GeoHealth

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Special Section:
The COVID-19 pandemic and environmental conditions in Africa

Key Points:
- The number of COVID-19 cases/death were observed to be higher, but with lower Case Fatality Ratio recorded during the second wave than in the first wave
- The spread of the pandemic in Nigeria is partly aided by lower temperatures and high relative humidity (RH)
- The transmission of the pandemic is higher in Nigeria when the RH is low, with dryer and dusty air, and at low temperatures

Supporting Information:
Supporting Information may be found in the online version of this article.

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The Impact of the First and Second Waves of COVID-19 Pandemic in Nigeria

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Abstract In recent times, the COVID-19 pandemic has been the subject of global concern. It has so far claimed over 5.4 million lives globally, with over 291 million cases recorded worldwide as of 5 January 2022. It is known to have different waves and variants, thus making it difficult to handle/manage. This study investigates the impact of the first and second waves of COVID-19 in Nigeria, West Africa. The data used is for the 36 states of Nigeria archived at the National Centre for Disease Control from February 2020 to April 2021. Results from the study reveal that the highest number of COVID-19 cases during the first/second wave was recorded at Lagos (23,238/34,616), followed by the Federal Capital Territory (FCT) (6,770/12,911) and alternates between Plateau (3,858/5,170) and Kaduna (3,064/5,908). Similarly, the highest number of deaths (during the first/second wave) was also recorded in Lagos (220/219), followed by Edo (112/73), and then FCT (83/81). The Case Fatality Ratio (CFR) was observed to be higher mostly in northern Nigeria during the first wave and the southeast during the second wave of the pandemic. On the average, the number of cases/deaths recorded during the second wave was higher than those of the first wave, but a decrease in the CFR values was observed during the second wave. Higher values of COVID-19 cases/death were mostly recorded in Nigeria during; maximum relative humidity (RH) (>70%) with minimum Temperatures (<25°C), Low temperatures, and low RH which is mostly observed during the cold/dusty periods.

Plain Language Summary This study investigates the validity of three different equations in the computation of the Case Fatality Ratio (CFR) of the COVID-19 pandemic and the impact of the pandemic in Nigeria. Results from the study revealed a higher number of COVID-19 cases/deaths with lower CFR recorded during the second wave than in the first wave. This is indicative of an improvement in the management of the pandemic, efficiency of the facilities for the treatment of the pandemic, and the efficacy of government policies for the control and management of the pandemic. It was also observed that the rate of transmission of the pandemic is higher when the country is mostly humid—with low temperatures—and during the harmattan season—when the relative humidity is mostly low, with dry and dusty air and low temperatures.

1. Introduction

In December 2019, the World Health Organization (WHO) received a report on the clusters of pneumonia cases of an unidentified cause in the city of Wuhan, Hubei Province of China (Cao et al., 2020). This was subsequently identified as a novel strain of Coronavirus (sars-cov-2) as the causative agent, by the Chinese authorities (WHO, 2020). However, on 30 January 2020, Coronavirus otherwise referred to as COVID-19 was declared a Public Health Emergency of international concern by the Director General of the WHO. This declaration was done in consultation with the International Health Regulation Committee. COVID-19 was later characterized as a pandemic on the 11 March 2020 (WHO, 2020). COVID-19 was reported to have gradually spread from one continent to another and from one country to the other. COVID-19 has since become a global health concern

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(Margallo et al., 2020), with total confirmed cases of COVID-19 infections of 291,794,418 and 5,463,779 death as of 5 January 2022 (WHO).

Nigeria recorded its first case of COVID-19 on 27 February 2020 in Lagos State. This index case was a 44-year-old Italian citizen, who returned from Milan, Italy on 24 February 2020. However, following the confirmation of the index case, a total of 216 people were identified as contacts to be traced. Out of this number, it was reported that 45 persons traveled out of Nigeria and the remaining 171 people were confirmed to be COVID-19 positive as of 9 March 2020. This number increased gradually from one state to the other and presently there are 243,450 confirmed cases, with over 3,039 deaths reported all over Nigeria as of 5 January 2022. The arrival of the index case signaled the commencement of the first wave of COVID-19 in Nigeria and it lasted for about 9 months (27 February–29 November 2020). Presently, Nigeria is in the fourth wave which began on 1 March 2022.

For an exceptional epidemic like COVID-19, it is important to periodically assess its hazards or impact on human lives. This is done by computing the Case Fatality Ratio (CFR) for the pandemic. The CFR is generally referred to as the ratio of death to total confirmed cases. Computing the CFR will help in assessing the severity of the pandemic (Reed et al., 2013), the efficiency of the treatment given to the patients, the efficacy of the facilities or structures put in place as well as the efficiency of government policies for the control or management of the pandemic. Owing to the effect of COVID-19 on health, specifically age >60 and underlying health conditions (Ali & Islam, 2020; X. Wu et al., 2020), researchers have been working to understand the risk factors for COVID-19, especially for policy recommendations. While there has been a variation in the CFR from COVID-19 with West African countries having lower records of COVID-19, there are possible justifications around meteorological variables influencing the CFR in such countries. For instance, the USA has a CFR estimated to be 5.8% (Liang et al., 2020) while available statistics for Nigeria show a CFR of 1.25% as of 5 January 2022.

This study investigates the variations in the CFR across the 36 states of Nigeria and the Federal Capital Territory (FCT) (Figure 1). Studies with this wide coverage of COVID-19 in Nigeria are not common in the literature (Gorris et al., 2021). Most studies have been done in developed countries while very few were done in developing countries. Scholars have examined the association between COVID-19 and air pollution (Ali & Islam, 2020; Coccia, 2020; Coker et al., 2020; Gorris et al., 2021; Ogen, 2020; Setti et al., 2020; X. Wu et al., 2020; Zhang et al., 2020, 2021; Zhu et al., 2020) but there is scant literature on CFR of COVID-19 (Alimohamadi et al., 2021; Yang et al., 2020). This study has its strength in examining the variation in the trend of CFR from the first and second waves of COVID-19 across 36 states in Nigeria. The study has also investigated the impact of temperature and relative humidity (RH) on the spread of COVID-19 in Nigeria.

2. CFR Computation

Ghani et al. (2005) has earlier shown that during an outbreak of a novel or emerging pandemic, one of the most important epidemiologic quantities to be determined is the CFR. They suggested two simple estimators for the computation of the CFR. These estimators are as follows.

First Estimator $= \frac{\text{total number of Death}}{\text{total number of Cases}}$, thus, giving rise to the following equation:

$$\text{CFR} = \frac{\text{total number of Death}}{\text{total number of Cases}} * 100\% \tag{1}$$

Equation 1 became the general method for computing the CFR of any pandemic. This can be observed in many recent studies (Yang et al., 2020 and the references therein). However, many researchers (Ashraf et al., 2020; Battegay et al., 2020; Ghani et al., 2005, etc.) have questioned the use of this estimator for an ongoing pandemic. For example, Ashraf et al. (2020) opined that while a pandemic is ongoing, it is not appropriate to use the first estimator. This is because, at this time, the eventual outcome is unknown for a number of patients who have contracted the disease and are currently either at or outside the health facility. Therefore, it is only right to use this estimator once an epidemic has ended. This will give the actual proportion of cases that died from the disease and thus the CFR.

In view of the aforementioned observation, Ashraf et al. (2020) suggested an alternative CFR estimator (Second Estimator).

Second Estimator $= \frac{\text{Deaths at day } X}{\text{Cases at day } X-T}$, resulting into:

$$\text{CFR} = \frac{\text{Deaths at day } X}{\text{Cases at day } X - T} * 100\% \tag{2}$$

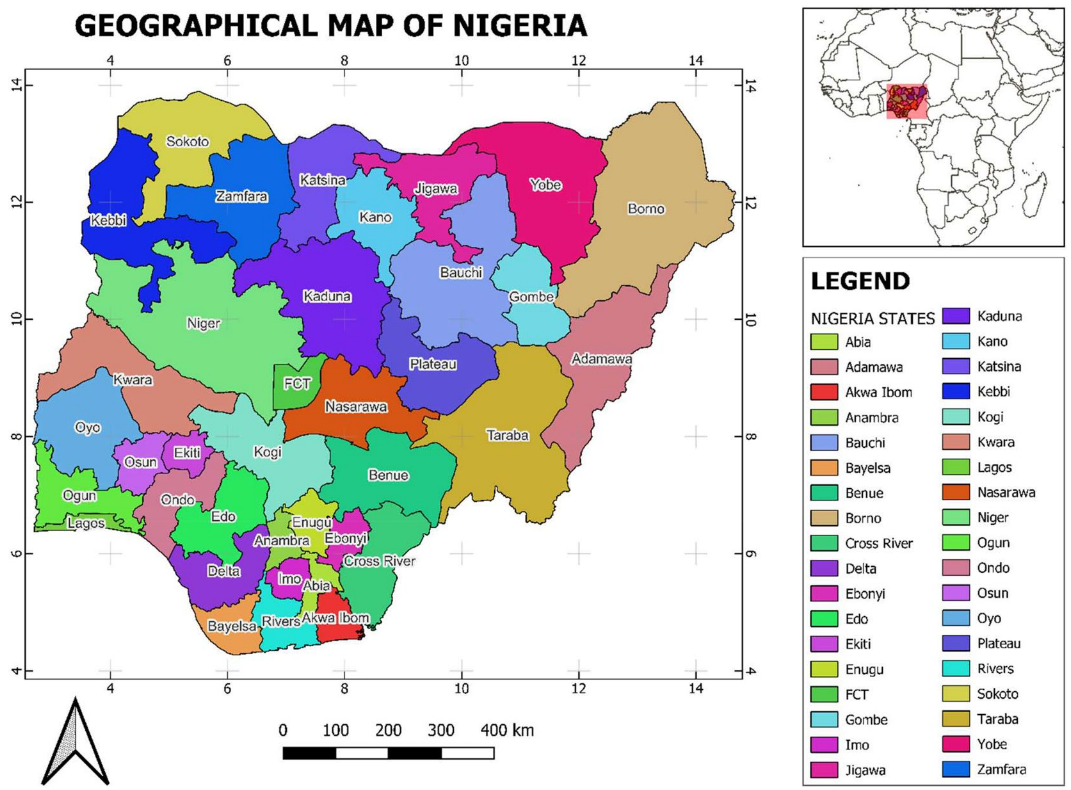

Figure 1. Geographical Map, showing the various states in Nigeria.

where T is the average period from case confirmation to death and they gave an estimate of T to be between 7 and 9 days.

Ghani et al. (2005), however, had earlier observed that the first estimator ignores the censoring that arises when patients are still ill in the health centres, thus suggesting another estimator that cater for the number of patients that recovered from the pandemic.

Third Estimator $= \frac{\text{total number of deaths}}{\{\text{number of deaths+number of recoveries}\}}$, giving rise to Equation 3.

$$\text{CFR} = \frac{\text{total number of deaths}}{\{\text{number of deaths} + \text{number of recoveries}\}} * 100\% \tag{3}$$

This third estimator considers the number of patients that died at any time (t) and those that recovered from the epidemic within that period.

The question now is which of these three equations gives the right/true estimation of the COVID-19 CFR? What is the quantified error in the use of any of the equations? What is the statistical correlation between the equations? Is it possible to use any of these equations to compute the CFR after a certain period even when the pandemic is ongoing? This study compares the outcome of CFR measurements from the three equations during the first and second waves of COVID-19 in Nigeria.

3. Data and Method of Analysis

3.1. COVID-19 Data for the States in Nigeria

The COVID-19 data for the various states in Nigeria (Figure 1) was obtained from the website of the Nigeria Centre for Disease Control; https://ncdc.gov.ng/diseases/sitreps/?cat=14&name=An%20update%20of%20COVID-19%20outbreak%20in%20Nigeria. The data sets were for the period February to 29 November 2020 for the first wave and from 1 December 2020 to 24 April 2021. This period was chosen to avoid the influence of vaccinations in the computation of the CFR in Nigeria.

In the analysis, the CFR was computed using each of Equations 1–3, and the results of the computations were compared using Equation 1 as a reference point. To identify the degree of relationship between the equations, the square of the Pearson product-moment correlation (R^2) was also computed.

The study also investigated the impact of some atmospheric parameters (temperatures and RH) on the spread of COVID-19 over Nigeria. This was achieved using the Satellite data obtained from the National Space Research and Development Agency for the period February 2020 to March 2021. The monthly variation of these parameters was studied in relation to the spread of the pandemic across the 36 states and the FCT of Nigeria. Regression analysis was also conducted to determine the extent of the correlation between monthly values of temperature, RH, and the number of COVID-19 cases in some selected states in Nigeria.

3.2. On the Meteorological Data

The Modern-Era Retrospective analysis for Research and Application (MERRA) was stimulated by the recognition that various aspects of the hydrologic cycle represented in previous generations of re-analyses were not adequate for climate and weather studies. MERRA proposed to improve upon the water cycle as a contribution to the science community and reanalysis research. MERRA's span of most of the satellite era is also intended to place observations from NASA's Earth Observing System (EOS) satellites, particularly those available since October 2002 from EOS/Aqua, in a climate context.

3.2.1. Data Assimilation System

The GEOS-5 atmospheric general circulation model (AGCM) used for MERRA is based on finite-volume dynamics (Lin, 2004) found to be effective for transport in the stratosphere (e.g., Pawson et al., 2007). It includes moist physics with prognostic clouds (Bacmeister et al., 2006), a modified version of the Relaxed Arakawa-Schubert convective scheme described by Moorthi and Suarez (1992), the shortwave radiation scheme of Chou and Suarez (1999), and the long-wave radiation scheme of Chou et al. (2001). Two atmospheric boundary-layer turbulent mixing schemes were used. The Louis et al. (1982) scheme is used in stable situations with no planetary boundary layer (PBL) clouds, while the Lock et al. (2000) scheme is used for unstable or cloud topped PBLs. GEOS-5 incorporates both an orographic gravity wave drag scheme based on McFarlane (1987), and a scheme for non-orographic waves based on Garcia and Boville (1994). The land surface is modeled with the Catchment Land Surface Model (Koster et al., 2000). The grid used for MERRA is ½° latitude × 2/3° longitude with 72 vertical levels, from the surface to 0.01 hPa.

MERRA uses a three-dimensional variation (3D-Var) analysis algorithm based on the Grid-point Statistical Interpolation scheme (Derber et al., 2003; Purser et al., 2003a, 2003b; W.-S. Wu et al., 2002) with a six-hour update cycle. In particular, the observation minus background departures is computed with increased temporal accuracy, and a dynamic constraint on noise is employed to improve the balance properties of the analysis solution. GEOS-5 uses an incremental analysis update procedure (Bloom et al., 1996) in which the analysis correction is applied to the forecast model gradually, through an additional tendency term in the model equations during the corrector segment. This has ameliorated the spin-down problem with precipitation during the very early stages of the forecast and greatly improved aspects of the stratospheric circulation.

MERRA, like other current re-analyses, makes extensive use of satellite radiance information, including data from hyper-spectral instruments such as the Atmospheric Infrared Sounder on Aqua. The assimilation of radiance data requires a forward radiative transfer model as the observation operator, to calculate the model-equivalent radiances, and the corresponding Jacobian to calculate the influences in model space of the radiance increments calculated from the analysis.

3.2.2. Boundary and Ancillary Data

Unlike more recent versions of the GEOS-5 system, the MERRA AGCM uses a climatological aerosol distribution generated using the Goddard Chemistry, Aerosol, Radiation, and Transport model with transport based on a previous (GEOS-4) version of the AGCM (Colarco et al., 2010). The MERRA AGCM does, however, use the analyzed ozone generated by the DAS. The sea surface temperature and sea ice concentration boundary conditions were derived from the weekly 1° sea surface temperature product of Raynolds et al. (2002), linearly interpolated in time to each model time-step. The MERRA system also nudges the stratospheric water vapor to zonal mean climatological values based on data from the Halogen Occultation Experiment (Randel et al., 1998) and the Microwave Limb Sounder on the Aura satellite.

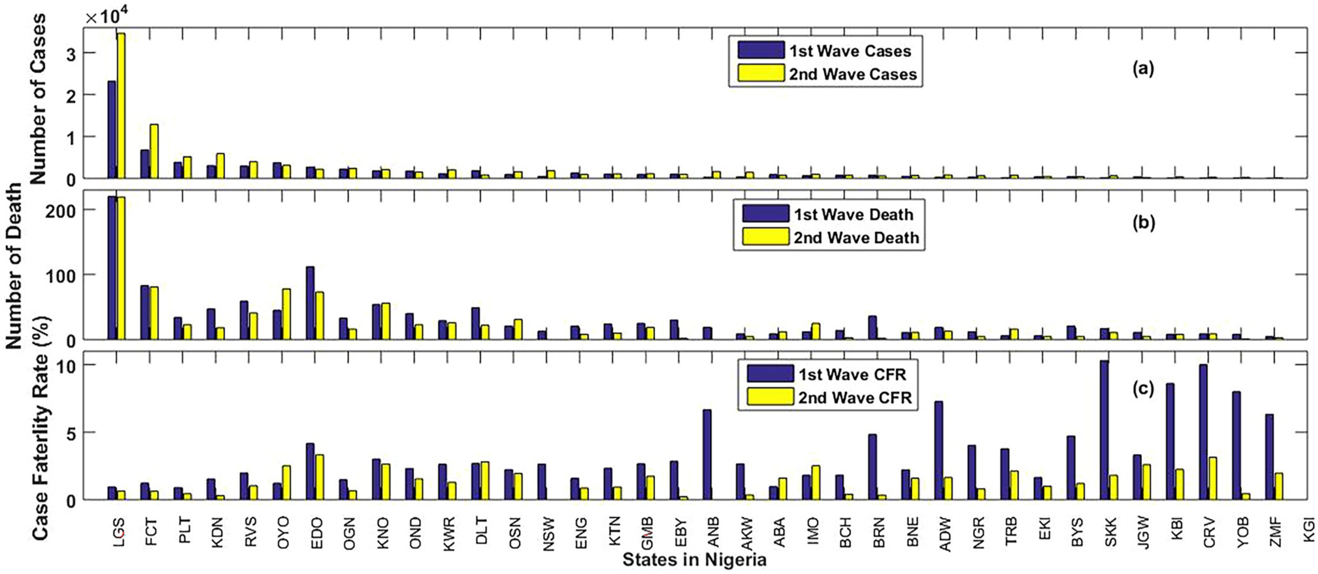

Figure 2. The statistics of (a) the number of COVID-19 confirmed cases, (b) the number of deaths, and (c) the Case Fatality Ratio, during the first and second waves of the Pandemic.

3.2.3. Merra Data Production

MERRA was processed in three separate streams, each spun up in two stages: a 2-year analysis at 2° × 2.5° and then a 1-year analysis on the MERRA grid. Unfortunately, some system changes were made between spin-up and production; these included small changes to the model that should have had little impact on the analysis. Since the spin-up was primarily aimed at the root-zone soil moisture, it was felt that these changes would not impede spin-up. However, Streams 1 and 2 were each extended to overlap the next stream so that the overlaps could be used to examine the adequacy of the spin-up procedure and to quantify the uncertainty in individual fields.

The final MERRA distribution is from Stream 1 for 1 January 1979 to 31 December 1992, followed by Stream 2 for 1 January 1993 to 31 December 2000, and then continues with Stream 3 for 1 January 2001 to the present. Hence, the distributed product segments from Streams 1, 2, and 3 have been spun up for 0, 4, and 3 years, respectively, at MERRA resolution with the precise MERRA system configuration. With the overlaps complete, and Stream 3 now at "the present," data production is being continued as a near-real-time climate analysis from Stream 3 alone.

4. Results and Discussion

Figure 2 shows the plot of (a) the total number of cases, (b) the number of deaths, and (c) the CFR against the 36 states of Nigeria (the states were arranged based on the recorded number of cases) and the FCT for the first wave (blue bar chats), and second wave (yellow bar chats) of the pandemic.

A careful look at the figure reveals that the highest number of COVID-19 cases in Nigeria during the first/second wave was recorded at Lagos (23,238/34,616), followed by the FCT (6,770/12,911) and alternates between Plateau (3,858/5,170) and Kaduna (3,064/5,908). Similarly, the highest number of deaths was also recorded in Lagos (220/219), followed by Edo (112/73) and then FCT (83/81), during both the first and second waves of the pandemic. It is evident from this figure that a comparison between the number of deaths at Edo and the FCT reveals that; while the number of deaths at Edo was higher during the first wave, it was observed to be higher at the FCT during the second wave. The high number of cases recorded in Lagos and FCT is expected since these locations are the two major entry points into Nigeria. Lagos is the Nation's most commercial and industrialized centre, also known as the most economically important state in Nigeria. This makes it a centre of attraction to nationals of other countries that gain entry either through the air, land, or water. It is also one of the most/densely populated states in the Country. FCT on the other hand is the Nation's Capital, hence the centre of administration of the country. This also indicates that the rate/frequency of COVID-19 testing is higher in these two locations compared to other states in the country.

Although Lagos, FCT, Plateau, Kaduna, and Edo States recorded higher values of COVID-19 cases and deaths, the CFR was observed to be higher mostly from northern Nigeria during the first wave and the southeast during

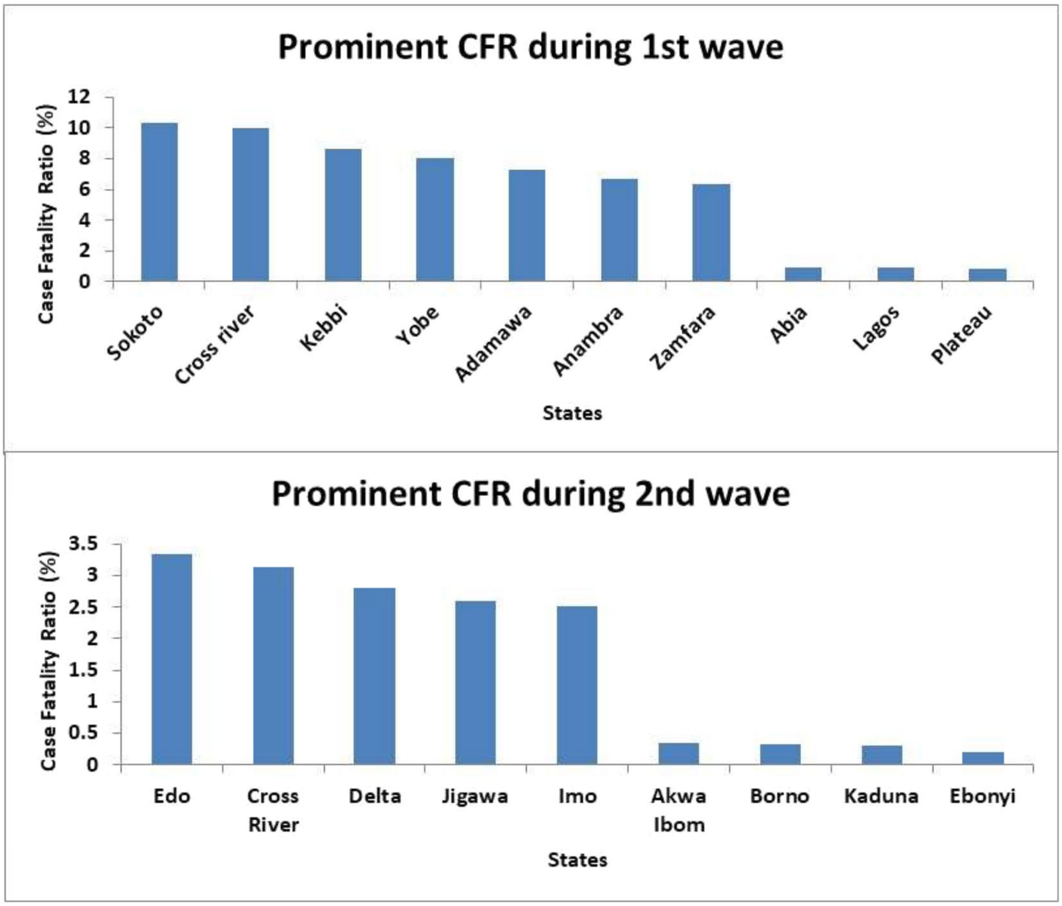

Figure 3. The plot of the prominent cases of Case Fatality Ratio during the first and second wave of COVID-19.

the second wave of the pandemic. The variation in terms of the CFR values can be attributed to the frequency and efficiency of COVID-19 testing, the general orientation of the populace about the pandemic, the level of poverty, and the literacy of the people around that region. In most cases particularly in the northern and eastern states, few numbers of cases were recorded but with high fatality rates.

Figure 3 depicts the plot of prominent CFR values during the first and second waves of the Pandemic. A close look at the figure reveals higher CFR values during the first wave with a maximum value of 10.3% recorded at Sokoto followed by Cross River with a CFR value of 10%, and the lowest CFR values were recorded at Abia, Lagos, and Plateau States with the values of 0.97%, 0.95%, and 0.88%, respectively. Figure 3, further shows a significant drop (from a maximum value of 10.3% recorded during the first wave to less than 3.5% during the second wave) in the CFR values was observed during the second wave of the pandemic. The highest CFR value for the second wave was recorded at Edo, followed by Cross River, and the lowest in Ebonyi with CFR values of 3.33%, 3.14%, and 0.21% respectively. The decrease observed in the CFR values during the second wave of the pandemic is an indication of an improvement in the management of the pandemic during the second wave. This informed the Efficiency of the treatment given to the patients, the efficacy of the facilities or structures put in place as well as the efficiency of government policies for the control or management of the pandemic (Reed et al., 2013).

4.1. On the Computation of CFR

Figures 4a and 5a show the plot that compares the CFR values calculated using Equations 1–3 during the first and second wave respectively. Figures 4b–4d (during the first wave) and Figures 5b–5d (during the second wave) on the other hand depicts the correlation between Equations 1 and 2, Equations 1 and 3, and Equations 2 and 3, within a scale of 0–1. Observations from Figure 4a show a close relationship between the CFR computation from the three equations across the states, except for Nasarawa and Zamfara States, and particularly for CFR computed from Equation 3. An observation from Figures 4b–4d shows a good correlation coefficient (R^2) of 0.998 between

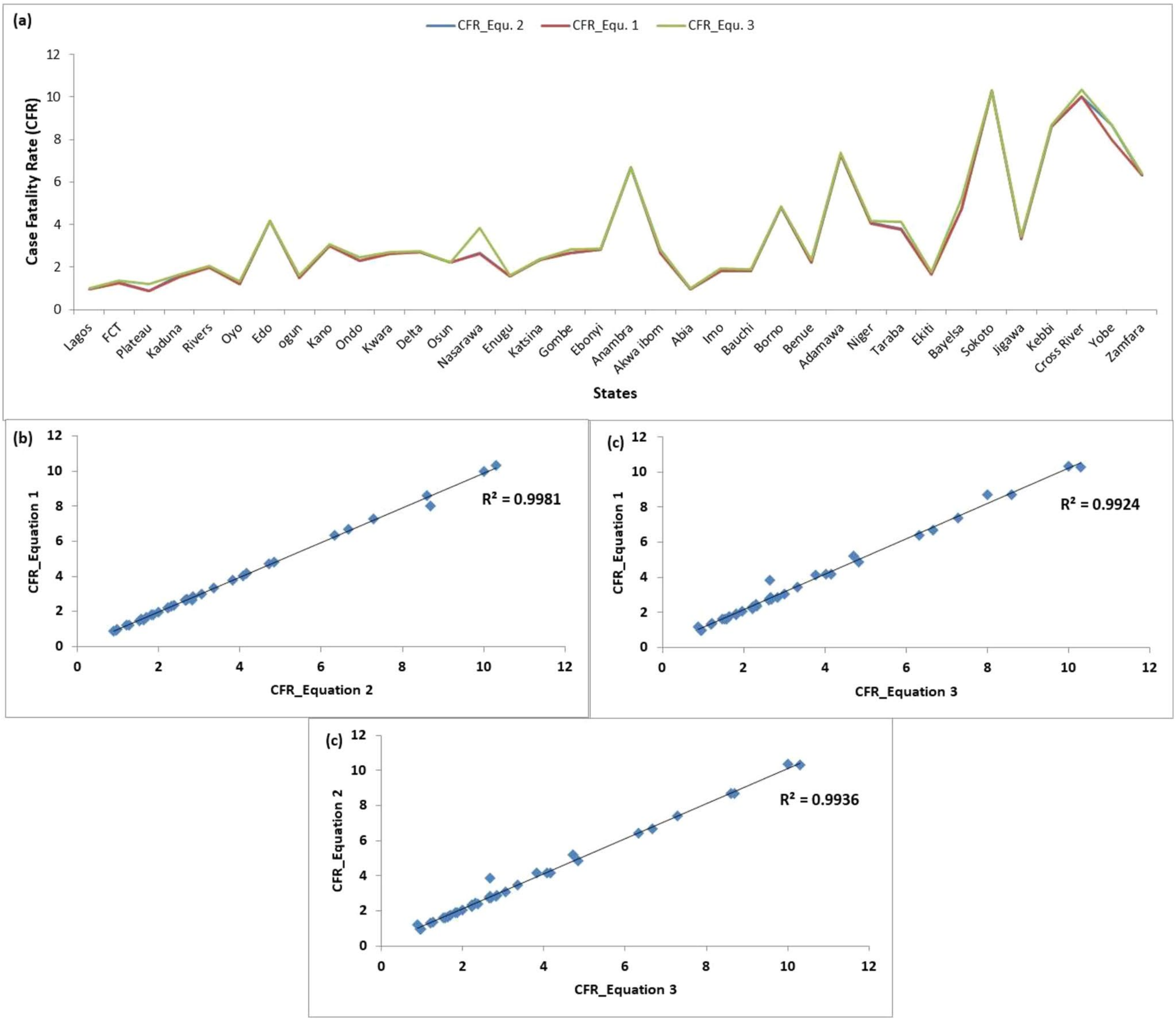

Figure 4. (a) Comparison of the Case Fatality Ratio (CFR) values computed from Equations 1–3 during the First Wave of COVID-19. (b–d) Correlation coefficient (R^2) between the CFR values computed from the three equations during the First Wave.

Equations 1 and 2, 0.992 between Equations 1 and 3, and 0.993 between Equations 2 and 3. Similar observations were made from Figures 5a–5d, except for the two major spikes observed at Delta and Adamawa States on the CFR computation using Equation 3. A good correlation was observed between the CFR computation using Equations 1 and 2 with a correlation coefficient of 0.996. The correlation coefficient between Equations 1 and 3, 2 and 3 was found to be 0.112 and 0.113, respectively during the second wave of COVID-19 in Nigeria.

4.2. CFR Computation for the Entire Period

Figure 6a depicts the plot for the cumulative period (from February 2020 to 24 April 2021), using the three CFR equations. Figures 6b–6d shows the plot of the coefficient of correlation (R^2) for Equations 1 and 2, 1 and 3, and 2 and 3. This is intended to see if the length of time taken for the CFR computation can lead to any improvement in the relationship between the three equations. Observation from the Figures reveal close relationships in the CFR computation using Equations 1 and 2 with a correlation coefficient of 0.984, followed by that of Equations 1 and 3 with an R^2 value of 0.433 and the least is that of Equations 2 and 3 with an R^2 value of 0.420. The spikes observed from the plot of Equation 3 occurred in Adamawa, Nasarawa, Delta, Ondo, and Benue States. Averagely,

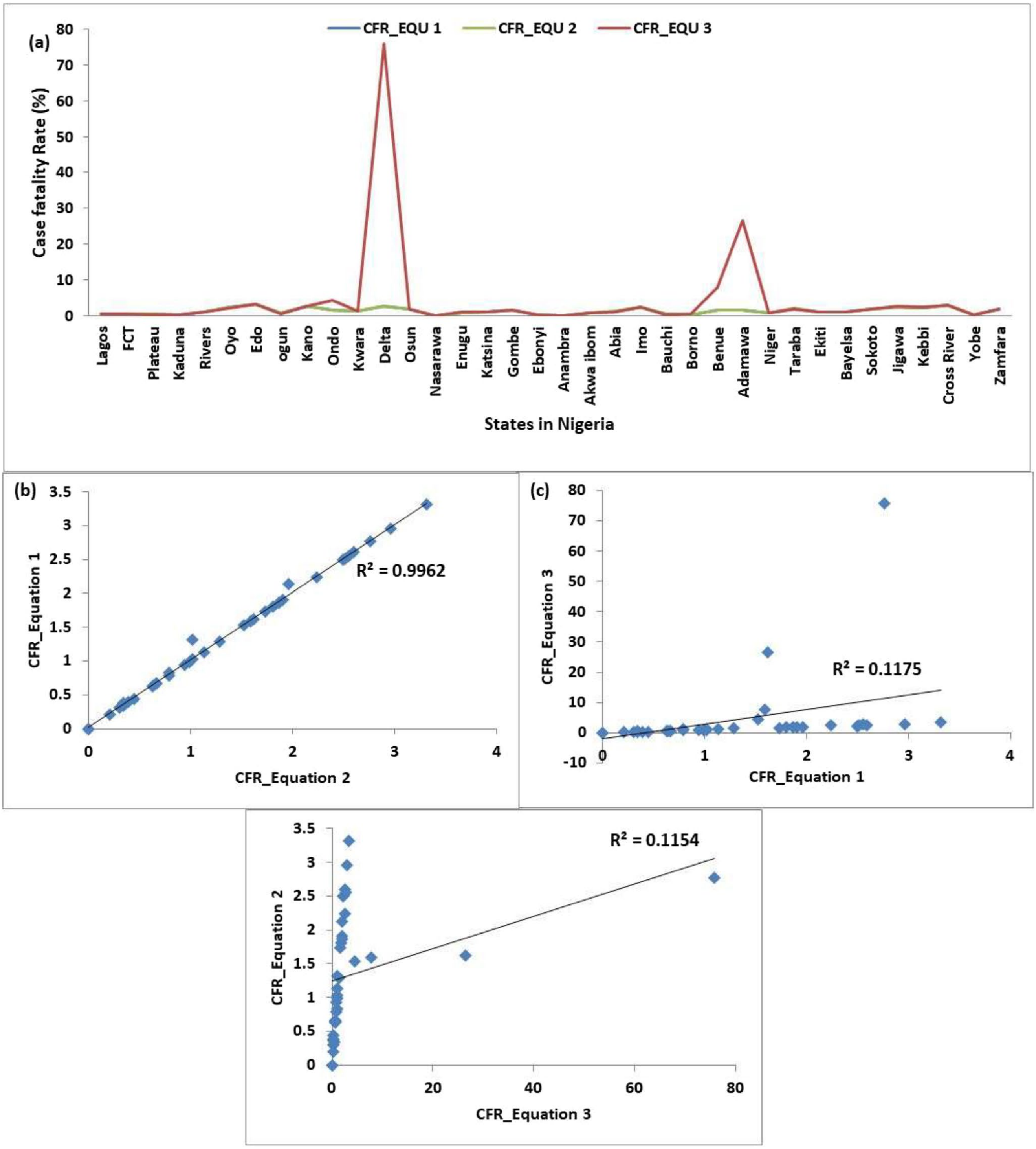

Figure 5. (a) The Case Fatality Ratio (CFR) values computed from Equations 1–3 during the Second Wave of COVID-19. (b–d) Correlation coefficient (R^2) between the CFR values computed from the three equations during the Second Wave.

the result indicates a significant relationship between the three equations, with Equations 1 and 2 having a better relationship. This indicates that either Equation 1 or Equation 2 is more reliable for the computation of the CFR in Nigeria at any point in time. The challenge with Equation 3 has to do with the availability of the recovery data from different states of the country as shown in Table 1. An observation from this table reveals a high number of cases with few recoveries, for instance, in Adamawa State where 1,063 COVID-19 cases were recorded, only 274

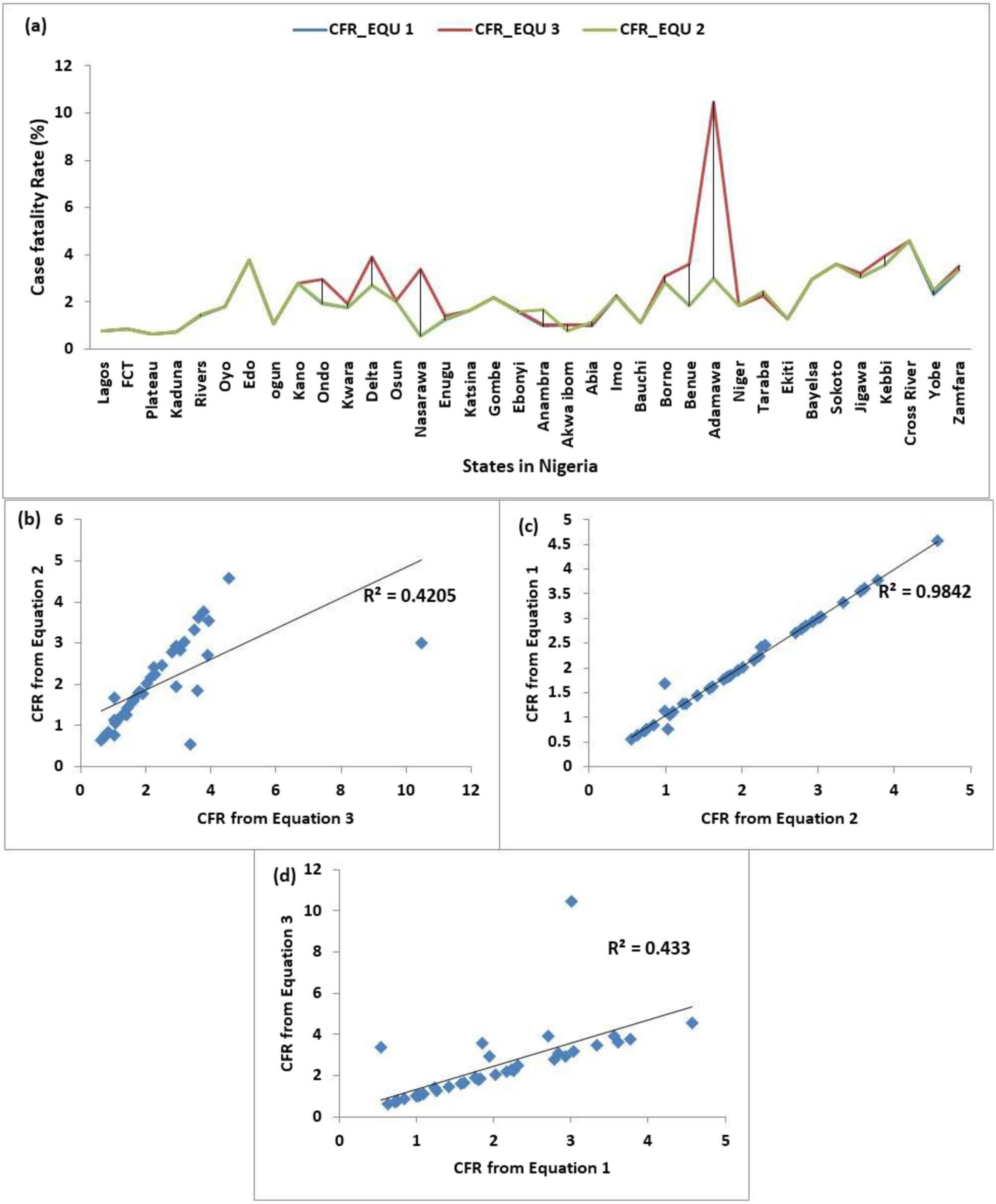

Figure 6. (a) Case Fatality Ratio (CFR) computation using the three equations for the entire period of study comprising both the first and second waves. (b–d) CFR computations using the three equations for the entire period (first and second wave) of study.

Table 1
Recorded Data From Some States in Nigeria as of 25 April 2021

State	Cases	Death	Recovery
Adamawa	1,063	32	274
Nasarawa	2,382	13	373
Delta	2,620	71	1,744
Ondo	3,242	63	2,080
Benue	1,188	22	591

recoveries were recorded after such a long time. Similar observations were made in Nasarawa, Delta, Ondo, and Benue States. This observation shows the limitation in the use of Equation 3 for the computation of the CFR.

It is, however, important to note that, the situation may not be the same in other regions or countries (particularly the developed countries) where relatively fair data records of cases, recoveries, and deaths are properly archived. The variations in terms of the use of these equations as observed by the studies earlier mentioned (Ashraf et al., 2020; Battegay et al., 2020; Ghani et al., 2005), are likely to be associated with the nature and the different variant of the pandemic observed at different countries and regions of the world.

4.3. The Impact of Temperature and Relative Humidity on the Spread of COVID-19 in Nigeria

It is generally believed that there is a likelihood that atmospheric parameters such as temperature and RH have effects on COVID-19 transmission. However, the limited number of studies available on the impact of these parameters on the spread of the pandemic has made it difficult to establish a strong relationship between these parameters and COVID-19 transmission. Other factors such as adherence to COVID-19 control policies like social distancing, use of face masks, hand washing, and use of disinfectants are also known to play a major role in curtailing the spread of the pandemic. Zhang et al. (2021) have studied the role of weather conditions on the spread of COVID-19. The result of this study reveals that temperature and RH are negatively correlated with COVID-19 transmission throughout the world and concludes that weather conditions are not the pivotal factor in COVID-19 transmission and that government intervention as well as public awareness, could contribute to the mitigation of the spreading of the virus. Given these, our study examines the physical relationship between temperature, RH, and the variation in the number of cases across the states of Nigeria.

Figures 7 and 8 show the plot of the monthly variation of atmospheric temperature and RH respectively over Nigeria. Observations from Figure 7 reveal a sudden rise in temperature which began in February 2020 reaching

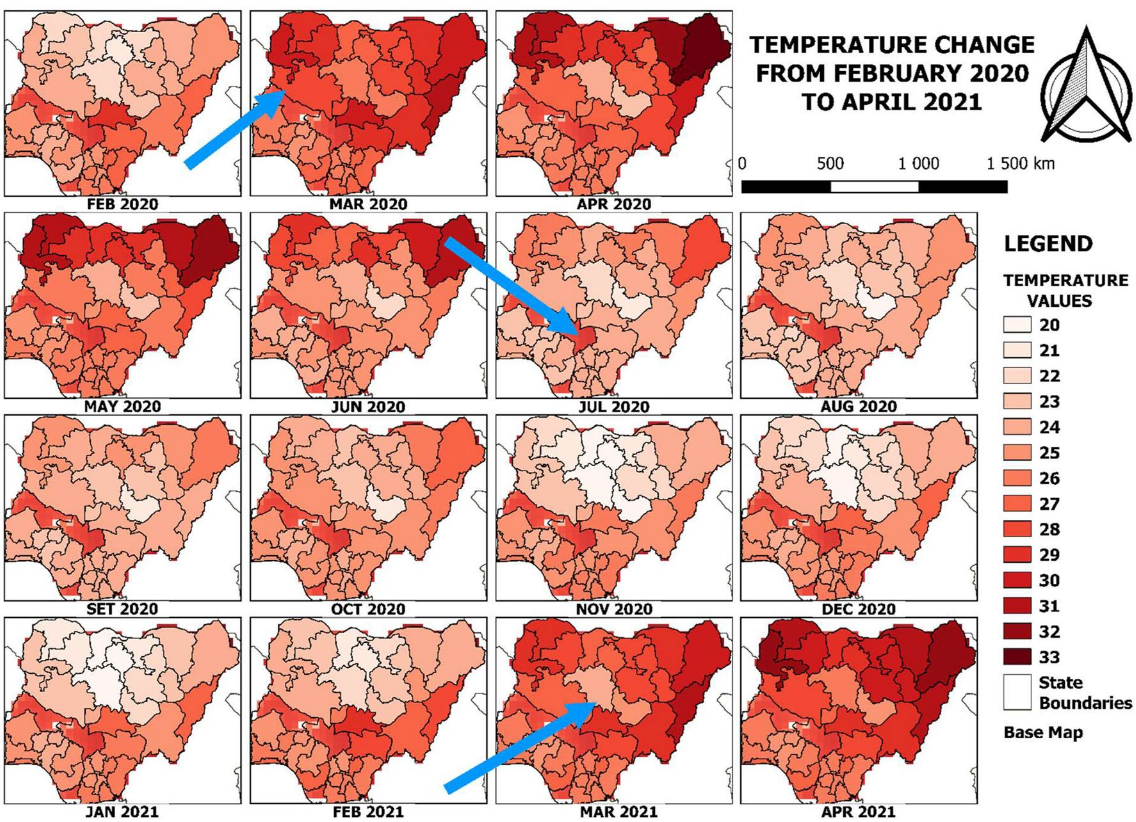

Figure 7. Temperature variations across Nigeria from February 2020 to April 2021.

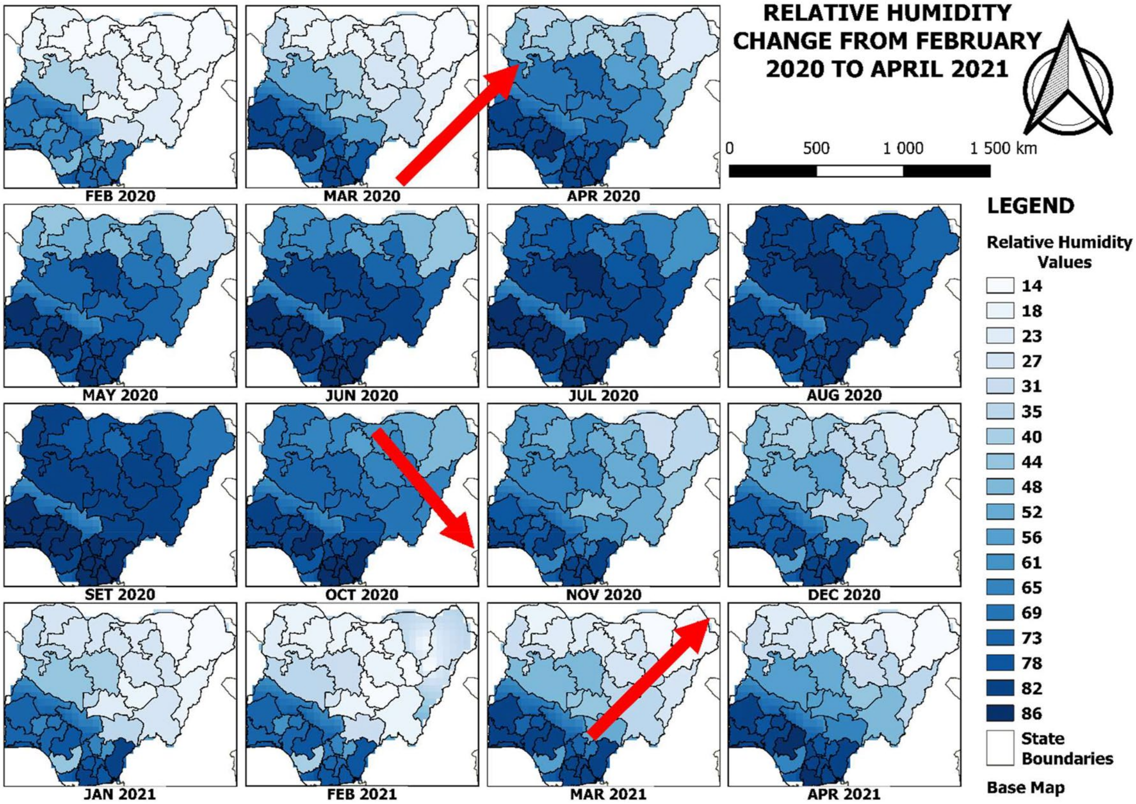

Figure 8. Spatial variations of Relative Humidity over Nigeria from February 2020 to April 2021.

Table 2
Cumulative Observation of the Impact of COVID-19 Over Nigeria

Months	Number of cases	Number of deaths	CFR
March 2020	139	2	1.44
April 2020	1,932	58	3.00
May 2020	10,162	287	2.82
June 2020	**25,694**	**590**	**2.30**
July 2020	**43,151**	**879**	**2.04**
August 2020	54,008	1,013	1.88
September 2020	58,848	1,112	1.89
October 2020	62,964	1,146	1.82
November 2020	67,412	1,173	1.74
December 2020	**90,147**	**1,311**	**1.45**
January 2021	**139,748**	**1,667**	**1.19**
February 2021	158,535	1,969	1.24
March 2021	163,195	2,058	1.26
April 2021	165,419	2,065	1.25

Note. Bold values are turning points, they show the significant increase in the number of cases and death during periods of maximum Relative Humidity and lower temperatures (June to July), and also during cold/dusty periods otherwise known as the Hamattan Period (December to January).

a peak around March/April 2020. A gradual decrease in the temperature began in the southern states, this was observed to be simultaneous with the increase in RH (Figure 8) across the nation. It is evident from both figures that the maximum values of RH (>70%) were observed when the minimum temperatures (<25°C) were mostly recorded all over the country in July/August 2020. During these months the entire country was completely Humid, with generally lower Temperatures. These coincide well with the significant rise in the number of observed cases from 10,162/287 cases/deaths in May 2020 to over 43,000/879 cases/deaths in July (Table 2). This indicates a difference of over 30,000 cases of COVID-19 (Table 3) recorded within these 2 months.

The decrease in RH began gradually in the northeastern states of the Nation from October 2020 and spread gradually over the entire northern states. However, the temperatures remain relatively low as the northern parts experienced the influx of harmattan dust, thus keeping the temperatures relatively low and RH significantly low until February 2021. Observations from Tables 1 and 2 also show an increase in the number of cases/deaths from 67,412/1,173 in November 2020 to 139,748/1,667 by January 2021. COVID-19 is known to be transmitted from infected persons/people to others basically through respiratory aerosols and droplets.

4.3.1. On the Correlation Between Temperature, Relative Humidity, and COVID-19 Cases and Deaths

Figures 9 and 10 show the temporal evolution of monthly COVID-19 cases with temperature and RH respectively in some selected cities within

Table 3
Monthly Variation of COVID-19 Cases, Death, and Case Fatality Ratio Over Nigeria

Months	Number of cases	Number of deaths	CFR
March 2020			
April 2020	1,793	56	3.12
May 2020	8,230	229	2.78
June 2020	**15,532**	**303**	1.95
July 2020	**17,457**	**289**	1.66
August 2020	10,857	134	1.23
September 2020	14,840	99	0.67
October 2020	4,116	34	0.83
November 2020	4,448	27	**0.61**
December 2020	**22,735**	**138**	**0.61**
January 2021	**49,601**	**356**	0.72
February 2021	18,787	302	1.61
March 2021	4,660	89	1.91
April 2021	2,224	7	0.31

Note. Bold values are turning points, they show the significant increase in the number of cases and death during periods of maximum Relative Humidity and lower temperatures (June to July), and also during cold/dusty periods otherwise known as the Hamattan Period (December to January).

Nigeria. The plots for the correlation between monthly COVID-19 cases with temperature and RH respectively in different cities within Nigeria, can be found in Supporting Information S1. It is evident from these figures that both temperature and RH share an inverse relationship with the number of COVID-19 cases in Nigeria. Figure 9 shows a significant relationship between temperature and COVID-19 cases. Careful observation from the Figure shows a stronger relationship in Osun ($R^2 = -0.5$) in southern Nigeria, followed by Plateau and Abuja ($R^2 = -0.4$ and -0.31 respectively) in the central part of Nigeria, the least is Maiduguri $R^2 = 0.06$) in the north-eastern part of Nigeria. Figure 10 also shows a significant inverse relationship in most of the cities, except in Asaba, Edo, and Port Harcourt in southern Nigeria. The relationship was observed to be stronger in Osun in the southwest ($R^2 = -0.50$), followed by Abuja and Plateau ($R^2 = -0.35$) in the central part of Nigeria. An R^2 value of -0.30 was recorded in the northern city of Kano. These observations are clear indications that temperature and RH partly contribute to the spread of COVID-19 Cases in Nigeria. It has been earlier shown that the movement of aerosols/droplets that transmit diseases like COVID-19 can be influenced greatly by some climatic conditions (Dalziel et al., 2018; Huang et al., 2020) or meteorological parameters (temperature, humidity, ultraviolet [UV] radiation). It has been suggested that these meteorological parameters influence the viral dynamics of the disease possibly by inactivating the sars-cov-2 virus or affecting human defense against viral infection in the respiratory airways (Soane et al., 2001).

A further observation from Table 2 shows a consistent decrease in the CFR from 3% in April 2020 to 1.19% in January 2021 (9 months of consistent decrease in CFR), although increases in the number of cases were observed within this period. This reveals an improvement in the management of the pandemic in Nigeria. It was observed that the Presidential Steering Committee (PSC) on COVID-19 in Nigeria, has from time to time reviewed the country's COVID-19 response in light of the rising trend in several countries and the high risk of a surge in cases in Africa. This periodic review of policies has been of great importance in controlling the spread and thus, reducing the CFR of the pandemic. Some of the policies made by the PSC include the precautionary step of restricting travel from countries where there is a high frequency of cases, high fatality rate, and widespread prevalence of variants of concern. They also reinforce the surveillance system at the Country's points of entry. It is evident that these and other policies earlier made in Nigeria, such as social distancing, washing of hands, wearing of face masks, lockdown, restriction on mass gatherings, and other relevant policies, have been of great help in the control of the pandemic.

5. Conclusion

In this study, the impact of the first and second waves of COVID-19 in Nigeria has been studied. Results from the study reveal that the highest number of COVID-19 cases and death during the first/second wave were recorded at the two major entry points to the Nation (Lagos and Abuja). However, the CFR was observed to be higher mostly from northern Nigeria during the first wave and the southeast during the second wave of the pandemic. A decrease in the CFR values was observed during the second wave, which is indicative of an improvement in the management of the pandemic. It is also evident from the results of the study, that the observed changes in the Atmospheric temperature and Relative Humidity may have influenced the severity of the pandemic. Significant increases in the number of cases and deaths were mostly recorded during; (a) maximum RH (>70%) with minimum Temperatures (<25°C) and (b) Low temperatures and low RH which is mostly observed during the cold and dusty periods (October–February) otherwise referred to as the harmattan period.

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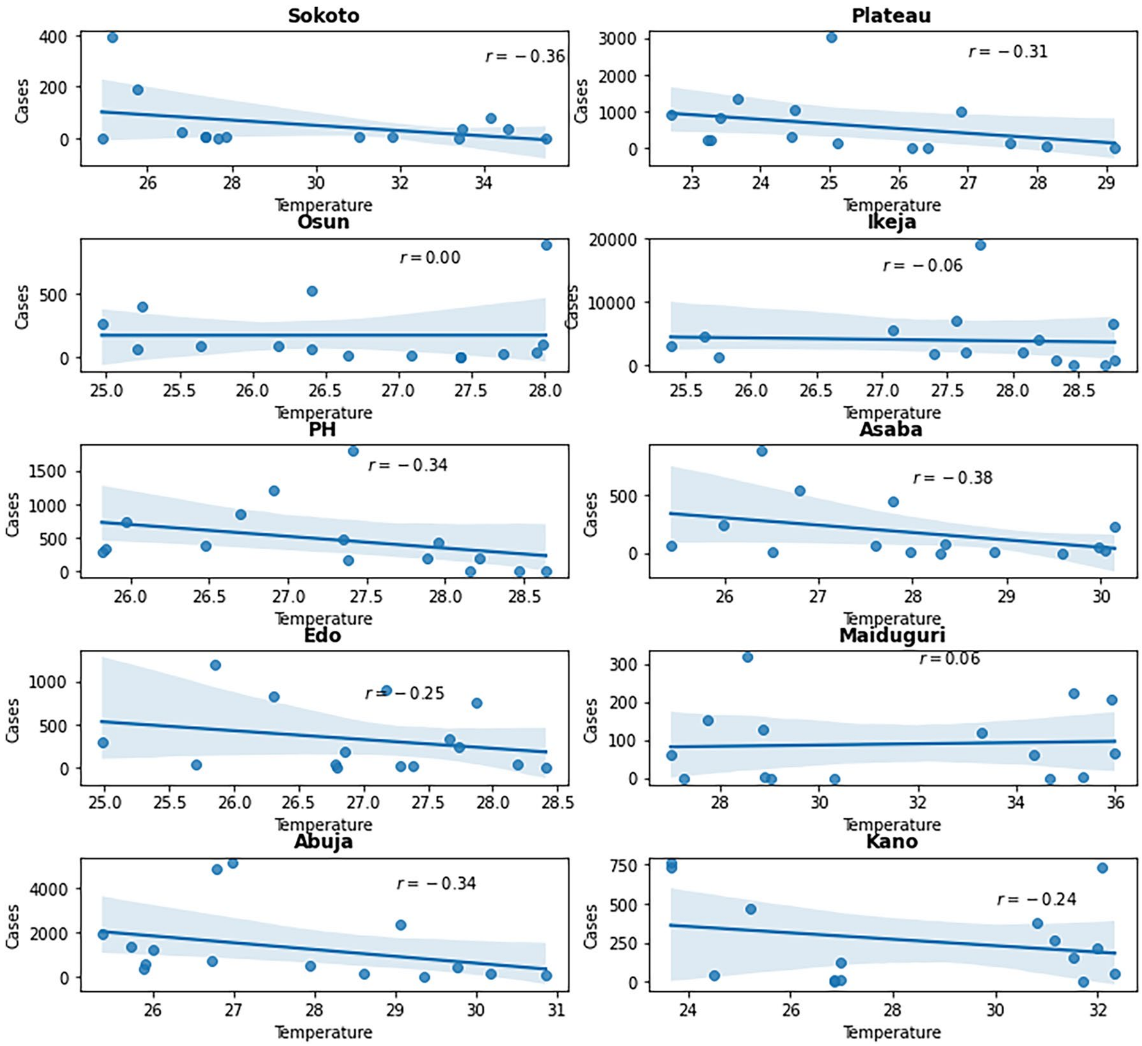

Figure 9. Statistical analysis of monthly COVID-19 cases with temperature in different cities within Nigeria.

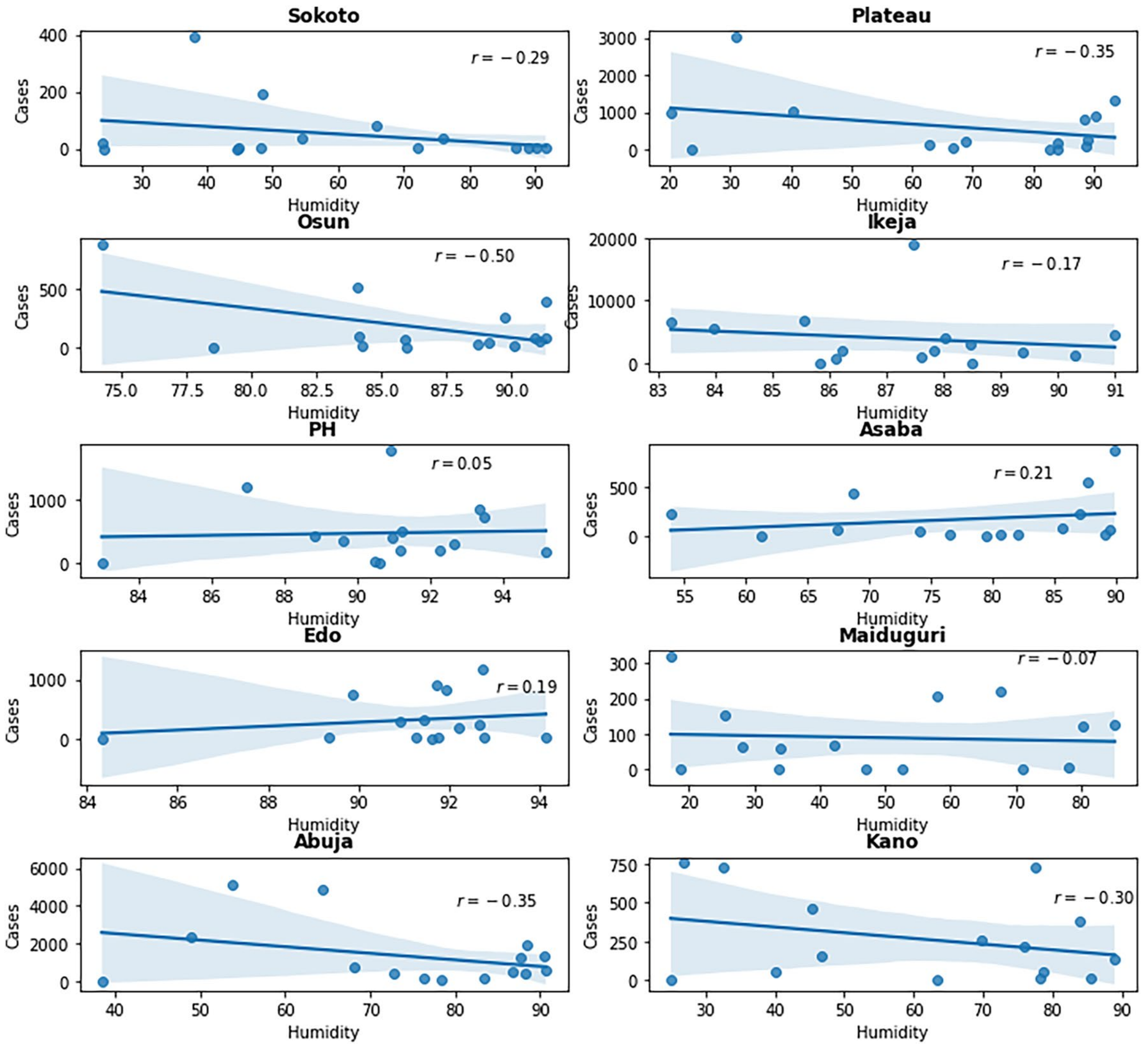

Figure 10. Statistical analysis of monthly COVID-19 cases with humidity in different cities within Nigeria.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The data that support the findings of this study are available at https://ncdc.gov.ng/diseases/sitreps/?cat=14&name=An%20update%20of%20COVID-19%20outbreak%20in%20Nigeria.

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References

Ali, N., & Islam, F. (2020). 'The effects of air pollution on COVID-19 infection and mortality - A review on recent evidence. *Frontiers in Public Health*, *8*, 1–7. https://doi.org/10.3389/fpubh.2020.580057

Alimohamadi, Y., Habyetes, T., Abbasi-Ghahramanloo, A., Janani, M., & Sepandi, M. (2021). Case fatality rate of COVID-19 meta-analysis. *Journal of Preventive Medicne*, *62*(2).

Ashraf, S., Fawziya, A., & Rania, E. (2020). COVID-19 virus case fatality rate: How to avoid errors in calculation of data during the outbreak? *Acta BioMedica*, *91*(2), 222–223. https://doi.org/10.23750/abm.v91i2.9530

Bacmeister, J. T., Suarez, M. J., & Robertson, F. R. (2006). Rain re-evaporation, boundary-layer/convection interactions and Pacific rainfall patterns in an AGCM. *Journal of the Atmospheric Sciences*, *63*(12), 3383–3403. https://doi.org/10.1175/jas3791.1

Battegay, M., Kuehl, R., Tschudin-Sutter, S., Hirsch, H. H., Widmer, A. F., & Neher, R. A. (2020). 2019-novel Coronavirus (2019-nCoV): Estimating the case fatality rate – A word of caution. *Swiss Medical Weekly*, *150*, w20203. https://doi.org/10.4414/smw.2020.20203

Bloom, S. C., Takacs, L. L., Da Silva, A. M., & Ledvina, D. (1996). Data assimilation using incremental analysis updates. *Monthly Weather Review*, *124*(6), 1256–1271. https://doi.org/10.1175/1520-0493(1996)124<1256:dauiau>2.0.co;2

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Cao, Y., Hiyoshi, A., & Montgomery, S. (2020). COVID-19 case-fatality rate and demographic and socioeconomic influencers: Worldwide spatial regression analysis based on country-level data. *BMJ Open*, *10*(11), e043560. https://doi.org/10.1136/bmjopen-2020-043560

Chou, M.-D., & Suarez, M. J. (1999). A solar radiation parameterization for atmospheric studies. *NASA Technical Report Series on Global Modeling and Data Assimilation*, *15*, 40.

Chou, M.-D., Suarez, M. J., Liang, X. Z., & Yan, M. M.-H. (2001). A thermal infrared radiation parameterization for atmospheric studies. *NASA Technical Report Series on Global Modeling and Data Assimilation*, *19*, 56.

Coccia, M. (2020). Diffusion of COVID-19 outbreaks: The interaction between air pollution-to-human and human-to-human transmission dynamics in hinterland regions with cold weather and low average wind speed. *SSRN Journal*.

Coker, E., Cavalli, L., Fabrizi, E., Guastella, G., Lippo, E., Parisi, M., et al. (2020). 'The effects of air pollution on COVID-19 related mortality in Northern Italy. *Environmental and Resource Economics*, *76*(4), 611–634. https://doi.org/10.1007/s10640-020-00486-1

Colarco, P. R., da Silva, A., Chin, M., & Diehl, T. (2010). Global aerosol distributions in the NASA GEOS-4 model and comparisons to satellite and ground-based aerosol optical depth. *Journal of Geophysical Research*, *115*(D14), D14207. https://doi.org/10.1029/2009JD012820

Dalziel, B. D., Kissler, S., Gog, J. R., Viboud, C., Bjornstad, O. N., Metcalf, C. J. E., & Grenfell, B. T. (2018). Urbanization and humidity shape the intensity of influenza epidemics in U.S. cities. *Science*, *362*(6410), 75–79. https://doi.org/10.1126/science.aat6030

Derber, J. C., Purser, R. J., Wu, W.-S., Treadon, R., Pondeca, M., Parrish, D., & Kleist, D. (2003). Flow-dependent Jb in a global grid-point 3D-Var. In *Proc. ECMWF annual seminar on recent developments in data assimilation for atmosphere and ocean* (pp. 8–12).

Garcia, R. R., & Boville, B. A. (1994). Downward control of the mean meridional circulation and temperature distribution of the polar winter stratosphere. *Journal of the Atmospheric Sciences*, *51*(15), 2238–2245. https://doi.org/10.1175/1520-0469(1994)051<2238:cotmmc>2.0.co;2

Ghani, A. C., Donnelly, C. A., Cox, D. R., Griffin, J. T., Fraser, C., Lam, T. H., et al. (2005). Methods for estimating the case fatality ratio for a novel, emerging infectious disease. *American Journal of Epidemiology*, *162*(5), 479–486. https://doi.org/10.1093/aje/kwi230

Gorris, M. E., Anenberg, S. C., Goldberg, D. L., Kerr, G. H., Stowell, J. D., Tong, D., & Zaitchik, B. F. (2021). Shaping the future of science: COVID-19 highlighting the importance of GeoHealth. *GeoHealth*, *5*, e2021GH000412. https://doi.org/10.1029/2021GH000412

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., et al. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan. *China Lancet*, *395*(10223), 497–506. https://doi.org/10.1016/S0140-6736(20)30183-5

Koster, R. D., Suárez, M. J., Ducharne, A., Stieglitz, M., & Kumar, P. (2000). A catchment-based approach to modeling land surface processes in a GCM, Part 1, Model structure. *Journal of Geophysical Research*, *105*(D20), 24809–24822. https://doi.org/10.1029/2000jd900327

Liang, D., Shi, L., Zhao, J., Liu, P., Sarnat, J. A., Gao, S., et al. (2020). Urban air pollution may enhance COVID-19 case-fatality and mortality rates in the United States. *The Innovation*, *1*(3), 100047.

Lin, S.-J. (2004). A vertically Lagrangian finite-volume dynamical core for global models. *Monthly Weather Review*, *132*(10), 2293–2307. https://doi.org/10.1175/1520-0493(2004)132<2293:avlfdc>2.0.co;2

Lock, A. P., Brown, A. R., Bush, M. R., Martin, G. M., & Smith, R. N. B. (2000). A new boundary layer mixing scheme. Part I: Scheme description and single-column model tests. *Monthly Weather Review*, *138*, 3187–3199.

Louis, J., Tiedtke, M., & Geleyn, J. (1982). A short history of the PBL parameterization at ECMWF. In *Proc. ECMWF workshop on planetary boundary layer parameterization* (pp. 59–80). ECMWF.

Margallo, L. N., II, Diaz, M., & Lim, P. P. (2020). 2019 novel coronavirus pandemic: What do we know? *South Dakota Med*, 73.

McFarlane, N. A. (1987). The effect of orographically excited gravity wave drag on the general circulation of the lower stratosphere and troposphere. *Journal of the Atmospheric Sciences*, *44*(14), 1775–1800. https://doi.org/10.1175/1520-0469(1987)044<1775:teooeg>2.0.co;2

Moorthi, S., & Suarez, M. J. (1992). Relaxed arakawa-schubert, A parameterization of moist convection for general-circulation models. *Monthly Weather Review*, *120*(6), 978–1002. https://doi.org/10.1175/1520-0493(1992)120<0978:rasapo>2.0.co;2

Ogen, Y. (2020). Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus (COVID-19) fatality. *Science of the Total Environment*, *726*, 138605. https://doi.org/10.1016/j.scitotenv.2020.138605

Pawson, S., Stajner, I., Kawa, S. R., Hayashi, H., Tan, W.-W., Nielsen, J. E., et al. (2007). Stratospheric transport using 6-h-averaged winds from a data assimilation system. *Journal of Geophysical Research*, *112*(D23), D23103. https://doi.org/10.1029/2006jd007673

Purser, R. J., Wu, W.-S., Parrish, D. F., & Roberts, N. M. (2003a). Numerical aspects of the application of recursive filters to variational statistical analysis. Part I: Spatially homogeneous and isotropic Gaussian covariances. *Monthly Weather Review*, *131*(8), 1524–1535. https://doi.org/10.1175//1520-0493(2003)131<1524:naotao>2.0.co;2

Purser, R. J., Wu, W.-S., Parrish, D. F., & Roberts, N. M. (2003b). Numerical aspects of the application of recursive filters to variational statistical analysis. Part II: Spatially inhomogeneous and anisotropic general covariances. *Monthly Weather Review*, *131*(8), 1536–1548. https://doi.org/10.1175//2543.1

Randel, W. J., Wu, F., Russell, J. M., Roche, A., & Waters, J. W. (1998). Seasonal cycles and QBO variations in stratospheric CH_4 and H_2O observed in UARS HALOE data. *Journal of the Atmospheric Sciences*, *55*(2), 163–185. https://doi.org/10.1175/1520-0469(1998)055<0163:scaqvi>2.0.co;2

Raynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C., & Wang, W. (2002). An improved in situ and satellite SST analysis for climate. *Journal of Climate*, *15*(13), 1609–1625. https://doi.org/10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2

Reed, C., Biggerstaff, M., Finelli, L., Koonin, L. M., Beauvais, D., Uzicanin, A., et al. (2013). Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics. *Emerging Infectious Diseases*, *19*(1), 85–91. https://doi.org/10.3201/eid1901.120124

Setti, L., Passarini, F., De Gennaro, G., Barbieri, P., Perrone, G., Piazzalunga, A., et al. (2020). The potential role of particulate matter in the spreading of COVID-19 in northern Italy: First evidence-based research hypotheses. medRxiv.

Soane, R. J., Carney, A. S., Jones, N. S., Frier, M., Perkins, A. C., Davis, S. S., & Illum, L. (2001). The effect of the nasal cycle on mucociliary clearance. *Clinical Otolaryngology and Allied Sciences*, *26*(11), 9–15. https://doi.org/10.1046/j.1365-2273.2001.00423.x

WHO. (2020). Archived: WHO timeline-Covid-19. Retrieved from https://www.who.int/news/item/27-04-2020-who-timeline---covid-19

Wu, W.-S., Purser, R. J., & Parrish, D. F. (2002). Three-dimensional variational analysis with spatially inhomogeneous covariances. *Monthly Weather Review*, *130*, 2905–2916.

Wu, X., Nethery, R. C., Sabath, M. B., Braun, D., & Dominici, F. (2020). Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study (pp. 2020–2104). medRxiv.

Yang, Z., Hao, J., Huang, S., Yang, W., Zhu, Z., Tian, L., et al. (2020). Acute effects of air pollution on the incidence of hand, foot, and mouth disease in Wuhan, China. *Atmospheric Environment*, *225*, 117358. https://doi.org/10.1016/j.atmosenv.2020.117358

Zhang, C., Liao, H., Strobl, E., Li, H., Li, R., Jensen, S. S., & Zhang, Y. (2020). The role of weather conditions in COVID-19 transmission: A study of a global panel of 1236 regions. *Science of the Total Environment*, *727*, 138704. https://doi.org/10.1016/j.scitotenv.2020.138704

Zhang, C., Liao, H., Strobl, E., Li, H., Li, R., Jensen, S. S., & Zhang, Y. (2021). The role of weather conditions in COVID-19 transmission: A study of a global panel of 1236 regions. *Journal of Cleaner Production*, *292*, 125987. https://doi.org/10.1016/j.jclepro.2021.125987

Zhu, Y., Xie, J., Huang, F., & Cao, L. (2020). Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Science of the Total Environment*, *727*, 138704. https://doi.org/10.1016/j.scitotenv.2020.138704