, Python, and R softwares. Findings showed that SO2, NO2, CO, and ultraviolet aerosol levels decreased during lockdown, while O3 levels were not significantly different. Significant ($p<0.05$) changes were recorded for three AQ parameters in one city (Abuja), one AQ parameter in three cities (Ogun, Kano, and Plateau), and two AQ parameters in the remaining five cities between the pre-lockdown and lockdown periods. Lagos recorded significant values ($p<0.05$) for all COVID-19 cases, deaths, and recoveries with t-test values of -3.72, -3.83 and -4.31 respectively, while Kano recorded significant values ($p<0.05$) for COVID-19 cases (t-test value of -3.41) only. The COVID-19 incidences were not significant ($p<0.05$) in other study locations. There were significant ($p<0.05$) negative correlation between average AQ parameters and COVID-19 cases, showing higher levels of the air pollutants were associated with fewer COVID-19 incidences in these cities. The study concludes that there is a relationship between AQ parameters and COVID-19 cases, deaths, and recoveries in the study locations.

Keywords

COVID-19
Lockdown
Air Quality
Mortality
Recovery

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1. Introduction

The outbreak of COVID-19 caused several deaths and affected various human socio-economic activities worldwide. Having first been detected in Wuhan, China, in 2019, it was declared a pandemic by the World Health Organization in 2020 [1,2] as confirmed cases reached a peak of 200,000 patients [3]. The first case of COVID-19 in Nigeria was reported on February 27, 2020, after the arrival of an Italian immigrant to Ogun State, Nigeria [4]. This forced the Nigerian Government to activate its first COVID-19 action to curtail the spread of the virus [5]. Eventually, the virus spread to different parts of Nigeria. Cumulatively, as of January 6, 2023, there were 266,450 confirmed cases of COVID-19, with 3,155 deaths in Nigeria [6]. A partial lockdown was declared for 14 days, after which a total lockdown was declared and enforced for at least four months, during which citizens were to stay at home, travels were restricted, and businesses and offices were closed.

The total lockdown in Nigeria affected many socio-economic activities, put restrictions on social gatherings, halted various industrial activities, and restricted vehicular movements. Though the lockdown posed its own set of challenges, it did improve the state of the physical environment, such as soil, water, and air. For instance, in a study conducted by Olusola *et al.* [2] to investigate the impact of COVID-19 on air quality, their result showed a "significant reduction in NO_2 levels during the lockdown period compared with its levels during the pre-lockdown period in 2019." According to the study, reduced NO_2 concentrations during lockdown were possibly due to fewer automobile movements, social distancing, and restricted business and human activities. In a similar vein, Fuwape *et al*. [7] reported the impact of lockdown on air pollution in three selected cities in Nigeria: Lagos, Kaduna, and Port Harcourt. Their result compared with historical mean values showed that NO_2 levels climbed somewhat in Lagos and Kaduna, by 0.3% and 12%, respectively. The levels of NO_2 and SO_2 fell by 1.1% and 215.5%, respectively, in the city of Port Harcourt. O_3 concentrations were seen to be high while the area was under lockdown. On the global scale, a study by Collivignarelli *et al*. [8] observed that the impact of partial and complete lockdowns imposed in Milan led to a reduction of air pollutants caused by automobile traffic. Confirmed studies have shown that restrictions on vehicular movement, industrial activities, and other anthropogenic activities have, in one way or another, reduced air pollution during COVID-19 [9-10]. An increasing body of research has linked exposure to poor air quality to many adverse health outcomes, including cancer, respiratory and cardiovascular illness, and early death [11-12].

Air pollutants have been observed to trigger the transmission of COVID-19. For example, particulate matter (PM) has been shown to induce inflammation in lung cells, thus increasing the susceptibility and severity of COVID-19 [13]. In a study conducted by Frontera *et al*. [14] to analyze the relationship between air pollutant concentrations (especially $PM_{2.5}$ and NO_2) and the COVID-19 transmission, infection, severity of infection, and number of deaths, some regions of the world had higher infection rates and mortality from SARS-CoV-2, and also those regions had higher concentrations of air pollutants, especially $PM_{2.5}$ and NO_2, and the study concluded that high ambient levels of ozone were to blame. Several studies have shown that air pollutants play critical roles in the initiation and spread of COVID-19 [15-19]. Gope et al. [20], who studied air quality parameters around the world during the global COVID-19 lockdown, reported better air quality, as measured by the indices. However, the study did not examine the incidence of COVID-19 as a function of air quality. Adam et al [21] also reported a rise in secondary air pollutants (such as ozone) and a decrease in primary air pollutants during the COVID-19 lockdown in many countries.

Air pollution has long been recognized as a significant environmental health risk. With the introduction of COVID-19, there is a growing interest in figuring out how air pollution might affect the spread and severity of the illness. While other studies have found no conclusive evidence of a link, some have hypothesized that exposure to air pollution may raise the likelihood of getting COVID-19 and exacerbate its results. In Nigeria, there has been a small amount of research done on the connection between air quality and COVID-19. This study was conducted to investigate the relationship between COVID-19 incidences (cases, mortality, and recovery) and air quality in selected Nigerian cities during the pre-lockdown and lockdown periods.

2. Materials and Methods

2.1 Study Areas

The areas covered by this study are highlighted on the map of Nigeria in Figure 1. The selected cities, which are dispersed around the nation, are Lagos, Abeokuta, Ibadan, Osogbo, Abuja, Jos, Kano, Onitsha, and Port Harcourt. These cities are also among the most polluted and most populous of Nigeria's major cities. They were selected based on reported, confirmed, and mortality rates, as well as on their population density and population density per person (Table 1).

Lagos State: Lagos State is situated along the Gulf of Guinea on Nigeria's southwest coast. Despite having the fewest swaths of land, Nigeria's most populous state is also the smallest. It is located between latitudes 6°23′ and 6°41′ and longitudes 2°42′ and 3°42′. Lagos State has a tropical environment with significant humidity and year-round temperatures between 24 and 33 degrees Celsius. The rainy season is between April and October, with July and August seeing the highest rainfall. The warmest temperatures in the dry season are in March, which lasts from November to March. Lagos' low-lying coastal location makes it vulnerable to flooding as well. With an estimated 21 million residents in the metro area, it is renowned for its high population density. The city is encircled by water on three sides and is located on the Atlantic coast. Nigeria's largest city, Lagos, is home to several different businesses, including manufacturing, banking, and the oil and gas extraction industry. The city is also a significant port, with several cargo ships entering and leaving its harbor. Due to the significant amounts of pollution from industrial and vehicular sources, the air quality in Lagos can be subpar. Due to its coastline, the city is also vulnerable to floods and other natural disasters. A wide variety of economic, cultural, and recreational activities are carried out by people in Lagos. The city is a well-liked tourist attraction and is home to many museums, galleries, and other cultural centers. Lagos is renowned for having a thriving nightlife, with many pubs, clubs, and eateries that may satisfy different preferences.

Ogun State: Ogun State shares a border with Lagos State in southwest Nigeria. The Republic of Benin borders it on the west, while Oyo and Osun states border it on the north. Ogun State is located in south-western Nigeria within latitudes 6°N and 8°N and longitudes 3°E and 5°E. Ogun State has a tropical environment with significant humidity and year-round temperatures between 24 and 33 degrees Celsius. The rainy season lasts from April to October, with July and August seeing the highest rainfall. The warmest temperatures in the dry season are in March, which lasts from November to March. Ogun State's average temperature ranges from 24 to 32 degrees Celsius, with the greatest and lowest readings occurring in March and December, respectively. Ogun state often experiences high relative humidity, ranging from 70 – 90 %. Air pollution causes in Abeokuta include: Traffic and population density in Abeokuta contribute to the city's high traffic volume and car emissions, which contribute to air pollution. Industrial facilities in Abeokuta include factories, refineries, and power plants, all of which have the potential to release air pollutants. Burning trash: Abeokuta residents frequently openly burn trash, including plastics that can emit dangerous pollutants into the atmosphere. Construction projects: The development of new structures and the building of infrastructure can also pollute the air in Abeokuta. Agriculture: Using fertilizers and pesticides in agriculture can potentially contaminate the air in Abeokuta.

Oyo State: Southwest of Nigeria, near the boundary of Lagos State, is where Oyo State is situated. Geographically, it is located at a longitude of 8.1574° N and a latitude of 3.6147° E. To the south, it is bounded by the states of Osun, Ogun, and Ondo, and to the north, by the states of Kwara and Kogi. Oyo State has a tropical environment with significant humidity and year-round temperatures between 24ºC and 33 ºC. The rainy season lasts from April to October, with July and August seeing the highest rainfall. The hottest temperatures come in March during the dry season, which runs from November to March. Oyo State's average temperature ranges from 24 to 32 degrees Celsius, with the maximum and minimum values happening in March and December, respectively. Oyo State experiences a high relative humidity on a year-round basis, varying from 70% to 90%. Oyo State is home to a number of air pollution sources, including construction activity, industrial emissions, burning of garbage, and automobile emissions. Air pollution in the state is also caused by agricultural practices, including the use of pesticides and fertilizers. Additionally, using fossil fuels for heating and cooking can aggravate Oyo State's air pollution problems.

Osun state: Southwest Nigeria, contains the state of Osun State. It can be found at latitude 7°46'E and longitude 4°32'N. Osun State experiences a tropical climate with two distinct seasons: a wet one from April to October and a dry one from November to March. The state has average temperatures between a low of about 21 °C (70 °F) and a high of about 31 °C (88 °F). In Osun State, pollution comes from a variety of places, including waste management techniques, agricultural runoff, and industrial pollutants. Particulates, heavy metals, and hazardous compounds can all be released into the air and water during industrial processes like manufacturing and mining. Pesticides, fertilizers, and other chemicals may be present in agricultural runoff, which can contaminate rivers and streams. Inadequate. Pollution of the air and water can also be brought on by ineffective waste management techniques, such as open dumping and burning of waste.

Abuja: Abuja, the federal capital of Nigeria, is located at longitude 9.0820° N and latitude 7.5478° E. It has a tropical savanna climate, with dry seasons and hot, muggy summers. Abuja, which lies in the center of Nigeria, is a plateau-style city that is 900 meters (3,000 feet) above sea level. Mountains, such as Zuma Rock and the Mambilla Plateau, encircle the city. The Gurara River and the Kainji Dam are only two of the numerous rivers and streams that pass through the city. The climate in Abuja is arid, and the city's landscape is mostly flat with a few rolling hills and valleys. Throughout the year, Abuja's average temperature fluctuates from roughly 20°C to 30°C (68°F to 86°F). Typically, March through May are the warmest months, with highs of 40 °C (104 °F). November through February are the coldest months, with lows as low as 15 °C (59 °F). Abuja experiences seasonal variations in relative humidity, but it is typically high and ranges from 60 to 90%. The wet season, which runs from April to October, sees the highest humidity levels, while the dry season, which runs from

November to March, sees the lowest.

Plateau State: Plateau State is situated in central Nigeria at 9.72°E longitude and 8.87°N latitude. Plateau State has a tropical climate with hot, muggy weather all year long. The wet season lasts from May to October, and the dry season is from November to April. Industrial pollution, automobile emissions, and problems with waste management are some of the pollution sources in Plateau State. Rolling hills and plateaus with elevations between 600 and 1,200 meters above sea level make up the geography of Plateau State. The average high temperature of Plateau State is roughly 30 °C all year round, making it typically warm. In general, the relative humidity is high, averaging around 70 %.

Kano State: Kano is located in the core north of Nigeria. Geographically, it is located at longitude 11.9955° N and latitude 8.5246° E are its longitude and latitude coordinates. The majority of the year is hot and dry in Kano State's generally arid and semi-arid environment. In the hottest months, the temperature can rise as high as 45°C (113°F), which is about 27°C (80°F) on average annually. Industrial pollutants, automobile exhaust, and agricultural waste are a few of the sources of pollution in Kano State. Cement, steel, and textiles are just a few of the significant industries with a presence in the state that contribute to air pollution. With a few low-lying places in the north and east, Kano State's geography is primarily flat. Between 30% and 60%, the relative humidity in the state is often low.

Anambra State: Onitsha (Anambra State) is located at longitude 6.15° N and latitude 6.78° E Onitsha experiences a tropical climate with high humidity and temperatures. In Onitsha, industrial emissions, vehicle exhaust, and solid waste management are the main sources of pollution. Onitsha has a flat topography with a few low-lying marshes. Onitsha experiences high levels of relative humidity due to the city's closeness to the Niger River, with an average temperature of about 28 °C.

Rivers State: Port Harcourt is located in latitude of 4.8767 and a longitude of 7.0089. Port Harcourt has a hot, humid, tropical climate with consistent, significant rainfall throughout the year. In Port Harcourt, pollution comes from a variety of places, including transportation, trash disposal, and industrial pollutants. Port Harcourt's geography is flat, with a few low-lying sections that are prone to floods. Between an average low of 25°C (77°F) and an average high of 32°C (90°F), the temperature in Port Harcourt fluctuates. On average, the relative humidity is high, hovering about 80%.

Table 1: Population information for study areas [22]

State/City	Population (2021)	Area(Km^2)	Population density	Population density (person / Km^2)
Lagos	21,00, 0000	4,235	4,990	2.3
Abeokuta	6,112,505	8.090	754	0.12
Ibadan	8.541,249	9.162	934	0.22
Osogbo	3.416,959	635	5,353	0.19
Abuja	2,972,534	1,470.54	2,013	2.01
Jos	4,681,052	10,000	467.7	0.2
Kano	9,391,561	13,823	679	10.07
Onitsha	4,055,048	17,532	231.35	0.07
Port Harcourt	5,198,716	18,772	278	0.05

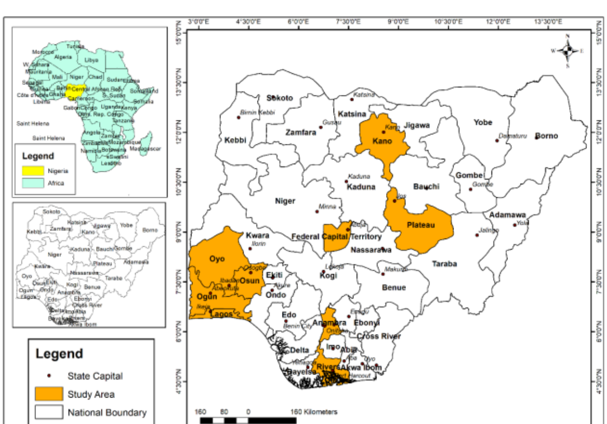

Figure 1. Map showing Nigeria and study areas.

2.2 Data and Sources

The Sentinel-5 precursor satellite, managed and administered by the European Commission under the "Copernicus" program, was used to measure the amounts of NO_2, O_3, SO_2, and CO in the troposphere (from the surface up to 10 km). The satellite has a sun-synchronous, 824-kilometer orbit with a 16-day orbital cycle. A TROPOspheric Monitoring Instrument (TROPOMI) on board the satellite offers (near-) worldwide coverage of NO_2 as well as other pollutants as O_3, SO_2, CO, CH_4, and aerosols [23].

With the exception of void data due to cloud coverage or time of capture, data downloaded was mostly accessed between the second and third weeks of the month. If it does not fall within the desired period, we have to make use of the first or last week of the month, while we strictly dwelled on the working days of the week and not weekends. This study necessitated the extraction of NO_2, O_3, SO_2, and CO data from Sentinel 5P Near Real Time Level 2 satellite images, achieved in NetCDF format and captured for specific exposure durations in seven separate months (December 2019 to July 2020). From the Sentinel 5P satellite images, Merra-2, and OMI, the extracted air quality parameters were used to compare the trend in their spread in the atmosphere before and during the COVID-19 lockdown in the Nigerian selected states (Lagos, Ogun, Oyo, Osun, Abuja, Plateau, Kano, Anambra, and Rivers).

The NetCDF (Network Common Data Format) files were converted into raster images using the Panoply 4.11.2 program, and then scaled to match the specific NetCDF concentration in the images. The national and state boundaries were exported into Panoply and superimposed on each map of an air quality metric after being further extracted and processed in shapefile format using ArcGIS 10.5 software.

Shapefiles representing national and state boundaries were taken from online collected data. The maps have a 1:60,000 scale. Textbooks, research publications, and journal papers, among other sources, were used to gather more secondary data. The different data types and their sources are displayed in Table 2 below.

Table 2. Data Sources for this Study

No.	Name Type	Data Source	Date Acquired	File Name	Filename Extension
1	NO_2, CO, and O_3 (Sentinel 5p)	https://s5phub.copernicus.eu/dhus/#/home & https://disc.gsfc.nasa.gov/information/glossary	Dec. 2019 – July 2020	NetCDF	.nc
2	SO_2 (Merra-2) and UV Aerosol (OMI) Index	https://giovanni.gsfc.nasa.gov/giovanni/#service	Dec. 2019 – July 2020	NetCDF	.nc
3	National and State Boundary	http://diva-gis.org/data	March 2020	Shape file	.shp

Panoply [24] is a NetCDF (Network Common Data Format) visualization software and Java application that enables the plotting of raster images of geo-gridded (georeferenced) data from datasets in NetCDF format. Depending on the data available, panoply can be used to create displays in a variety of ways, such as plotting longitude-latitude data as global maps or zonal averages, using any of over 40 global map projections, overlaying continent outlines or masks on longitude-latitude plots, or just plotting a particular region, and displaying specific latitude-longitude or latitude-vertical arrays from larger multidimensional variables as slices. Panoply displays plots that compare data values between arrays, which may be different time intervals for a single variable within one dataset, or the same variable from two different datasets.

Additionally, from December 2019 to July 2020, Sentinel 5P Near Real Time Level 2, Merra-2 Model, and OMI air quality images for the study area were plotted and processed in Panoply. Each NetCDF file's nitrogen dioxide tropospheric vertical column was visualized using a georeferenced longitude and latitude color contour graphic. The UV Aerosol Index was scaled to 10-6 for easy count capture, scaled in kg/mol2 using the scalar unit of micromole per meter square, with a scale range of minimum 0 and maximum 100, and the plotted images were further enhanced and exported to Portable Network Graphics file format. In addition to the above, daily COVID-19 cases, mortality, and recoveries for the selected study areas were collected from the Nigerian Centre for Disease Control (NCDC) database for the study.

2.3 Data Analysis

Univariate and multivariate analyses were applied to the datasets gathered for this investigation. In univariate analysis, percentages were included, whereas in multivariate analysis, paired t-tests and Kendall Tau correlations were included. Kendall Tau correlation statistics were used to test the relationship between atmospheric pollutants or aerosols and each of the cases, deaths, and recoveries from the COVID-19 virus, with the aid of regression statistics by using Statistical Package for Social Sciences (SPSS) 25. A paired t-test analysis was conducted to compare the means between the pre-lockdown and lockdown periods in the study locations for the atmospheric pollutants, aerosols, and COVID-19 incidences. This was done using Python 3 software. A time series plot showing the distribution of the daily averages of air quality parameters (NO_2, SO_2, CO, O_3, and UV Aerosol) before and during the lockdown was also carried out using the R statistical package.

3. Results and Discussion

Figure 2 shows a time series plot of the distribution of daily averages of air quality parameters (NO_2, SO_2, CO, O_3, and UV Aerosol) in the study areas before and after the lockdown policy was implemented. Relative changes (%) between the pre-lockdown and lockdown concentrations of air quality parameters in the 9 states were also derived and presented in Table 3. The percentage change in the mean concentration of air pollutants before and after the lockdown policy was enforced in Lagos, the most important commercial nerve of the country, showed that the SO_2, NO_2, CO, and UV Aerosol concentrations in the air were significantly reduced, except for O_3 (5%). A significant percentage decrease was observed for all the parameters. However, the concentration of O_3 was observed to have increased in Oyo (-8%), Anambra (-14%), and Ogun (-15%) States. Also, CO concentrations increased in Kano (-22%) and the Plateau (-0.2%). The decrease in transportation and human activity during the lockdown may have had an impact on O_3 and CO concentrations in Oyo, Anambra, Ogun, Kano, and the Plateau. Carbon monoxide and ozone-forming pollution emissions may have dropped with fewer vehicles on the road and less industrial activity, resulting in lower concentrations of these pollutants in the air. Additionally, the observed increase in ozone (O_3) and carbon monoxide (CO) concentrations during the lockdown may have been caused by elements like altered weather patterns or higher emissions from other sources. An increase in O_3 due to weather conditions has been reported [25]. Lockdown measures put in place by the Nigerian government may have led to the production of lower oxides of nitrogen, and may lead to production of higher VOC-NOx emissions, thus increasing O_3 production. Furthermore, a reduction of particulate matter could lead to an increase in ozone concentrations [26]. The reduction of NO_2 can be attributed to the lockdown policy enforced by the government of Nigeria. This is because vehicular movement and road traffic, which are the major sources of NO_2, were brought to a halt, contributing to low NO_2 emissions during the lockdown period. NO_2 is a priority air pollutant, and its primary sources are vehicular and industrial emissions. The percentages of change in the concentration of NO_2 are in the order of Osun > Plateau > Oyo > Ogun > Anambra > Abuja > Lagos > Rivers > Kano. While some states were under full lockdown, some essential economic activities were going on in the commercial nerve centers of the country, such as Lagos, Rivers, and Kano.

It is noteworthy that, though there was a reduction of other atmospheric pollutants during the course of this study, there was also an increase in the production of O_3 in some of the cities. O_3 is a secondary pollutant. As a secondary pollutant, increased ozone levels can harm people's health in a number of ways. Shortness of breath, chest pain, and coughing are just a few of the symptoms that can result from ozone's irritation and damage to the respiratory system [27-28]. Asthma and other pre-existing lung diseases might potentially be made worse by it. Ozone exposure over an extended period of time has been associated with reduced lung function, a higher chance of developing chronic respiratory conditions, and even early mortality. Ozone can irritate the eyes, give people headaches, and make existing cardiac issues worse. Children, elderly adults, and those with pre-existing cardiovascular or pulmonary conditions are more vulnerable to the negative effects of ozone on their health [29-30].

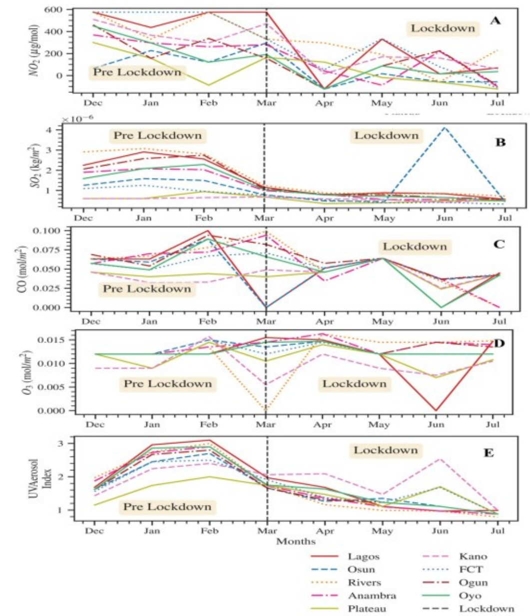

Figure 2. Time series of monthly averages of NO_2, SO_2, CO, O_3, and UV Aerosol concentration between Dec 2019 and July 2020

Table 3. Percentage change in the concentration of air quality parameters between the pre-lockdown and lockdown phase.

Air Pollutants	NO_2	SO_2	CO	O_3	UV Aerosol
Lagos	66	69	61	5	56
Osun	88	13	45	1	45
Oyo	85	63	22	-8	48
Rivers	60	69	30	4	36
Anambra	77	65	31	-14	52
Abuja	76	56	8	4	35
Kano	55	10	-22	21	10
Plateau	86	33	-0.2	8	15
Ogun	84	68	33	-15	46

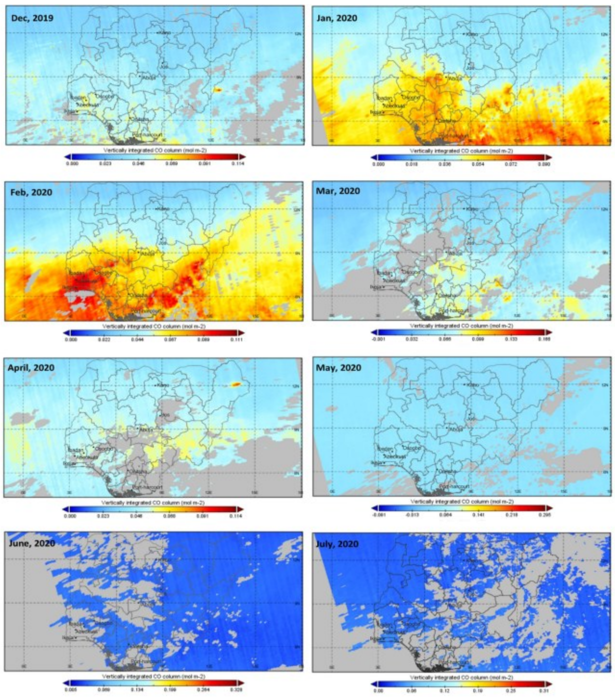

Figure 3. Vertical integrated CO column 'before' (Dec 2019-March 2020) and 'during' (April 2020-July 2021) lockdown phases.

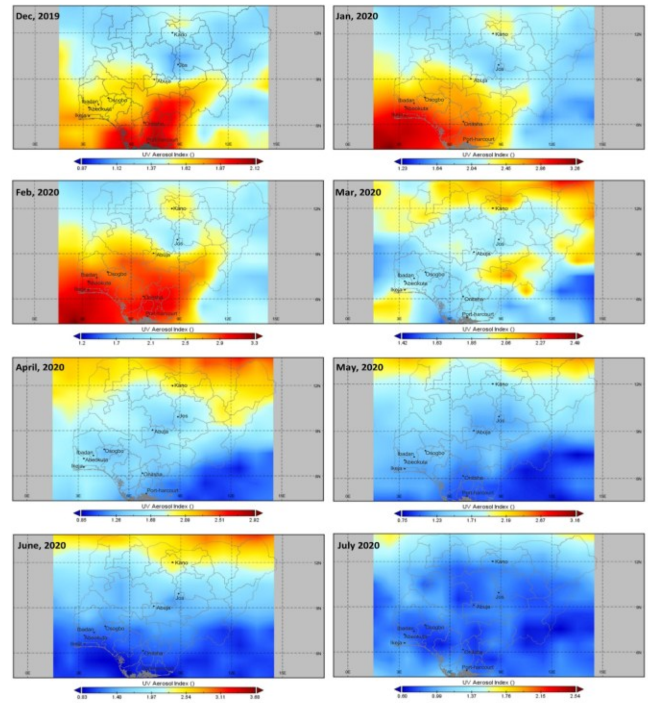

Figure 4. UV Aerosol 'before' (Dec.2019-March 2020) and 'during' (April 2020-July 2021) lockdown phases

Figures 3, 4, 5, 6, and 7 show the vertical distributions of air quality parameters before and during CoVID-19 lockdown phases in the cities of study. Figure 3 shows the changes in vertical column CO concentrations (mol/m^2) in Ikeja, Abeokuta, Ibadan, Osogbo, Abuja, Jos, Kano, Onitsha, and Port Harcourt before and during the lockdown period imposed due to the COVID-19 pandemic. Before the lockdown period, the concentrations of CO showed a gradual increase in most cities. For example, in Ikeja, Osogbo, and Ibadan, there was a steady increase in CO concentrations from December 2019 to February 2020. However, there was a slight decrease in March 2020. The concentrations of CO in Port Harcourt and Onitsha showed a similar pattern, with a gradual increase until February 2020, followed by a decrease in March 2020. During the lockdown period, there was a significant decrease in CO concentrations in most cities. For example, in April 2020, there was a decrease in CO concentrations in all cities compared to the previous month. This decrease was particularly significant in Onitsha and Abeokuta, where the CO concentrations dropped from 0.141 to 0.0114 and from 0.134 to 0.026, respectively. In May 2020, there was a significant decrease in CO concentrations in Ikeja, Osogbo, Ibadan, and Port Harcourt. In June and July 2020, there was a gradual increase in CO concentrations, but they remained lower than the concentrations before the lockdown period.

Percentage-wise, in December 2019, there was no change in the vertically integrated CO column concentrations compared to the previous month. In January 2020, there was a significant decrease of 21.05% in CO concentrations compared to December 2019. However, in February 2020, there was a sharp increase of 22.22% in CO concentrations compared to January 2020. March 2020 saw the largest increase in CO concentrations at 48.15%, which could be attributed to the initial spread of COVID-19 in Nigeria and the consequent increase in industrial activity as the country responded to the pandemic. In April 2020, there was no change in CO concentrations compared to March 2020. The lockdown period started in April 2020, and May 2020 saw a significant decrease of 156.14% in CO concentrations compared to April 2020. This could be attributed to the significant decrease in industrial and transportation activities due to the lockdown.

However, the CO concentrations showed an increase of 87.5% in June 2020 compared to May 2020, which could be attributed to the partial easing of lockdown restrictions and a consequent increase in industrial and transportation activities. July 2020 saw a further increase of 100% compared to June 2020, which could be attributed to the gradual opening of the economy and resumption of normal activities.

The UV Aerosol (OMI index) values for the study's months and years are shown in Figure 4. Higher values in the UV Aerosol (OMI Index) indicate higher aerosol concentrations, which are a measure of aerosol concentration in the atmosphere. Figure 4 demonstrates how the UV Aerosol levels changed during the course of the specified months. The UV Aerosol levels in December 2019 ranged from 0.87 to 2.12. Values progressively climbed from December through March, with March 2020 recording the highest value (1.42 to 2.40). The levels of UV Aerosol did, however, significantly decline between April and July 2020, with values ranging from 0.60 to 2.54. The imposition of lockdown measures in Nigeria is responsible for this decline since it reduced human activity, industry, and transportation-related emissions. Lower results for the UV Aerosol were obtained as a result of the reduction in emissions, which in turn led to a drop in aerosol concentrations in the atmosphere.

According to Fig. 4, there is a substantial drop in UV Aerosol throughout the lockdown period (April to July 2020) in comparison to the months before lockdown (December 2019 to March 2020). Particularly, as compared to the months before the lockdown, the aerosol index values revealed a drop of between 2 to 20%. This drop is probably because there were fewer anthropogenic emissions and human activity during the lockdown, which improved the air quality. It is important to note that additional factors, such as weather patterns and natural occurrences, may have impacted the observed fluctuations in the aerosol index readings from the study.

The levels of SO_2 (kg/m^2) significantly changed before and throughout the lockdown, as seen in Fig. 5. The levels of SO_2 were generally steady before the lockdown, with a few slight changes. The SO_2 concentration was 0.0000000276 kg/m^2 in December 2019, and it rose to 0.000000441 kg/m^2 in February 2020. This was a roughly 1500% rise in proportion. The levels of SO_2 did, however, significantly decline throughout the lockdown. The SO_2 level was 71% lower in April 2020 than it was in February 2020 at 0.000000127 kg/m2. In May 2020, the SO_2 level declined further to 0.00000689 kg/m2, which represented a decrease of 98% from the February 2020 level. Through June and July 2020, when there were almost no SO_2 levels recorded, the trend of declining SO_2 levels persisted. Overall, the evidence points to a large drop in SO_2 levels during the lockdown, possibly as a result of less industrial and vehicular movements.

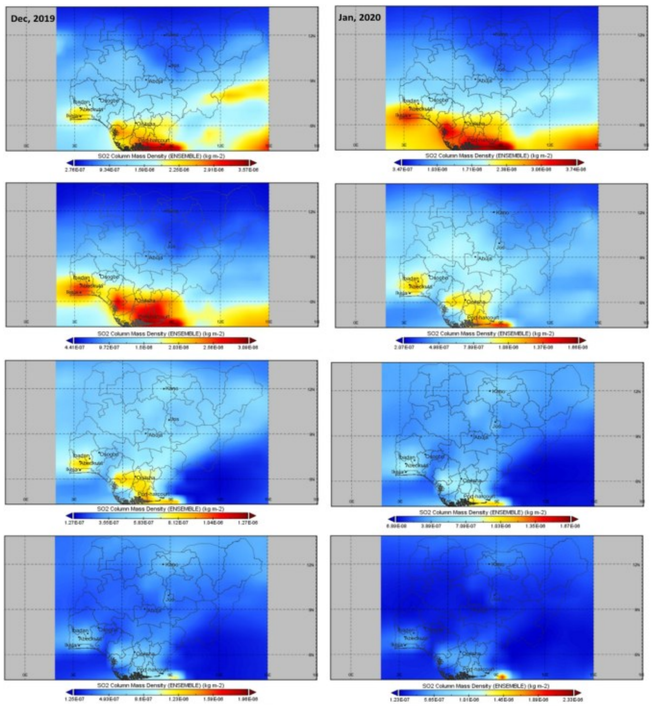

Figure 5. Average tropospheric SO_2 mass density (kg/m^2) before' (Dec.2019-March 2020) and 'during' (April 2020-July 2021) lockdown phases

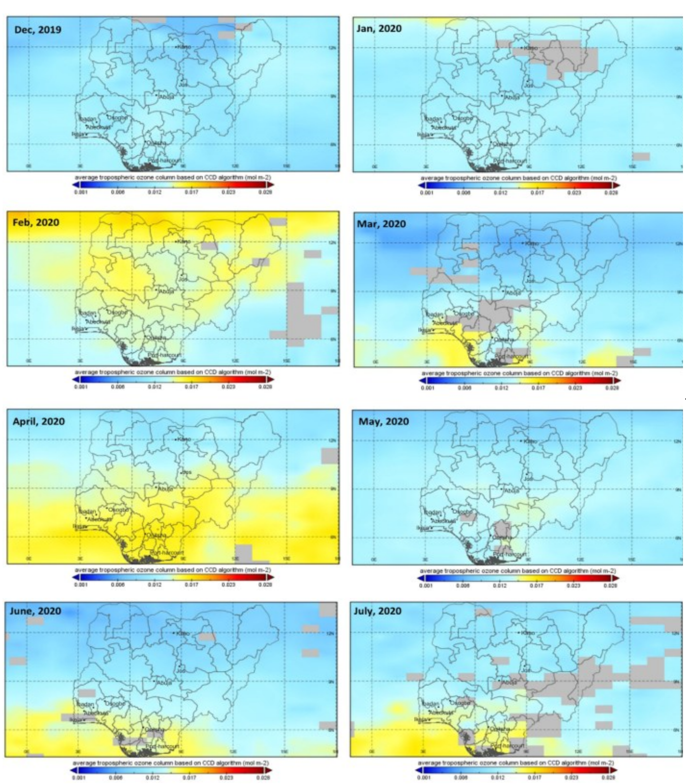

Figure 6. Average tropospheric Ozone (O_3) column 'before' (Dec.2019-March 2020) and 'during' (April 2020-July 2021) lockdown phases

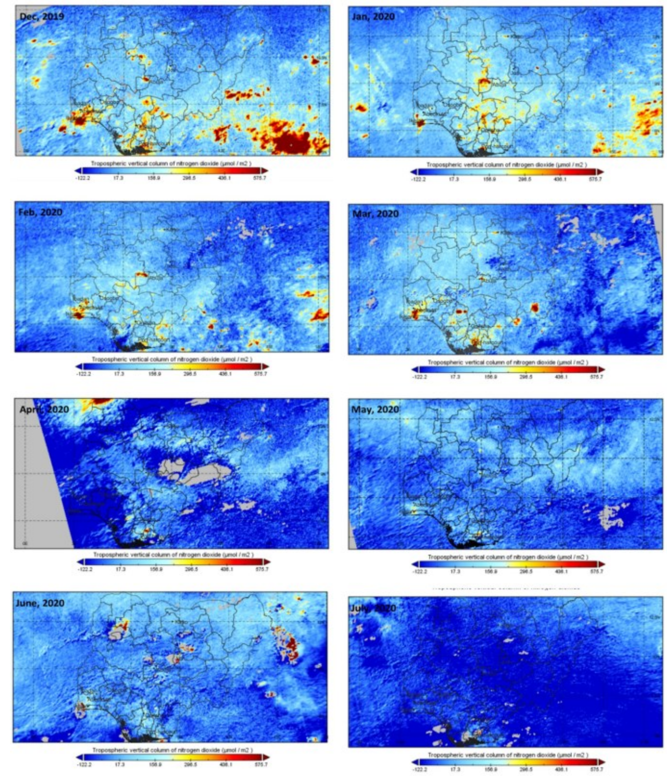

Figure 7. Tropospheric vertical column NO_2 'before' (Dec.2019-March 2020) and 'during' (April 2020-July 2021) lockdown phases

Table 4: T-test values during pre-lockdown and lockdown periods

Parameters/States-->	Lagos	Ogun	Osun	Oyo	Rivers	Anambra	Abuja	Kano	Plateau
NO_2	3.67*	2.17	5.66*	2.46	2.38	3.47	6.66*	3.65*	2.34
SO_2	4.73*	4.08*	-0.11	4.43*	4.3*	4.48*	6.54*	2.25	4.74*
CO	0.55	1.24	0.22	1.66	1.92	2.06	1.16	-0.48	-0.19
O_3	0.75	-1.14	0.37	-0.05	-1.81	-1.11	0.11	0.02	0.23
UV Aerosol	2.58	2.6	3.69*	3.36*	4.61*	3.72*	3.64*	0.65	1.43
Covid 19 Cases	-3.72*	-2.75	-1.44	-2.12	-2.19	-2.06	-2.39	-3.41*	-1.66
Covid 19 Deaths	-3.83*	-2.85	-2.12	-2.35	-2.88	-1.69	-2.77	-1.37	-2.15
Covid 19 Recoveries	-4.31*	-2.27	-1.32	-2.03	-1.82	-1.51	-2.41	-2.19	-1.84

* = Significant at $p<0.05$

Results from the paired t-test analysis are presented in Table 4. Of the atmospheric pollutants and aerosols compared, SO_2 values were significant ($p < 0.05$) in Lagos, Ogun, Oyo, Rivers, Anambra, Abuja, and Plateau. Similarly, UV Aerosol values were significant ($p < 0.05$) in Osun, Oyo, Rivers, Anambra, and Abuja. NO_2 values were also significant ($p < 0.05$) in Lagos, Osun, Abuja, and Kano. CO and O_3 values were not significant in all the study locations. Abuja recorded significant values ($p < 0.05$) for three of the five atmospheric pollutants or aerosols compared between the pre-lockdown and lockdown periods, the highest among all the study locations. Five states recorded significant values for two atmospheric pollutant types (aerosols), while the remaining three states recorded significant values for only one atmospheric pollutant.

COVID-19 cases, deaths, and recoveries in the study locations were also compared between the pre-lockdown and lockdown periods, as shown in Table 4. Lagos recorded significant values for all COVID-19 incidences (cases, deaths, and recoveries), while Kano recorded significant values for COVID-19 cases only. The COVID-19 incidences were not significant in all the other study locations. A similar study by Chaudhary *et al.* [31] reported lower pollutant concentrations (NO_x, SO_2, O_3, and particulate matter) during lockdown compared to pre-lockdown periods, except for O_3 in 13 locations in India. Adam *et al.* [21] also reported lower concentrations of NO_2, SO_2, and CO, while O_3 either increased or was not different before lockdown and during lockdown in the major cities studied. Also, air quality parameters measured in two Asian economies (China and India) during the pre-lockdown and lockdown periods showed a significant reduction in air pollution [32]. NO_2 concentrations were also significantly lower, as reported in three cities in Italy between the pre-lockdown and lockdown periods, while O_3 concentrations were not significantly different [33]. Other studies [34-37] support the findings of the atmospheric pollutants from this study. On the other hand, the COVID-19 incidence comparison between pre-lockdown and lockdown periods was supported by Meo *et al.* [38]. They showed that there was a significant difference in the number of COVID-19 cases and deaths before lockdown and during lockdown in Nigeria and the other 26 locations studied.

Table 5 presents the results of the correlation analysis between atmospheric aerosols and air pollutants (NO_2, SO_2, CO, and O_3) and cases of the COVID-19 virus across the study areas. The correlations (r) and p-values (p) are reported for the average (avg), maximum (max), and minimum (min) levels of each pollutant. The results show a negative correlation between NO_2, CO, and O_3 and the number of COVID-19 cases in some of the study areas. Specifically, a negative correlation was found between the average levels of NO_2 and CO and the number of COVID-19 cases in Lagos, Osun, Oyo, Abuja, Anambra, and Rivers. A negative correlation was also found between the maximum levels of NO_2 and the number of COVID-19 cases in Lagos, Ogun, Osun, Oyo, Abuja, Plateau, Anambra, and Rivers. In addition, a negative correlation was found between the average levels of O_3 and the number of COVID-19 cases in Lagos, Ogun, Oyo, and Rivers.

On the other hand, Table 5 also showed a positive correlation between the level of SO_2 and O_3 and the number of COVID-19 cases in some states. For example, a positive correlation was found between the average levels of SO_2 and the number of COVID-19 cases in Lagos, Ogun, Osun, Oyo, Abuja, Anambra, and Rivers. A positive correlation was also found between the maximum levels of SO_2 and the number of COVID-19 cases in Lagos, Ogun, Osun, Oyo, Abuja, Plateau, Anambra, and Rivers. In addition, a positive correlation was found between the minimum levels of SO_2 and the number of COVID-19 cases in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. It is important to note that the correlations reported in Table 5 should be interpreted with caution, as the p-values suggest that some of the correlations may not be statistically significant. In particular, the correlations with p-values greater than 0.05 should be interpreted with caution, as they may not be statistically significant. The results of Table 5 suggest that there may be a relationship between air pollutant levels and the number of COVID-19 cases in some states in Nigeria.

The results of Table 5 indicate a relationship between certain atmospheric aerosols and air pollutants and the number of cases of COVID-19 in different states in Nigeria. For example, the negative correlations between NO_2 avg, NO_2 max, and NO_2 min and cases of COVID-19 in Lagos, Abuja, the Plateau, Anambra, and the Rivers show that higher levels of these air pollutants were associated with fewer cases of COVID-19 in these states. This study is similar to one conducted by Zhang et al. [39], who found that air pollutants were associated with increased COVID-19 cases in Chinese cities.

Table 5: Cases of COVID-19 and Air Pollutants

Air Pollutants	coefficients	Lagos	Ogun	Osun	Oyo	Abuja	Plateau	Anambra	Rivers	Kano
NO_2 _avg	r	-0.550	-0.293	-0.550	-0.586	-0.700*	-0.617	-0.688*	-0.878**	-0.411
	p	0.091	0.362	0.091	0.068	0.032	0.060	0.039	0.006	0.210
NO_2 _max	r	-0.474	-0.732*	-0.577	-0.808*	-0.808*	-0.569	-0.572	-0.577	-0.756*
	p	0.154	0.029	0.091	0.018	0.018	0.114	0.098	0.091	0.034
NO_2 _min	r	-0.527	-0.683*	-0.550	-0.550	-0.738*	-0.103	-0.476	-0.705*	-0.617
	p	0.113	0.033	0.091	0.091	0.026	0.754	0.153	0.037	0.060
SO_2_avg	r	-0.293	-0.238	-0.293	-0.293	-0.195	-0.103	-0.159	-0.293	-0.103
	p	0.362	0.453	0.362	0.362	0.543	0.754	0.634	0.362	0.754
SO_2_max	r	0.390	0.524	0.390	0.390	0.488	0.514	0.476	0.390	0.514
	p	0.224	0.099	0.224	0.224	0.129	0.117	0.153	0.224	0.117
SO_2_min	r	0.488	0.333	0.293	0.293	0.390	0.411	0.476	0.488	0.617
	p	0.129	0.293	0.362	0.362	0.224	0.210	0.153	0.129	0.060
CO_avg	r	-0.450	-0.524	-0.390	-0.586	-0.390	0.105	-0.688*	-0.586	0.206
	p	0.167	0.099	0.224	0.068	0.224	0.751	0.039	0.068	0.530
CO_max	r	-0.350	-0.238	-0.650*	-0.195	-0.098	0.309	-0.476	-0.586	0.474
	p	0.282	0.453	0.046	0.543	0.761	0.347	0.153	0.068	0.154
CO_min	r	-0.550	-0.429	-0.350	-0.450	-0.683*	-0.264	-0.582	-0.683*	0.316

	p	0.091	0.176	0.282	0.167	0.033	0.428	0.081	0.033	0.342
O_3_avg	r	-0.211	0.265	-0.346	0.067	-0.405	-0.206	0.167	0.350	-0.053
	p	0.526	0.427	0.310	0.848	0.249	0.530	0.627	0.282	0.874
O_3_max	r	0.527	0.476	0.115	-0.359	-0.115	-0.054	0.343	0.474	-0.056
	p	0.113	0.153	0.735	0.303	0.735	0.873	0.321	0.154	0.870
O_3_min	r	0.211	0.000	0.150	0.000	-0.231	-0.685*	0.111	0.000	0.000
	p	0.526	10.000	0.645	10.000	0.499	0.039	0.746	10.000	1.000
UVAeroso	r	-0.976**	-0.905**	-0.976**	-0.878**	-0.781*	-0.738*	-0.900**	-0.878**	-0.309
l_avg	p	0.002	0.004	0.002	0.006	0.015	0.026	0.007	0.006	0.347
UVAeroso	r	-0.878**	-0.905**	-0.878**	-0.781*	-0.781*	-0.896**	-0.688*	-0.683*	-0.617
l_max	p	0.006	0.004	0.006	0.015	0.015	0.007	0.039	0.033	0.060
Aerosolizi	r	-0.878**	-0.810*	-0.683*	-0.750*	-0.781*	-0.791*	-0.794*	-0.683*	-0.411
ng	p	0.006	0.011	0.033	0.021	0.015	0.017	0.017	0.033	0.210

* = Significant at $p<0.05$
** = Significant at $p<0.01$
avg, max, and min = average, maximum, and minimum values respectively.

As shown in Table 6, there is a negative correlation between the level of some air pollutants (NO_2, CO, and O_3) and the number of deaths from COVID-19 in some states. Specifically, a negative correlation was found between the average levels of NO_2 and CO and the number of deaths from COVID-19 in Lagos, Osun, Oyo, Abuja, Anambra, and the Rivers. A negative correlation was also found between the maximum levels of NO_2 and the number of deaths from COVID-19 in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. In addition, a negative correlation was found between the minimum levels of NO_2 and the number of deaths from COVID-19 in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. On the other hand, the results also show a positive correlation between the level of some air pollutants (SO_2 and O_3) and the number of deaths from COVID-19 in some states. Specifically, a positive correlation was found between the minimum levels of SO_2 and the number of deaths from COVID-19 in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. In addition, a positive correlation was found between the average levels of O_3 and the number of deaths from COVID-19 in Lagos, Ogun, Osun, Oyo, and Rivers. The results of Table 6 suggest that there may be a relationship between certain atmospheric aerosols and COVID-19 deaths in different states in Nigeria. For example, the negative correlations between NO_2 avg, NO_2 max, and NO_2 min and deaths from COVID-19 in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers are an indication that higher levels of these air pollutants may be associated with fewer deaths from COVID-19 in these states. This finding is consistent with that of Wu *et al*. [40], who examined the relationship between air pollution and COVID-19 mortality in the United States and found that higher levels of $PM_{2.5}$ were associated with increased COVID-19 mortality.

It is important to note that the correlations reported in Table 6 should be interpreted with caution, as the p-values suggest that some of the correlations may not be statistically significant. In particular, the correlations with p-values greater than 0.05 should be interpreted with caution, as they may not be statistically significant. Nevertheless, Table 6 showed that there may be a relationship between air pollutant levels and the number of deaths from COVID-19 in some states in Nigeria.

Table 6: Deaths from COVID-19 and Air Pollutants

Pollutants	coefficients	Lagos	Ogun	Osun	Oyo	Abuja	Plateau	Anambra	Rivers	Kano
NO_2 _avg	r	-0.632	-0.105	-0.759*	-0.688*	-0.300	-0.620	-0.507	-0.823*	-0.411
	p	0.057	0.751	0.025	0.039	0.357	0.065	0.132	0.012	0.210
NO_2 _max	r	-0.611	-0.730*	-0.751*	-0.751*	-0.693*	-0.467	-0.365	-0.730*	-0.756*
	p	0.072	0.037	0.035	0.035	0.042	0.207	0.296	0.037	0.034
NO_2 _min	r	-0.556	-0.527	-0.813*	-0.813*	-0.316	0.056	-0.282	-0.743*	-0.411
	p	0.102	0.113	0.016	0.016	0.342	0.867	0.402	0.032	0.210
SO_2_avg	r	-0.206	-0.309	-0.265	-0.265	-0.195	0.056	-0.056	-0.206	-0.309
	p	0.530	0.347	0.427	0.427	0.543	0.867	0.867	0.530	0.347
SO_2_max	r	0.411	0.309	0.370	0.370	0.488	0.620	0.507	0.411	0.309
	p	0.210	0.347	0.266	0.266	0.129	0.065	0.132	0.210	0.347
SO_2_min	r	0.514	0.617	0.265	0.265	0.781*	0.507	0.620	0.514	0.617
	p	0.117	0.060	0.427	0.427	0.015	0.132	0.065	0.117	0.060
CO_avg	r	-0.369	-0.617	-0.159	-0.476	-0.195	-0.058	-0.507	-0.720*	0.206
	p	0.267	0.060	0.634	0.153	0.543	0.866	0.132	0.028	0.530
CO_max	r	-0.264	-0.309	-0.434	-0.159	0.098	0.169	-0.394	-0.617	0.264
	p	0.428	0.347	0.199	0.634	0.761	0.615	0.241	0.060	0.428
CO_min	r	-0.474	-0.514	-0.108	-0.217	-0.488	-0.289	-0.507	-0.823*	0.316

	p	0.154	0.117	0.748	0.521	0.129	0.398	0.132	0.012	0.342
O_3_avg	r	-0.333	0.171	-0.250	0.073	-0.539	-0.282	0.059	0.474	-0.053
	p	0.327	0.620	0.481	0.842	0.125	0.402	0.864	0.154	0.874
O_3_max	r	0.444	0.514	0.250	-0.194	-0.231	-0.118	0.243	0.444	-0.056
	p	0.191	0.137	0.481	0.592	0.499	0.732	0.486	0.191	0.870
O_3_min	r	0.111	-0.158	0.108	0.056	-0.346	-0.808*	0.000	0.054	-0.122
	p	0.744	0.634	0.748	0.871	0.310	0.018	10.000	0.873	0.727
UVAeroso	r	-0.926**	-0.720*	-0.794*	-0.688*	-0.586	-0.635	-0.732*	-0.823*	-0.103
l_avg	p	0.005	0.028	0.017	0.039	0.068	0.063	0.029	0.012	0.754
UVAeroso	r	-0.823*	-0.720*	-0.688*	-0.582	-0.586	-0.808*	-0.507	-0.617	-.411
l_max	p	0.012	0.028	0.039	0.081	0.068	0.018	0.132	0.060	.210
UVAeroso	r	-0.823*	-0.617	-0.794*	-0.759*	-0.586	-0.693*	-0.620	-0.617	-.206
l_min	p	0.012	0.060	0.017	0.025	0.068	0.042	0.065	0.060	.530

* = Significant at $p<0.05$
** = Significant at $p<0.01$
avg, max, and min = average, maximum, and minimum values respectively.

The findings in Table 7 show that in some states, the rate of COVID-19 recoveries is negatively correlated with the concentrations of NO_2, CO, and O_3. In Lagos, Osun, Oyo, Abuja, Anambra, and the Rivers, a negative association was discovered between the average levels of NO_2 and CO and the rate of recovery from COVID-19. The maximum NO_2 concentrations and the recovery rate of COVID-19 were shown to be negatively correlated in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. Additionally, a negative association between the minimum NO_2 levels and the levels of COVID-19 recoveries was observed in Lagos, Ogun, Osun, and Oyo; Abuja ; the Plateau; Anambra; and the Rivers. However, the findings from this study also indicate a positive correlation between the concentration of SO_2 and O_3 and the rate of COVID-19 recoveries in some states. The minimal SO_2 concentrations and COVID-19 recoveries were specifically correlated positively in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers. The average O_3 levels and the quantity of COVID-19 recoveries were also shown to be positively correlated in Lagos, Ogun, Osun, Oyo, Abuja, Plateau, Anambra, and the Rivers.

This study's findings of a link between air pollution and COVID-19 recovery do not necessarily imply a causal relationship. Further research is needed to determine the several ways that air pollutants may influence the COVID-19 recovery rate. Our results are in line with those of a related study by Curtis [41], who found that greater levels of $PM_{2.5}$ were linked to a rise in COVID-19 mortality.

The results of Table 7 suggest that there may be a relationship between certain atmospheric aerosols and COVID-19 recoveries in different states in Nigeria. For example, the negative correlations between NO_2 avg, NO_2 max, and NO_2 min and recoveries from COVID-19 in Lagos, Ogun, Osun, Oyo, Abuja, the Plateau, Anambra, and the Rivers (as indicated by the negative r values and statistically significant p values) suggest that higher levels of these air pollutants may be associated with fewer recoveries from COVID-19 in these states.

In general, the results of Tables 5, 6, and 7 suggest a relationship between certain atmospheric aerosols or air pollutants and COVID-19 outcomes in Nigeria. Further research is needed to confirm these findings and better understand the underlying mechanisms behind this relationship.

Table 7: Correlations between air pollutants and recoveries from COVID 19

Pollutants	coefficients	Lagos	Ogun	Osun	Oyo	Abuja	Plateau	Anambra	Rivers	Kano
NO_2 _avg	r	-0.450	-0.350	-0.685*	-0.617	-0.632	-0.620	-0.617	-0.720*	-0.394
	p	0.167	0.282	0.039	0.060	0.057	0.065	0.060	0.028	0.241
NO_2 _max	r	-0.369	-0.693*	-0.730*	-0.730*	-0.730*	-0.467	-0.500	-0.730*	-0.621
	p	0.267	0.042	0.037	0.037	0.037	0.207	0.141	0.037	0.091
NO_2 _min	r	-0.422	-0.650*	-0.843*	-0.843*	-0.778*	0.056	-0.411	-0.629	-0.394
	p	0.205	0.046	0.011	0.011	0.022	0.867	0.210	0.069	0.241
SO_2_avg	r	-0.390	-0.195	-0.206	-0.206	-0.103	0.056	-0.206	-0.103	-0.056
	p	0.224	0.543	0.530	0.530	0.754	0.867	0.530	0.754	0.867
SO_2 max	r	0.293	0.488	0.411	0.411	0.514	0.620	0.411	0.514	0.507
	p	0.362	0.129	0.210	0.210	0.117	0.065	0.210	0.117	0.132
SO_2 min	r	0.586	0.390	0.309	0.309	0.411	0.507	0.514	0.411	0.620
	p	0.068	0.224	0.347	0.347	0.210	0.132	0.117	0.210	0.065
CO_avg	r	-0.350	-0.586	-0.103	-0.411	-0.514	-0.058	-0.617	-0.823*	-0.169
	p	0.282	0.068	0.754	0.210	0.117	0.866	0.060	0.012	0.615
CO_max	r	-0.250	-0.293	-0.369	-0.103	-0.206	0.169	-0.514	-0.514	0.231
	p	0.442	0.362	0.267	0.754	0.530	0.615	0.117	0.117	0.499
CO_min	r	-0.450	-0.488	-0.053	-0.158	-0.720*	-0.289	-0.617	-0.720*	-0.173
	p	0.167	0.129	0.874	0.634	0.028	0.398	0.060	0.028	0.612

O_3_avg	r	-0.316	0.271	-0.243	0.071	-0.355	-0.282	0.216	0.580	-0.231
	p	0.342	0.422	0.486	0.843	0.323	0.402	0.522	0.081	0.499
O_3_max	r	0.422	0.488	0.243	-0.126	-0.122	-0.118	0.389	0.556	-0.365
	p	0.205	0.149	0.486	0.724	0.727	0.732	0.253	0.102	0.296
O_3_min	r	0.105	-0.050	0.053	0.000	-0.122	-0.808*	0.162	0.162	-0.267
	p	0.751	0.878	0.874	10.000	0.727	0.018	0.631	0.631	0.458
UVAeroso	r	-0.878**	-0.976**	-0.720*	-0.617	-0.720*	-0.635	-0.823*	-0.926**	-0.169
l_avg	p	0.006	0.002	0.028	0.060	0.028	0.063	0.012	0.005	0.615
UVAeroso	r	-0.781*	-0.976**	-0.617	-0.514	-0.720*	-0.808*	-0.617	-0.720*	-0.394
l_max	p	0.015	0.002	0.060	0.117	0.028	0.018	0.060	0.028	0.241
UVAeroso	r	-0.781*	-0.878**	-0.823*	-0.791*	-0.720*	-0.693*	-0.720*	-0.720*	-0.169
l_min	p	0.015	0.006	0.012	0.017	0.028	0.042	0.028	0.028	0.615

* = Significant at $p<0.05$
** = Significant at $p<0.01$
avg, max, and min= average, maximum, and minimum values, respectively

4. Conclusions

Findings from this study show a general reduction in the levels of the air quality parameters in the nine cities studied, except for O_3. At least four cities recorded significant changes in NO_2, SO_2, and UV Aerosol levels when compared before the lockdown and during the lockdown period, while CO and O_3 levels were insignificant in all study locations during the study period. The average SO_2 and O_3 levels were not significant when correlated with COVID-19 cases, deaths, and recoveries in all study locations, while the average UV Aerosol levels were significant in at least six cities (excluding Kano) when correlated with COVID-19 cases, deaths, and recoveries. Average NO_2 levels were significant in Rivers when correlated with COVID-19 cases, deaths, and recoveries, while average CO levels were also significant in Rivers when correlated with COVID-19 deaths and recoveries. It is noteworthy that only Lagos and Kano recorded significant changes in COVID-19 cases when compared before the lockdown and during the lockdown period. This study's findings of a link between air quality parameters and COVID-19 cases, deaths, and recoveries in the study locations do not necessarily imply a causal relationship. Further research is needed to determine the several ways that air pollutants may influence the COVID-19 case, death rate, and recovery rate. Further research can consolidate these findings to understand the mechanisms responsible for this relationship.

Statements and Declarations

Authors' contributions

JAO, AAS, MOA, AEE, and IAO conceived the paper, contributed to the data analysis, and reviewed the final draft for intellectual content. JAO and AEE wrote the initial drafts of the manuscript. AAS, MOA, AEE, and IAO contributed to the data analysis. JAO and AEE reviewed multiple drafts of the manuscript for intellectual content.

Ethics and consent

Not applicable

Acknowledgments

None

Data availability statement

Data and publications from this project will be Open Access. All data links have been included in the study.

Disclosure statement

The authors report no conflicts of interest.

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