EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 6 (1): December 2024

Towards predicting daily national COVID-19 confirmed cases in Africa using selected weather and environmental parameters

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Abstract

The contribution of weather and environmental factors (WEF) to the increase in daily confirmed cases of coronavirus disease 2019 (COVID-19) is not fully understood. This study focused on the influence of average national daytime temperature (°C), night-time temperature (°C), daytime relative humidity (%), night-time relative humidity (%), Ultraviolet index at noon, Aerosol Optical Depth and volumetric soil moisture (%) on the COVID-19 cases. Daily national COVID-19 data was obtained from Datopian of the total number of confirmed COVID-19 cases reported in Kenya, Ethiopia, Ghana, Nigeria, South Africa and Egypt. Daily COVID-19 data for the period 1st March 2020 and 31st July 2020 were compared with each of the six countries' WEF. National area average time-series of the atmospheric parameters, using data from National Aeronautics and Space Administration (NASA) Giovanni website, were generated by computing spatial averages over the given variable for each country. Incubation period of COVID-19 ranged from 1-14 days. Therefore, the effects of each parameter within 1, 5, and 14 days were examined. The analyses were conducted based on Pearson correlation coefficient. Generally, a marked heterogeneity of relationships of factors assessed was evident among the countries. Highest positive correlation was observed for Ultraviolet index 14 days earlier (r=0.852, p=0.000), while negative correlations were observed for daytime temperature 5 days earlier (r = -0.840, p=0.000), and on the day (r= -0.869, p=0.000), respectively. Generally night-time temperatures favored COVID-19 transmission more that daytime temperatures. Nigeria depicted relatively the highest sensitivity to weather and environmental factors. These findings may prove foundational in evolving predictive potential of COVID-19 transmission using weather and environmental factors.

Keywords: *Africa; Coronavirus; Daytime temperature; Environmental factors; Ultraviolet index*

Received: 29/06/24
Accepted: 29/11/24
Published: 13/12/24

Cite as, *Muthama and Mbau, (2024)*. Towards predicting daily national COVID-19 confirmed cases in Africa using selected weather and environmental parameters. *East African Journal of Science, Technology and Innovation 6(1).*

Introduction

COVID-19, a highly transmittable and pathogenic viral infection caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), demonstrated rapid spreading. As of 14th September 2020, there were more than 29 million confirmed COVID-19 cases worldwide (Worldometer, 2020) since its first reported case in Wuhan, China in December, 2019 (World

Health Organization, Regional Office for Africa, 2020a). In Africa there were over 1.3 million confirmed COVID-19 cases. The rapid spread of COVID-19 is related to SARS-CoV-2 carriers being highly infectious while being asymptomatic and the high capability of the virus to survive in various environmental conditions (Yu *et al.*, 2020). The contribution of environmental factors to the increase in daily confirmed cases is not fully understood. Forecasting the spread of COVID-19 pandemic and its effect on society is useful as a tool for optimizing control strategies (Scafetta, 2020).

Most countries have been following syndromic and risk-based surveillance. The former is a traditional and vigilant approach of disease surveillance majorly based on case identification. The latter involves contact tracing and testing of high-risk individuals. However, these methods are devoid of the possibility of early warning or forecasting ahead of time for decision making about best control measures (Foddai *et al.*, 2020).

The COVID-19 outbreak continued to evolve in the African continent since its first detection in Algeria on 25 February 2020 (World Health Organization, Regional Office for Africa, 2020b). As of 30 June 2020, the countries reporting high numbers of deaths were: South Africa 2657 (43%), Algeria 912 (15%), Nigeria 590 (9.6%), Cameroon 313 (5.1%), Democratic Republic of the Congo 169 (2.8%), Kenya 148 (2.4%), Mauritania 128 (2.1%), Mali 116 (2.0%), Senegal 112 (1.8%), Ghana 112 (1.8%) and Ethiopia 103 (1.7%). South Africa, Nigeria, Algeria and Cameroon accounted for 73% of the total deaths reported in the region. By the end of June 2020, 30 (64%) countries in the region were experiencing community transmission, 9(19%) with clusters of cases and 8 (17%) with sporadic cases of COVID-19. The continent had also observed increased incidences of importation of cases from affected countries within the region, largely fuelled by long-distance truck drivers and illicit movement through porous borders (World Health Organization, Regional Office for Africa, 2020b).

The question of airborne transmission is increasingly important to not only health workers, waste treatment plant workers, but also communities. The use of face masks in the outdoor environment, in many countries around the world, attested to this. Studies on Influenza indicate the possibility that it is transmitted from person to person in various routes, including airborne. The relative importance of each pathway still remains poorly understood (Liu *et al.*, 2020). Aerosol particle range and amount of aero sized viruses contribute to the probability of air borne transmission. Airborne particles of less than 5μm in aerodynamic diameter are of particular concern because they remain airborne for an extended time. This indicates that the state of the outdoor atmospheric environment contributes to the probability of transmission. Research findings indicate that COVID-19 can be transmitted from person to person through droplets, aerosols and direct contact (Lindsley *et al.*, 2010; Liu *et al.*, 2020; Ziros *et al.*, 2011).

The coronavirus transmission can also be affected by various factors such as climate conditions (temperature, humidity and wind speed), population density and available medical facilities (Dalziel *et al.*, 2018).

This study sought to explore the relationship between daily confirmed COVID-19 cases and environmental parameters, namely: average national daytime temperature (DTT), night time temperature (NTT), daytime relative humidity (DRH), night-time relative humidity (NRH), Ultraviolet (UV) index at noon and volumetric soil moisture (VSM).

Materials and Methods

Study area

The scope of the study was six African Countries, namely: Kenya, Ethiopia, Ghana, Nigeria, South Africa and Egypt (Figure 1). They were chosen as representatives of four regions of the continent, that is, eastern, western, southern and northern Africa. These regions also depict unique environmental and climatic conditions. The other criterion was based on the heterogeneity of the number of reported COVID-19 cases.

Data collection methods

Data on the total number of confirmed COVID-19 cases reported in Daily COVID-19 data for each country for the period 13th March 2020 and 5th July 2020 were collected from the Datopian, an open-source database (Datopian opensource data repository, 2020/2020; Dong *et al*., 2020). National area average time-series of environmental parameters, using data from National Aeronautics and Space Administration (NASA) Giovanni website, were generated by computing spatial averages over the user-selected area of the selected surface temperature variable for each time step within the given national boundary (Acker and Leptoukh, 2007). The seven parameters are elaborated below in Table 1.

Table 1

Type, resolution and sources of satellite-based weather and environmental data

Parameter	Source	Units	Spatial resolution
Relative humidity (daytime)	AIRS	%	1^{o}
Relative humidity (night time)	AIRS	%	1^{o}
Air temperature at Surface (Daytime)	AIRS	^{o}C	1^{o}
Air temperature at Surface (Night Time)	AIRS	^{o}C	1^{o}
Aerosol Optical Depth	MODIS Aqua	Unit less	1^{o}
UV Index	OMI	Unit less	1^{o}
Volumetric Soil Moisture from 6.9 GHZ	AMSR-2	%	10km

Aerosol Optical Depth (AOD) or "Aerosol Optical Thickness" is the degree to which aerosols prevent the transmission of light by absorption or scattering of light (Acker and Leptoukh, 2007).
The Atmospheric Infrared Sounder (AIRS) is a grating spectrometer (R = 1200) aboard the second Earth Observing System (EOS) polar-orbiting platform, EOS Aqua. In combination with the Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder for Brazil (HSB), AIRS constitutes an innovative atmospheric sounding group of visible, infrared, and microwave sensors. (Acker and Leptoukh, 2007).

Ultraviolet index or Erythemal UV Exposure is a measure of the potential for biological damage due to solar ultraviolet radiation. The Total Ozone Mapping Spectrometer (TOMS) and Ozone Measuring Instrument (OMI) Erythemal

UV Exposure are calculated using UV irradiance reaching the surface of earth (deduced from measured UV irradiance entering the atmosphere, Total Ozone, and Surface Reflectivity info) and weighted by a model value of the susceptibility of Caucasian skin to sunburn (erythema) (Acker and Leptoukh, 2007).

Average layer soil moisture is the depth-averaged amount of water present in a specific soil layer beneath the surface. Soil moisture content can be measured as Gravimetric Soil Moisture (GSM). GSM is the mass of water compared to the mass of solid materials per unit volume of soil. Soil moisture can also be expressed as Volumetric Soil Moisture (VSM) which is the volume of water per unit volume of soil. As water is of a known density, the mass of water per unit volume of soil (g/cm3) can be easily determined (Acker and Leptoukh, 2007).

Data analysis

Pearson correlation coefficients were calculated between the daily environmental parameters and the daily records of COVID-19 cases. Recent studies have used both Pearson Correlation and Spearman test to calculate the correlation coefficient between COVID-19 and weather, climate and environmental parameters. For instance, (Scafetta, 2020) calculated the Pearson correlation coefficients between the weather indices and the logarithm of the Deaths per one Million records because the latter can be hypothesized to increase exponentially with environmental variables. On the other hand, (Sfîcă *et al*., 2020) applied Spearman test for correlation between UV solar radiation data and

COVID-19 cases, while significance of weather parameters from long-term means was checked using Student and Mann-Whitney tests.

Lagged correlation analysis was performed between the confirmed COVID-19 cases and the environmental parameters. Considering its incubation period, which is of around 1 to 14 days according to (Backer *et al*., 2020; Lai *et al*., 2020), a period of 14 lag correlations was used for Correlation analysis. Backer *et al*., (2020) and Lai *et al*., (2020) documented a significant correlation between temperature and COVID-19 confirmed cases with a temperature lead time of 5 days. Şahin, (2020) analysed the impact of temperature, dew point, humidity, and wind speed within 1, 3, 7, and 14 days of the case on COVID-19 cases using data in Turkey. In this study computations were done for lag zero, lag 5 and lag14. Regression analysis was then performed on the variables with strong correlations (>0.75).

Results

Exploratory correlation analysis was initially performed to establish pertinent relationships. Lagged correlation analyses between confirmed COVI-19 case on one hand and day time temperature (DTT), Night Time Temperature (NTT), Day Time Relative humidity (DTRH), Night Time Relative Humidity (NTRH), noon time UV index (UV), Aerosol Optical Depth (AOD), and Volumetric Soil Moisture (VSM) on the other, were performed on four regions of Africa. Kenya and Ethiopia represented Eastern Africa, Egypt represented Northern Africa; Ghana and Nigeria represented western Africa and South Africa represented Southern Africa.

Five out of the seven environmental parameters, namely: UV index, AOD, NTRH, NTT and DTT are significantly correlated with covid-19 cases at lag zero, with the highest r and p values being UV index (-0.787, p=0.000), AOD (0.598, p=0.000), NTRH (0.723, p=0.000), NTT (-0.534, p=0.032) and DTT (-0.869, p=0.000), respectively (Table 2). There is a clear uniqueness at national level with both positive and negative correlation coefficients reported at $p<0.05$. The UV index is significantly and inversely correlated with COVID-19 cases in all the countries apart from South Africa. Strong UV index correlations are recorded over Ethiopia and Egypt.

Regional heterogeneity in most of the relationships is discerned. For instance, at lag zero, northern Africa shows a significant positive relationship between COVID-19 cases and UV index as opposed to Western and Eastern Africa that recorded significant negative relationships. Southern Africa recorded insignificant relationship with UV. However, night time temperatures depict homogeneity in three countries where significant relationships are reported.

Nigeria and Kenya, at lag zero, have four parameters with significant correlations while Ethiopia has only one. On the other hand, the satellite data for Ghana had many missing values hindering the computation of p values. This is a pointer to the fact that local weather environmental factors may be responsible for the observed relationships. More localized studies will shed light into this assertion.

At lag five (Table 3), six environmental parameters are significantly correlated with COVID-19 cases. Strong correlations are depicted by Day time temperature over Nigeria (r= -0.840, P=0.0001), UV index over Egypt (r=0.805, P=0.003), and Day time temperature over Egypt (r=0.761, P=0.000). Consequently, UV index still remains the most prominent atmospheric parameter associated with the COVID-19 transmission followed by daytime temperature. Nigeria and Kenya, at lag 5, still have four parameters with significant correlations while each of the rest have only two parameters.

Table 2

Correlation coefficients between the weather and environmental parameters and COVID-19 cases at Lag zero

EP	Kenya C19	PV	Ethiopia C19	PV	Egypt C19	PV	Ghana C19	Nigeria C19	PV	South Africa C19	PV
UV	-0.652	0.000	-0.787	0.000	0.777	0.057	-0.484	-0.651	0.000	-0.532	0.227
AOD	0.598	0.000	0.239	0.200	-0.171	0.003	-0.363	-0.450	0.006	0.222	0.000*
DTRH	-0.011	0.000	0.557	0.839	-0.273	0.001	0.523	0.753	0.864	-0.427	0.181
NTRH	-0.218	0.013	0.284	0.529	-0.106	0.001	0.318	0.723	0.000	-0.510	0.000*
NTT	-0.334	0.008	-0.284	0.000	0.746	0.675	-0.582	-0.455	0.015	-0.543	0.032*
DTT	-0.357	0.000	-0.536	0.955	0.714	0.000	-0.792	-0.869	0.000	-0.464	0.054*
VSM	0.008	0.636	0.402	0.165	-0.307	0.298	0.677	0.712	0.149	0.027	0.605

*EP= Environmental Parameter, PV= p value, UV= Ultraviolet radiation Index, AOD= Aerosol Optical Depth, DTRH= Day-time relative humidity, NTRH = Night time Relative Humidity, NTT= Night time Temperature, VSM = Volumetric soil moisture, C19 = COVID-19 cases.

Table 3

Correlation coefficients between the weather, environmental parameters and COVID-19 cases at Lag 5.

Environmental parameter	Kenya C19		Ethiopia C19		Egypt C19		Ghana C19	Nigeria C19		South Africa C19	
	r	PV	r	PV	r	PV	R	r	PV	r	PV
UV	-0.656	0.000	-0.791	0.000	0.805	0.003	-0.464	-0.647	0.000	-0.580	0.143
AOD	0.603	0.000	0.443	0.130	-0.151	0.004	-0.346	-0.410	0.001	0.207	0.000
DTRH	-0.013	0.000	0.544	0.360	-0.304	0.012	0.545	0.752	0.706	-0.441	0.371
NTRH	-0.215	0.014	0.258	0.584	-0.168	0.000	0.279	0.722	0.001	-0.568	0.000
NTT	-0.334	0.008	-0.140	0.002	0.787	0.539	-0.529	-0.372	0.092	-0.579	0.025
DTT	-0.357	0.000	-0.520	0.357	0.761	0.000	-0.781	-0.840	0.000	-0.508	0.016
VSM	0.005	0.619	0.457	0.020	-0.320	0.911	0.727	0.665	0.372	0.102	0.424

*PV= p value, UV= Ultraviolet radiation Index, AOD= Aerosol Optical Depth, DTRH= Day-time relative humidity, NTRH = Night time Relative Humidity, NTT= Night time Temperature, VSM = Volumetric soil moisture, C19 = COVID-19 cases.

We demonstrate that, at lag 14 (Table 4), five weather and environmental parameters are significantly correlated with COVID-19 cases. Strong correlations are depicted by UV index over Egypt (r=0.852, P=0.000) Day time temperature over Nigeria (r= -0.779, P=0.000), and Day time temperature over Egypt (r=0.783, P=0.004).

Table 4

Correlation coefficients between the weather and environmental parameters and COVID-19 cases at Lag 14.

Country specific EP	Kenya C19	PV	Ethiopia C19	PV	Egypt C19	PV	Ghana C19	Nigeria C19	PV	South Africa C19	PV
UV	-0.673	0.000	-0.758	0.000	0.852	0.000	-0.478	-0.613	0.000	-0.656	0.983
AOD	0.529	0.013	-0.758	0.478	-0.149	0.010	-0.267	-0.323	0.014	0.157	0.000
DTRH	-0.134	0.000	0.337	0.126	-0.360	0.034	0.555	0.753	0.838	-0.345	0.060
NTRH	-0.220	0.021	0.468	0.687	-0.207	0.001	0.199	0.708	0.000	-0.428	0.001
NTT	-0.179	0.192	-0.469	0.555	0.813	0.349	-0.381	-0.171	0.002	-0.638	0.159
DTT	-0.281	0.002	0.110	0.191	0.783	0.004	-0.728	-0.779	0.000	-0.617	0.002
VSM	-0.034	0.255	-0.381	0.046	-0.342	0.583	0.746	0.645	0.168	0.165	0.495

*PV= p value, UV= Ultraviolet radiation Index, AOD= Aerosol Optical Depth, DTRH= Day-time relative humidity, NTRH = Night time Relative Humidity, NTT= Night time Temperature, VSM = Volumetric soil moisture, C19 = COVID-19 cases.

Comparing the three different lag correlation coefficients we observe that Night-time Relative Humidity is significantly related to COVID-19 cases at lag zero, 5 and 14 in Kenya, South Africa and Nigeria. However, the correlations are moderate. It is notable that Egypt shows weak relationship between Daytime RH and COVID-19 cases. Ethiopia too records a weak correlation between Volumetric Soil Moisture and COIVID-19 cases at lag 14.

Nigeria and Egypt, at lag 14, have three parameters with significant correlations while each of the rest have only two parameters. It may be inferred that Nigeria as a country is most sensitive to environmental factors as far as COVID-19 is concerned, with the least sensitive.

Linear regressions between the COVID transmission cases for those with strongest lag 14 correlation, that is, Egypt and Nigeria Figures 2 and 3. Scatter plots of the strongest lag 14 correlations at national levels are presented in Figures 4 to Figure 6.

It may be noted that Egypt depicted the strongest correlation (Table 2). A non-linear pattern is evident even though the coefficient of determination (R^2) is 0.749 (Figure 2). An exponential curve fit yielded R^2 = 0.874. (Figure 3). Predictability of COVID-19 at national level using ultraviolet radiation may be promising especially for Egypt as depicted in Figures 2 and 3.

The second strongest correlation is between COVID-19 cases and daytime temperature in Nigeria (Figure 4). The remaining countries, including South Africa, Kenya and Ethiopia, had moderate to weak correlation coefficients (Figure 5). The R^2 ranges from 0.38 to 0.573 implying that the predictive potential of these parameters is low to moderate.

However, it is vital to state that our study forms a preliminary view and has some limitations. A longer study period might better represent the relation between meteorological conditions and the COVID-19 transmissibility.

Discussion

Climate and seasonality

The findings confirm that ultraviolet radiation is one of the most important weather parameters for the control of Covid-19 virus control (Gunthe *et al.*, 2022; Sagripanti and Lytle, 2007; Sfîcă *et al.*, 2020). According to Sagripanti and Lytle, 2007 UV radiation has been noted to contribute to inactivation of coronaviruses. The germicide power of UV light depends on factors such as wavelength and the type of targeted microorganism. UV radiation is classified in subtypes, depending on their wavelength: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm) (Kerr and Fioletov, 2008). It is widely considered that UV-C types of radiation with shorter wavelength (< 280 nm) is the unique type of UV radiation that induces a germicide effect (Pozo-Antonio and Sanmartín, 2018). The effect of atmospheric temperature on viral inactivation has been reported for Middle East respiratory syndrome coronavirus (MERS-CoV), SARS-CoV-2-related coronaviruses SARS-CoV and COVID-19. Some previous studies have similarly reported possible inactivation of bacteria and viruses by solar radiation (Bezabih *et al*., 2020; Casanova *et al*., 2010).

Scientific evidence on COVID-19 and the weather presents mixed results in literature. Several studies have reported significant positive and negative correlations between weather parameters such as temperature, dew point, humidity, wind speed, rainfall and COVID-19 transmissions and fatality (Ma *et al*., 2020; Pirouz *et al*., 2020; Qi *et al*., 2020; Şahin, 2020; Shakil *et al*., 2020). Further, previous studies on the relationship between weather and COVID cases indicate that temperature and humidity have a significant influence on the number of confirmed cases for certain locations (Ahlawat *et al*., 2020; Backer *et al*., 2020). Backer *et al*., (2020) and Liu *et al*., (2020) reported significant correlation between COVID-19 cases and average air temperature at lag 5. This is in congruence with the findings of this study. These findings on lagged relationship between weather parameters and COVID -19 cases support the assertion by Sfîcă *et al*., (2020) that there is high possibility that weather factors play a role in either the emergence, early-stage transmission, and probably re-emergence in different areas.

The current study findings are supported by laboratory and epidemiological studies which indicate that atmospheric temperature plays an important role in the survival and transmission of coronavirus (Bezabih *et al*., 2020). Indeed, studies have already demonstrated that respiratory infectious diseases are influenced by weather and climate (Mirsaeidi *et al*., 2016). Therefore, there is a need to consider the relationship between the emergence and development of the COVID-19 outbreak on one side and the weather conditions.

As far as wind is concerned, analysis has shown that dry soils surface moisture and threshold wind speed depend significantly on air humidity (Ravi *et al*., 2004).

In terms of seasonality, previous studies have demonstrated that wintertime climate (temperatures below 10^0C) and host behaviour can favour the influenza transmission (Chattopadhyay *et al*., 2018; Shaman *et al*., 2011) and other human coronaviruses (Killerby *et al*., 2018; Neher *et al*., 2020). Further, seasonality of pneumonia, as well, has been explained by a series of combined factors such as indoor crowding (derived from the colder season and producing closer contacts) and poor indoor air quality in association with other seasonal respiratory pathogens, as well as outdoor conditions such as low relative humidity and low amounts of ultraviolet radiation (Mirsaeidi *et al*., 2016; Sfîcă *et al*., 2020).

Weather systems as drivers of weather elements

There is scant literature on how key drivers of weather elements are connected to COVID-19 pandemic (Ramírez and Lee, 2021). These weather elements, including temperature, rainfall and wind over the African continent are driven by the Inter-tropical Convergence Zone (ITCZ), the El-Nino Southern Oscillation (ENSO), High pressure cells, Madeen- Julian Oscillation (MJO) and solar cycle, among others (Omondi *et al*., 2013; Palmer *et al*., 2023; Van Oldenborgh *et al*., 2021).

The El Niño–Southern Oscillation (ENSO) has two opposing phases: El Niño and La Niña. During El Niño, warmer-than-usual sea surface temperatures occur in the tropical eastern Pacific Ocean. Atmospheric pressure anomalies at specific locations (e.g., higher pressure at Darwin, Australia, and lower pressure at Tahiti, French Polynesia) also characterize El Niño over the African continent (Omondi *et al*., 2013; Palmer *et al*., 2023). A temperature increase during El-Nino and the change in wind speeds would in turn enhance COVID-19 spread. Increase in temperature during El-Nino increases humidity, thus enhancing quantities of water droplets which act as carries of COVID-19. The El Niño generally leads to above-normal rainfall conditions (Omay *et al*., 2023).

Regional weather characteristics

The heterogeneity observed in most of the relationships in the current study are likely attributable to the varying drivers of temperature, rainfall and wind. This is supported by findings of Auler *et al*., (2020) who noted that temperature and relative humidity deserve special attention in relation to the spread of COVID-19. The study observed that COVID-19 transmission rate was initially favoured by higher mean temperatures (27.5 °C) as well as intermediate relative humidity (near 80%).

The Indian Ocean Dipole (IOD) is characterized by differences in sea surface temperature (SST) anomaly between the western (50° E to 70° E, 10° S to 10° N) and eastern (90° E to 110° E, 10° S to 0° S) Indian Ocean (Palmer *et al*., 2023). IOD is a driver of rainfall variability at inter-annual scale. The positive IOD is designated to an SST anomaly difference of at least +0.4 °C for at least three months between the warmer west and cooler east, and it is linked to wetter short rains over Eastern Africa. Future studies on the link between weather systems and COVID-19 would provide new insights.

In Eastern Africa, the weather conditions vary depending on location and time of year and is characterized by distinct wet and dry seasons. The wet season typically occurs between March and May, during which rainfall is more frequent and intense (Omondi *et al*., 2013). Closer to the equator, the climate is typically equatorial, characterized by high temperatures year-round and minimal seasonal variation. However, altitude plays a significant role, with cooler temperatures at higher elevations (Muthama *et al*., 2008; Omondi *et al*., 2013; Palmer *et al*., 2023). Cooler temperatures are associated with elevated cases of COVID-19.

The Inter-Tropical Convergence zone (ITCZ), is a belt of low pressure near the equator where trade winds from the northern and southern hemispheres converge. It plays a crucial role in determining the distribution of rainfall across tropical regions and hence COVID-19 cases as influenced by seasonality (Nicholson, 2018). Over Africa, the ITCZ's north-south displacement corresponds to the movement of the rainy seasons. The Influence of ITCZ shows unique regional footprints on the continent (Omay *et al*., 2023; Zaitchik, 2017). In eastern Africa (from southern Ethiopia to central Tanzania), there are two distinct rainy seasons: First Rainy Season (Long Rains) occurs between February and May. During this period, the ITCZ moves northward, bringing rain to countries like Kenya, Tanzania, and Ethiopia. Second Rainy Season (Short Rains) occurs between October and December. The ITCZ shifts southward during this time, affecting rainfall in the same region (Nicholson, 2018). This characteristic of ITCZ is thus expected to influence the dynamics of COVID-19 spread.

Historically, summers leading up to El Niño winters tend to be hotter than average across parts of northern Africa (Gizaw and Gan, 2017). West Africa is particularly affected during El Niño events. Increased risk of drought occurs in this region due to changes in weather patterns caused by El Niño. The warming phase of the El Niño Southern Oscillation leads to disruptions in trade winds, allowing warm water to spread eastward across the Pacific. This disruption affects rainfall patterns, and West Africa becomes more susceptible to drought and famine (Emmanuel, 2022; Gizaw and Gan, 2017). All these extreme weather event influence the prevalence of COVID-19 cases.

The Madden–Julian Oscillation (MJO) is characterised by the eastward propagation of enhanced regional convective rainfall across the tropics. It is a driver of sub-seasonal rainfall variability over Eastern Africa, influencing both the long and short rains on a monthly basis (Palmer *et al*., 2023; Zaitchik, 2017). MJO phases 2 – 4 are connected to large-scale convection in the Indian Ocean. This has been observed to lead to increased rainfall over east Africa highlands and westerly wind anomalies. This relationship is strongest in November, December, March and May, but tends to be weaker during October and April. The MJO phases 6 – 8 on the other hand are linked to wet conditions over low-lying coastal regions and depressed convective rainfall activity over Eastern Africa and the western Indian

Ocean (Palmer *et al*., 2023). The above two scenarios would favour spread of COVID-19.

The South African region is located South of 15°S and has a subtropical climate. The climate of the region is influenced by various weather systems, including temperate and tropical weather systems (Zaitchik, 2017). Most rainfall occurs during austral summer, that is, from December to February. In addition, the south western region experiences winter rainfall. During El Niño, drought tends to occur in southern Africa due to higher atmospheric pressure anomalies and weakened moisture transport from the Indian Ocean. La Niña tends to bring above-normal rainfall conditions. Southern Africa often experiences sinking air due to subtropical high-pressure systems, which suppress thundercloud formations and rainfall (Mason, 2001; Zaitchik, 2017). It is expected that sinking air would enhance concentration of COVID-19. The above scenario provides conducive environmental conditions for the spread of COVID-19. The above view is indeed supported by the number of cases documented in this study.

Further, in arid regions variations in surface soil moisture can be significantly affected by changes in atmospheric humidity, with an important effect on wind erosion potential (Omay *et al*., 2023).

Air pollution meteorology

The relationship between covid-19 cases and aerosol optical depth is supported by recent studies on air pollution- meteorology – covid-19 nexus (Muthama, 2021; Shahzad *et al*., 2023). For instance, Studies have indicated that aerosols containing corona virus generated by sneezes and coughs are major routes for spread of virus (Srivastava, 2021). In addition, the link between air quality and weather parameters is well understood, for instance, Srivastava (2021) noted that local meteorology plays crucial role in the spread of corona virus and mortality. For instance, the study noted declining number of COVID-19 cases with rising temperature. It further observed that during lockdowns which were characterized by decreased human activity air quality improved. This led to significant reduction in gaseous and particulate pollutants and hence a reduction in cases of COVID-19 (Srivastava, 2021). A comprehensive study on environmental elements and weather parameters in Turkey revealed that air quality and temperature significantly influence COVID-19 deaths in Istanbul (Shahzad *et al*., 2023).

In this study, inter-country heterogeneity in the relationship between environmental factors and COVID-19 was observed. This alludes to the partial contribution of localized factors that influence air pollution to driving the observed cases of COVID-19 in each country studied. Such factors may include urban – rural micro climate, aerosol load and air quality differentials (Muthama, N.J, 2021; Shahzad *et al*., 2023).

Conclusion

Unlike other studies, the present study analyses the association between national daily daytime temperature, night time temperature, daytime relative humidity, night time relative humidity, Ultraviolet index at noon and volumetric soil moisture within same day, 5 days, and 14 days of the case on COVID-19 cases using national data of five Africa countries. These represent four regions, namely: eastern Africa represented by Kenya and Ethiopia; northern Africa represented by Egypt; Western Africa represented by Ghana and Nigeria; and southern Africa represented by South Africa. Our study demonstrates the existence of high probability that weather and environmental factors contribute significantly at least in the emergence, early-stage transmission, and probably in its re-emergence in different countries in Africa. Ultraviolet radiation index shows the strongest correlation with COVID-19, followed by Daytime temperature, night time relative humidity, aerosol Optical depth and volumetric soil moisture in that order. Further, ultraviolet index depicts a non-linear relationship with COVID-19 cases. Further, it may be generally observed that night time temperatures favour COVID-19 transmission more than daytime temperatures. COVID-19 cases in Nigeria seem comparatively most sensitive to weather and environmental factors. However, inter-country heterogeneity in relationships is manifest and may be connected to the unique local environments in the countries studied. Researchers are encouraged to repeat this study in the near future to enhance the robustness of the findings. Still, the results are compelling even though, in addition to weather and environmental conditions, several other factors are related to COVID-19 spread.

Acknowledgement

We acknowledge the MODIS mission scientists and associated NASA personnel for the production of the data used in this research effort.

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