Scientific African 16 (2022) e01257

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

COVID -19 Morbidity and mortality in tropical countries: The effects of economic, institutional, and climatic variables

Wisdom Akpalu[a,*], J. Atsu Amegashie[b], Selma T. Karuaihe[c]

[a] School of Research and Graduate Studies (SRGS, Ghana Institute of Management and Public Administration (GIMPA), P. O. Box AH 50, Achimota-Accra, Ghana
[b] Department of Economics and Finance, Gordon S. Lang School of Business and Economics, University of Guelph, Guelph, ON, N1G 2W1
[c] Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria, Private Bag X20, Hatfield 0028, Pretoria, South Africa

ARTICLE INFO

Article history:
Received 3 November 2020
Revised 21 March 2022
Accepted 20 June 2022

Editor DR. B Gyampoh

JEL Classification:
I15
I18
C21
Q54

Keywords:
Tropical countries
COVID-19
Temperature
Institutions
Demography

ABSTRACT

Despite the significant and rising human and economic costs of the novel coronavirus disease (COVID-19), our knowledge on its epidemiology remains limited necessitating expedited research to aid public policy. This study contributes to the knowledge gap by focusing on exploring the effects of potential covariates (economic, institutional, and climatic conditions) on COVID-19 in tropical countries. Using an Ordinary Least Square (OLS) regression, our results showed a non-linear relationship between temperature and infection-to-test ratio. Specifically, temperatures warmer than 18 °C can favor the spread of the disease. In addition, strikingly, countries with better democratic principles registered more positive cases than their counterparts at high levels of corruption.

Introduction

A novel coronavirus disease (COVID-19), which is induced by severe acute respiratory syndrome, was first detected in early November 2019 in Wuhan, China. It rapidly assumed a global dimension owing to its rapid human-to-human transmissibility. On January 30, 2020, the disease was declared an international public health emergency and a pandemic by the World Health Organization (WHO) owing to its fast spread across nations over a short period. Although declared as "the first pandemic of the 21st century" by the WHO, the disease is not new. According to [31], COVID-19 belongs to a family of viruses (share similar genome) termed severe acute respiratory syndrome coronavirus 1 (SARS-CoV-1) and the Middle East respiratory syndrome coronavirus (MERS-CoV), which were discovered in 2003 and 2012, respectively. However, although the virus or its symptoms was known in some parts of the world where the previous SARS related diseases appeared, its

* Corresponding author.
E-mail address: Wakpalu@gimpa.edu.gh (W. Akpalu).

https://doi.org/10.1016/j.sciaf.2022.e01257

magnitude has been severe and the pace of transmission was too fast [31] to allow a coordinated approach to its treatment at the global level. Most countries were left to fend for themselves including the developing world with its inadequate health system, relying on the WHO guidelines. Although several vaccines[1] have been approved by the WHO by the beginning of 2021, the pandemic left most countries in a state of despair, with accelerating levels of disparities and widening the gap for the most vulnerable populations.

To date, May 22, 2021, the WHO Coronavirus Disease (COVID-19) Dashboard[2] shows over 165.8 million confirmed cases with over 3.4 million deaths, globally. At the regional level, COVID-19 mortality rates vary significantly, with the Western Pacific and Americas regions registering the lowest (less than 2.8 million) and highest (over 65 million) confirmed cases, respectively. Several vaccines (at least 7) have been developed for the disease and over 1.4 trillion doses have been administered to date. While the developed world, (with the Americas leading) has made great progress in vaccination, the world is still far from reaching the most needed areas, particularly those in the developing world, with Africa lagging behind the rest of the world. Currently, no known treatment exists for the disease and effective implementation of preventative non-pharmaceutical interventions (NPIs) are necessary to mitigate its impact.

In addition to the human costs, government policies and preventive measures taken by individuals to limit the spread have imposed significant economic costs on countries. Globally, and especially in developing countries, the pandemic has overstretched the healthcare systems jeopardizing efforts made at controlling other diseases [1]. Yet, COVID-19 infection and recovery processes are complex making it hard to determine the effectiveness of governments' costly social isolation policies. Globally, the pandemic had two waves to date, depending on the region, and this informs measures taken based on country specific needs. The first wave at the onset of the pandemic (March 2020) hit most countries hardest stretching the global economy and health sectors to the limit. The second wave (and third for some countries) have been more manageable owing to improved information about the pandemic and the discovery of vaccines. Nevertheless, epidemiological dynamics of the disease are largely driven by guestimates due to lack of information. For example, the decline of the infection rate of the severe acute respiratory syndrome (SARS) epidemic during the warmer season (April and May) in China in 2003, and the relatively low COVID-19 infection and mortality rates in tropical countries reinforced the belief that warmer temperatures mitigate the spread of the coronavirus. In addition, it has been argued that demographic patterns of African countries have slowed the spread of the virus. Nevertheless, results from studies published on COVID-19 thus far are largely mixed, highlighting the complex nature of the epidemiology of the disease and our knowledge deficit, hence the need for more expedited research.

Many aspects of the COVID-19 pandemic remain uncertain and not yet fully understood, especially at spatial levels. The existing studies typically concentrates on a few variables, which potentially biases the estimated coefficients. As noted by Prata et al. [23], who studied the effect of temperature in a tropical country (Brazil), several factors such as political, social, economic, and cultural conditions, affect the spread of COVID-19 and should be accounted for in epidemiological studies. Ahmadi et al. [2] and Wang et al. [29] also emphasized the need to account for many factors when investigating transmission of viruses. To contribute to the fast-growing literature and enrich our understanding of the spread and death rates of the coronavirus disease across tropical countries, since they share similar climatic conditions, this study investigates the effect on infection and mortality rates, of temperature variations, institutional quality, social and economic conditions, and the demographic patterns. We are not aware of any study that investigated the spread and mortality of COVID-19 in several tropical countries while accounting for potential covariates. As noted by Farzanegan et al. [11], there is an increasing need to understand factors driving cross-country differences in the pattern of COVID-19 impacts.

For this study, two empirical models were estimated, and the preliminary results reveal a non-linear relationship between tropical temperature and infection-to-test ratio, but no evidence in support of the effect of temperature on mortality among the infected or infection rate (i.e., infection in a million population). Secondly, the population of 60 years or older are more likely to be infected and, also, to die from the COVID-19 disease. Remarkably, the tropical countries that have better quality democracy, but are more corrupt registered higher positive cases than their counterparts that are less corrupt, all else equal. The reverse however applies for mortality cases among the infected population.

The remainder of the paper is organized as follows. The next section presents a brief overview of the existing literature on how some key variables relate to COVID-19 spread. Section 3 presents the data for the analysis and the ad hoc empirical model estimated. This is followed by the presentation and discussion of the key findings (Section 4), and the final section (Section 5) contains concluding remarks.

Brief review of literature

The theoretical literature (COVID-19 as an SIR virus)

The seminal works of Kermack and McKendrick [15–17] developed the principles of modern epidemiological models for the spread of viruses employing a set of non-linear differential equations. Specifically, the authors investigated the causal factors responsible for the size and frequency of epidemic and found that the occurrence of epidemics is influence by the

[1] To date, the following vaccines have been approved by the WHO and administered in different parts of the world, albeit some health challenges (e.g., blood clots in some individuals). The Johnson and Johnson vaccine, Moderna, AstraZeneca, Pfizer, Sinovac or CoronaVac, CoviVac, among others.

[2] The WHO dashboard can be accessed at https://covid19.who.int.

interaction of population density, infectivity, recovery, and mortality. In every human population attacked by a virus, some individuals are classified as *susceptible (S)* to the virus, others are *infected (I)*, and the remainder is *removed (R)* either by mortality or recovery from the disease. The model is therefore termed as the SIR model. This classification of subjects underlies their proposition that every epidemic flourish, wane and eventually terminate. By contrast, if individuals of a given population are classified as susceptible, infection, and susceptible (SIS) to a virus, then it could potentially exterminate the population. Given its nature, COVID-19 is classified as an SIR virus in the literature.

The authors proved that (based on the SIR model) the termination of an epidemic depends on how the density of the affected population compares with a critical threshold of population density, and the infection rate within the population. Thus, all else equal, if the density of a given population is lower than the threshold, the epidemic will terminate. Conversely, if the population density exceeds the critical threshold, even marginally, an increase in infection rate could result in a large outbreak of an epidemic. Furthermore, introduction of new individuals, through birth and immigration, into the population results in higher infection and mortality rates.

These theoretical results, although interesting, are driven by a critical assumption of age neutrality of susceptibility, recovery, and mortality of an infection. This is a strong assumption since empirical studies have found that age is a particularly important factor when explaining COVID-19 mortality. In addition, Kermack and McKendrick [17] by dividing the population to susceptible (S), infective (I), and removed (R), individuals showed that accounting for comorbidity did not influence the key results, specifically the existence of thresholds. Empirical studies have however found that pre-existing conditions significantly impact COVID-19 related mortality (see e.g., [26]).

Empirical review

Several empirical studies have already been carried out to better understand the rate of transmission of the coronavirus disease and its mortality rates, and several covariates have been identified. Owing to lack of sufficient data, most of the findings are only spatially applicable creating the need for more research. Among the factors identified are climate, demographic, institutional and social economic variables. The choice of variables for this study is guided by the earlier studies.

The current study focusses on the tropical countries (see Table A1 in the Appendix). The variable temperature has been widely used in several Covid-19 studies [4,18,24,27,29,30] and was found to play a role, but the findings are inconclusive. Wang et al. [29] and Shi et al. [27], for example, found a non-liner relationship between the two variables (temperature and transmission rate), with lower (higher) temperature stimulating (mitigating) transmission rate. Furthermore, Wang et al. [29] found that, to a certain extent, there might be an optimal or conducive temperature for viral transmission, which may partly explain why it first broke out in Wuhan during the winter. Therefore, countries and regions with lower temperatures in the world need to adopt the strictest control measures to prevent future reversal of progress made towards controlling the pandemic. Liu et al. [18] found that lower temperatures are likely to favor COVID-19 transmission, and Falsey and Walsh, [10] concluded that temperature plays a role, such that viral infections become more acute during the cold winter months. On the other hand, Xie and Zhu [30] found no evidence in support of a mitigating effect of rising temperature. This finding is supported by Prata et al. [23] who showed that for temperatures lower than 25.8 °Celsius, the spread of the disease decreases with temperature. This trend reverses at warmer than the threshold temperature.

The role of institutional quality variables, like democracy versus authoritarian, corruption, culturalism, etc., may influence COVID-19 transmission, mortality, and testing. Some studies have attributed governments' actions to implement the lockdown, hence mitigating the spread of Covid-19, to the nature of political regimes. According to Frey et al. [13], a widely held belief is that autocratic governments have been more effective in reducing the movement of people to curb the spread of Covid-19. They found that autocratic regimes imposed more stringent lockdown regulations and relied more on contact tracing, with no evidence of effectively reducing travel. However, countries with democratically accountable governments, despite introducing less stringent lockdowns, were more effective in reducing geographic mobility at the same level of policy stringency. They concluded that, in terms of reducing mobility and thus, the spread of Covid-19, collectivist and democratic countries have implemented relatively effective responses compared to autocratic regimes. On the contrary, Cepaluni and Dorsch [6] concluded from their study that nations with more democratic political institutions experienced more COVID-19 deaths than their counterparts with less democratic values.

Several studies have investigated the relationship between infectious diseases, more so COVID-19, and age distribution of populations [10,14,18]. A study on clinical features of the pandemic in China found that the mortality of elderly patients (over 60) with COVID-19 is higher than that of young and middle- aged (less than or equal to 60) patients [18]. The authors concluded that patients over 60 with COVID-19 are more likely to progress to severe disease, compared to the younger patients. Furthermore, Gavazzi, et al. [14] and Lloyd-Sherlock et al. [19] found that the elderly populations in developing countries are more vulnerable to infectious disease, which have a distinct spectrum in that population, as well as a greater relevance in the developing world. Gavazzi, et al. [14] argued that tropical diseases have a specific presentation and epidemiology in elderly patients, due to immune deficiency compromised by malnutrition in the developing world. This is supported by Falsey and Walsh [10], who argued that viruses account for a substantial portion of respiratory illnesses, including pneumonia, in the elderly population.

Another important factor that influences the spread of viruses and other diseases is urbanization and population increase. According to Carl-Johan Neiderud [22], urbanization leads to many challenges for global health and the epidemiology of infectious diseases. The influx of people to cities lead to megacities becoming incubators for new epidemics, and zoonotic diseases that can spread in a fast manner and become a world pandemic. Regarding COVID-19, Diop et al. [9] found that sparsely populated places have been observed to have limited spread of the disease.

Although several studies have investigated the economic impact of Covid-19 (see e.g., [5,11,12,21,32], those on the effect of economic variables such as trade openness and GDP per capita on the spread and mortality rate of the disease are limited ([1,3]; and [28]). In its working paper on trade and pandemic containment measures for Africa, the World Bank argued that trade in goods and services will play a key role in overcoming the pandemic and limiting its health and economic impact, especially on the poor [5]. While low-income countries may be less likely to adhere to lockdowns and/or adhere to safety protocols, as well engage largely in reactive testing of people, they are typically less urbanized, hence could have slower transmission rate of the coronavirus disease.

Data and empirical model

The data for the study was obtained from several secondary sources. The data for the coronavirus disease (COVID-19) infection and death rates were extracted from the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University, and the COVID-19 test rate and temperature were obtained from Worldometer and Weather Base, respectively. An attempt has been made to include other climate variables (precipitation and wind speed) in the model but missing observations in these variables reduced the sample size considerable. In addition, wet bulb temperature has been considered, but there is lack of reliable data on the countries used for this study. An attempt was made to generate the data using average monthly data (instead of daily data) on temperature and relative humidity, but the data did not fit the model owing to perhaps the low frequency nature of the data (see Table A4 in the Appendix). As a result, only the temperature variable was used for the analysis instead of the wet bulb temperature (thus we revert to the original model). Five (5) variables (population density, urban population, trade openness, international tourism, and GDP per capita) were taken from World Development Indicators (WDI); Corruption Perception Index (CPI) – which is measured from high level of corruption (0) to the lowest level (100) – and Polity2 – which measure the level of democracy on the scale of −10 to 10 – were obtained from Transparency International and Sustainable Competitiveness Observatory (SCO), respectively. Table A.2, in Appendix A, contains the list of variables and the corresponding sources of data.

All tropical countries were considered for the study. However, owing to lack of data on some of the variables, the sample for the empirical analysis ranged from 45 to 51 countries.[3] The endogenous variables considered in this regression include the COVID-19 infection rate, the proportion of the people tested who are positive, and mortality rate among those infected with the virus. The covariates include two institutional variables: Polity2, and CPI, international tourism, population density, proportion of the population over 60 years of age, trade openness (i.e., trade as a proportion of GDP), GDP per capita, and average temperature.

The empirical models estimated are presented in Eq. (1) as follows:

$$LnY_{ij} = \alpha_j + \beta_j LnT_{ij} + \phi_j \left(LnT_{ij}\right)^2 + \eta_j A + k_j(x)_{ij} + \sigma_j(E)_{ij} + \theta_j(D)_{ij} + \varepsilon_{ij}, \quad (1)$$

where $i = 1, \ldots, n$ tropical countries considered for this study; $j = 1, 2$ models; T is average annual temperature; A is the proportion of the population that is 60 years or more; $\mathbf{x}$,$\mathbf{E}$,$\mathbf{D}$ are vectors of economic and demographic conditions, respectively;$\alpha, \beta, \eta, \mathbf{k}, \sigma, \theta$ are the parameters to be estimated; and ε_{ij} is a normally distributed error term. The models (1) and (2) explore the relationship between the following dependent variables (Y_{ij}) on one hand: proportion of people who tested positive (Y_{i1}) and mortality rate among those who tested positive (Y_{i2}); and the right hand side variables in the equation. The vector of institutional variables ($\mathbf{x}$) include CPI, polity2; the economic variables ($\mathbf{E}$) are trade openness (Trade/GDP), outbound tourism which is a proxy for openness and exposure to the disease, and GDP per capita; and the vector of demographic variables ($\mathbf{D}$) include proportion of urban population in each country, and population density.

The results

From the descriptive statistics, which is presented in Table 1, the mean infection rate (infection in a million population) is 650 people with a standard deviation that is much higher than the mean, indicating a very wide range. Among those tested, on average, 10.2% were infected and of the infected people 4.2% died. The average temperature of the countries considered for the analysis is 25 °Celsius with a low standard deviation of 4.1. The mean CPI is 34.3 out of 100, which is quite low implying a high level of corruption, with standard deviation of 13. Moreover, the mean of the democracy variable, polity2 is also quite low (4.7). On average, approximately 7% of the population is over 60 years, and one-half of the population reside in urban areas.

As earlier indicated, two models were estimated using a simple ordinary least square regression (OLS) approach. We could not estimate a panel regression model because a higher frequency data (e.g., monthly data) on testing was not available, and data on the number of people infected and death due COVID-19 were only available on a limited number of countries. The two dependent variables are infection to test ratio and mortality to infection ratio. The independent variables include the average temperature for May 2020, population distribution, trade openness (Trade/GDP ratio), and institutional

[3] The list of countries is in Table A1 in Appendix A.

Table 1
Descriptive statistics of variables for the Ordinary Least Square (OLS) regression.

Variable	Mean	Std. Dev.
Infection per million (continuous)	650.6062	1615.238
Infection/Test (continuous)	0.1020	0.1161
Death/Infection (continuous)	0.0423	0.0508
Population Density (continuous)	286.6009	1097.89
Temperature (continuous)	25.1412	4.0824
Population Over 60 (%)	6.9608	3.5130
Corruption Perception Index (CPI) (cont.)	34.2941	13.2201
Polity2 (−10 to 10)	4.7451	4.4714
Trade/GDP	80.8673	59.6244
Tourism (outbound expenditures to imports ratio)	6.37195	3.85812
GDP per Capita	3795.241	11,169.87
Urban Population (%)	50.1569	21.0546

Table 2
Institutional quality and COVID-19 infection and mortality rates in tropical countries.

Variables	Ln (Infection/Test)	Ln (Death/Infection)	
		(1)	(2)
Ln (Temperature)	−65.29***	−24.28	−19.59
	(22.36)	(21.51)	(20.25)
Ln (Temperature)-*Squared*	10.72***	4.046	3.345
	(3.520)	(3.411)	(3.223)
Population Over 60 years (%)	0.273***	0.125**	
	(0.0757)	(0.0522)	
CPI (Corruption Perception Index)	−0.0218	−0.0641***	−0.0472***
	(0.0199)	(0.0166)	(0.0121)
Polity2	0.391***	−0.145*	−0.195**
	(0.105)	(0.0745)	(0.0942)
CPI#Polity2	−0.00677***	0.00424**	0.00478**
	(0.00237)	(0.00177)	(0.00230)
Trade/GDP	−0.00109	−0.00555**	−0.00535*
	(0.00249)	(0.00257)	(0.00271)
Ln (GDP per Capita)	0.00386	−0.112*	−0.112*
	(0.0863)	(0.0635)	(0.0662)
Ln (Urban/Total Population)	0.00923	0.212	0.176
	(0.181)	(0.152)	(0.170)
Tourism (Outbound to Imports Ratio)	0.0555		
	(0.0444)		
Ln (Population Density)	0.0478	−0.00218	−0.0232
	(0.209)	(0.110)	(0.112)
Continental Dummy (*Ref: Africa*)			
Americas (1/0)	−0.392		0.866**
	(0.507)		(0.421)
Asia (1/0)	−1.338**		0.556
	(0.523)		(0.651)
Constant	93.54**	32.48	25.38
	(34.11)	(33.24)	(30.90)
Observations	45	51	51
R-squared	0.645	0.440	0.447

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Corruption Perception Index (CPI) is measured from high level of corruption (0) to the lowest level (100) and Polity2 measures the level of democracy on the scale of −10 to 10. Infection and death are measured per million of the population, and tourism refers to outbound tourism expenditure as a ratio of total imports of the nation. Except the climate variable and the infection and mortality rate which are for 2020 and the Polity2 data which is 2018, data on all the other variables are for 2019.

quality variables (i.e., CPI and Polity2). The sample consisted of the all-tropical nations (83), but data limitations restricted the analysis to 45–51 countries. Other climate variables (precipitation and wind speed) were used but lack of data on some countries reduced the sample size to 36, which is quite low (see Appendix A3). The regression results are reported in Table 2. The test of goodness of fit (i.e., F-test) indicated that, for each of the two models, the line is a good fit at 1% significant level, with the adjusted R-squares also revealing that 43% to 56% of the variability of the dependent variables are explained.

The first model (i.e., Infection-to-Test ratio reported in the second column of Table 2) indicates a non-linear relationship between temperature and the proportion of people who tested positive for the COVID-19 among tropical countries. For temperatures between 15.5 °Celsius (i.e., the minimum among the countries considered) and approximately 21 °Celsius (estimated from our model), there is a negative relationship between temperature and the infection-to-test ratio. Thus, within this range, a decrease in temperature increases infections. Interestingly, warmer temperatures above 21° correlate positively with the infection-to-test ratio. Thus, within this range, a decrease in temperature decreases infections.[4] Like Ma et al. [20] and Prata et al. [23], this study found a non-linear relationship between the two variables. Moreover, except for the threshold value, this finding is consistent with Prata et al. [23]. On the other hand, it contrasts Falsey and Walsh, [10] who found that the transmission rate of human metapneumovirus (hMPV), a common respiratory virus that causes an upper respiratory infection, is higher under colder temperatures. As noted earlier, the climate variables precipitation and wind speed were included in the regression, but their coefficients were not statistically significant, although the overall results were less reliable due to the limited number of observations (see Appendix A3).

The non-linear relationship between temperature and infections is interesting. From a purely scientific point of view, there is evidence that the SARS-COV-2 virus has a lower probability of survival in the air, on surfaces, etc., at sufficiently high temperatures (e.g., [25]). This is expected to reduce transmission. On the other hand, at high temperatures (warmer temperatures), people are more likely to go out, interact, and engage in social activities. Furthermore, wearing a mask is more uncomfortable in warmer temperature. Thus, an increase in temperature could increase transmission. These two opposing effects of temperature on transmission could explain the non-linear relationship between temperature and transmission.

Secondly, countries with a higher proportion of older people (above 60 years) recorded higher infection-to-test ratios than their counterparts with fewer older people, all else equal. This stems from immune deficiency owing to malnutrition among the older population [10]. It is not surprising that the WHO recommends that COVID-19 vaccines are first administered to vulnerable groups including the elderly.

Furthermore, the marginal effect of the quality of democracy on the infection to test ratio depends on how corrupt a country is. Specifically, all else equal, for countries that scored beyond 57.75% on the corruption-free scale, the marginal effect of the quality of democracy on infection-to-test ratio was negative, whilst their counterparts who were relatively more corrupt (i.e., less than the 57.75% score) registered a positive marginal effect. This is likely due to a relatively more proactive, rather than reactive, testing in countries that are more democratic and less corrupt. Finally, outbound tourism and trade openness did not have any effect on the infection-to-test ratio in the countries of interest. This suggests that the current spread is largely community based and not imported. Moreover, the mandatory COVID-19 tests prior to arrival and tests at some airports may have dampened the effect of tourism. We controlled for regional differences and found that, compared to Africa and Asia, the tropical countries in the Americas had lower infection to test ratio within the period under consideration.

The two results of the second model (i.e., death/infection ratio) (denoted (**1**) and (**2**) in Table 2) are equally compelling. The regional dummy variable for the Americas and proportion of the population over 60 years are highly correlating, hence the two results are presented. From the results, firstly, when infected, the likelihood of mortality does not depend on differences in the temperature among tropical countries. Thus, the temperatures within the tropical region affect the chances of being infected but not the likelihood of morbidity if infected.[5]

Secondly, tropical countries with relatively high-quality democracies but with corruption levels higher than 34% registered lower mortality rates. On the other hand, when corruption levels are lower than the threshold, the mortality rates are higher among the infected population in countries with higher quality democracy. The plausible explanation is that less corrupt countries are more likely to gather reliable statistics on COVID-19 mortality and be more transparent than their counterparts that are more corrupt, all else equal.

Furthermore, tropical countries that are relatively more exposed to the international community through trade (i.e., trade openness) or are economically better-off (i.e., higher GDP per capita), registered lower mortality rates among the infected population. This is possibly due to access to information on treatment options and affordability of treatment.

Among those who tested positive to the virus in tropical countries, those who are more than 60 years were more likely to die (i.e., from result (1) of Table 2). The elasticity of mortality among those infected with respect to the proportion of the aged population is fairly-elastic with the coefficient of 5.6. This implies a percentage increase in the proportion of the aged population will increase the mortality among the infected population by nearly six-fold. On the other hand, compared to Africa and Asia, the mortality rate is higher among those infected in the Americas, where the mean proportion of the elderly (60 years and older) is highest (10.5%).

Conclusions

Despite the substantial and mounting human and economic costs of the novel coronavirus disease (COVID-19), to date, a few vaccines have been approved by the WHO and administered in all the regions of the world, yet many aspects of the disease remain uncertain and not fully understood. While the developed world, (with the Americas leading) has made great progress in vaccination, the world is still far from reaching the most needed areas, particularly those in the developing world, with Africa lagging behind. This calls for expedited research to fill the vast knowledge gaps; and several scholars

[4] Since temperature could theoretically affect economic performance (e.g., per capita GDP growth) and the dependent variable, it is a potential cofounder (Dell et al., 2008,2012; Nguyen et al. 2019). However, the data on temperature is an average temperature for 2020 and that of per capita GDP is for 2019, hence the endogeneity problem is not present in our empirical estimation. Moreover, the two variables are only weakly correlated (0.07).

[5] The other climate variables (precipitation and wind speed) also do not explain mortality among infected people as per the results presented at the Appendix (Table A3).

have heeded this call. Yet, most of the studies focus on specific variables, which could potentially bias the effect of those variables on the spread of the virus. This study contributes to the literature by building on Prata et al. [23].

Like Prata et al. [23], the effect of tropical temperature on the transmission of the virus has been explored. But, unlike Prata et al. [23], several tropical countries were considered and potential covariates such as institutional, social, economic, and demographic variables analyzed. Without improving our understanding of the role of these factors, public health responses may be erratic and impulsive, and therefore costly. Strikingly, this study also found a non-linear effect of temperature on infection. An attempt to use wet bulb temperature was made. However, the model did not perform well possibly due to the reliability of the data. We recommend that future studies on the topic consider this data limitation. Other climate variables (precipitation and wind speed) have been tested in the models but were found to have no influence on the infection to test ratio or the mortality rates. Furthermore, we have found that the quality of democracy coupled with corruption, demographic patterns, economic prosperity, and trade openness affect the disease transmission and/or mortality rate in tropical countries.

Funding for this research

This study only received support in the form of access to the services of a research assistant and library resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1
Countries used for the regression.

Angola	Cote d'Ivoire	Guatemala	Malawi	Paraguay
Bahamas	Cuba	Guinea	Malaysia	Peru
Barbados	Djibouti	Guinea-Bissau	Mali	Philippines
Benin	Dominican Republic	Guyana	Mauritania	Sao Tome and Principe
Bolivia	Ecuador	Haiti	Mauritius	Senegal
Brazil	El Salvador	Honduras	Mexico	Singapore
Brunei	Equatorial Guinea	India	Netherland	Suriname
Burundi	Ethiopia	Indonesia	Niger	Togo
Colombia	Gabon	Jamaica	Nigeria	Trinidad and Tobago
Costa Rica	Ghana	Kenya	Panama	Venezuela
				Zambia

Table A2
Variable description and source of data.

Variables	Description	Data Source
COVID-19 Infection	# of people infected by the virus as of December 2020.	Center for Systems Science and Engineering (CSSE) at Johns Hopkins University
COVID-19 Deaths	# of people killed by the virus as of December 2020.	Center for Systems Science and Engineering (CSSE) at Johns Hopkins University
COVID-19 Test	# of people tested for the virus as of December 2020.	Worldometer (http://www.worldometers.info/coronavirus/)
Temperature	Average annual temperature for 2020	Weather base (https://www.weatherbase.com/)
Precipitation	Average annual precipitation for 2020	ERA5
Wind speed	Average annual wind speed for 2020	ERA5
Population Over 60	Percentage of the population that are over 60 years of age	Global finance (https://www.gfmag.com/global-data/non-economic-data/world-population-distribution)
Corruption Perception Index	Measured from 0 (very corrupt) to 100 (no corruption) for 2019.	Transparency International
Polity2	Measured from −10 (total autocracy) to 10 (total democracy) for 2018	Sustainable Competitiveness Observatory (SCO)
Population Density	Population divided by geographical area	World development Indicators (WDI)
Trade/GDP	The sum of Export and Import as a ratio of Gross Domestic Product (GDP) for 2019	World development Indicators (WDI)
Tourism (International Outbound Expenditures)	International outbound tourism expenditures as a percentage of total imports for 2019.	World development Indicators (WDI)
GDP per Capita	GDP as a ratio of the nation's population for 2019	World development Indicators (WDI)
Urban Population	Proportion of the population in urban areas for 2019	World development Indicators (WDI)

Table A3
OLS Regression of the effect of climate variables On COVID-19 infection and mortality.

Variables	(1) Ln (Infection/Test)	(2) Ln (Death/Infection)
Ln (Temperature)	−65.71***	5.694
	(20.83)	(31.48)
Ln (Precipitation)	2.664	−1.439
	(1.671)	(1.350)
Temperature^2	11.12***	−1.028
	(3.465)	(5.101)
Precipitation^2	−0.267	0.183
	(0.200)	(0.174)
Ln (Wind speed)	−0.274	0.322
	(0.244)	(0.300)
CPI (Corruption Perception Index)	−0.0695***	−0.0413
	(0.0210)	(0.0262)
Polity2	0.242	−0.160
	(0.156)	(0.131)
CPI #Polity2	−0.00430	0.00240
	(0.00301)	(0.00302)
Trade/GDP	0.000488	−0.0108***
	(0.00273)	(0.00180)
Tourism Arrivals	0.000343	−0.0409
	(0.0572)	(0.0677)
Population Over 60 (%)	0.226**	0.162
	(0.0809)	(0.0974)
Ln (Population density)	−0.317**	−0.0794
	(0.130)	(0.138)
Constant	88.45**	−6.403
	(33.01)	(50.03)
# Observation	37	36
R-squared	0.580	0.610
F-Stat	5.74	106.85

Table A4
Institutional quality and COVID-19 infection and mortality rates in tropical countries.

Variables	Ln (Infection/Test)	Ln (Death/Infection)	
		(1)	(2)
Ln (Wet bulb Temperature)	−25.44	−10.89	−3.424
	(35.32)	(24.28)	(25.65)
Ln (Wet bulb Temperature)-*Squared*	4.701	1.936	0.663
	(6.082)	(4.221)	(4.465)
Population Over 60 years (%)	0.306***	0.0946*	
	(0.0893)	(0.0516)	
CPI (Corruption Perception Index)	−0.0130	−0.0550***	−0.0424***
	(0.0244)	(0.0172)	(0.0130)
Polity2	0.436***	−0.137*	−0.175*
	(0.122)	(0.0802)	(0.0968)
CPI#Polity2	−0.00827***	0.00398*	0.00446*
	(0.00300)	(0.00198)	(0.00245)
Trade/GDP	−0.00237	−0.00537**	−0.00523*
	(0.00301)	(0.00253)	(0.00264)
Ln (GDP per Capita)	−0.0256	−0.113*	−0.114*
	(0.0845)	(0.0607)	(0.0628)
Ln (Urban/Total Population)	−0.0650	0.193	0.143
	(0.193)	(0.144)	(0.173)
Tourism (Outbound to Imports Ratio)	0.0642		
	(0.0463)		
Ln (Population Density)	−0.247	−0.0703	−0.0883
	(0.238)	(0.122)	(0.126)
Continental Dummy (*Ref: Africa*)	−0.943		0.642*
Americas (1/0)	(0.602)		(0.379)
	−1.461**		0.576
Asia (1/0)	(0.630)		(0.725)
Constant	31.25	12.05	2.031
	(50.18)	(34.83)	(36.15)
Observations	45	51	51
R-squared	0.579	0.406	0.407

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Corruption Perception Index (CPI) is measured from high level of corruption (0) to the lowest level (100) and Polity2 measures the level of democracy on the scale of −10 to 10. Infection and death are measured per million of the population, and tourism refers to outbound tourism expenditure as a ratio of total imports of the nation. Except the climate variable and the infection and mortality rate which are for 2020 and the Polity2 data which is 2018, data on all the other variables are for 2019.

References

[1] Achoki, T., Alam, U., Were, L., Gebremedhin, T., Senkubuge, F., Lesego, A., Kinfu, Y. (2020). COVID-19 pandemic in the african continent: forecasts of cumulative cases, new infections, and mortality. MedRxiv.
[2] M. Ahmadi, A. Sharifi, S. Dorosti, S.J. Ghoushchi, N. Ghanbari, Investigation of effective climatology parameters on COVID-19 outbreak in Iran, Sci. Total Environ. (2020) 138705.
[3] E. Alirol, L. Getaz, B. Stoll, F. Chappuis, L. Loutan, Urbanisation and infectious diseases in a globalised world, Lancet Infect. Dis. 11 (2) (2011) 131–141.
[4] A.C. Auler, F.A.M. Cássaro, V.O. da Silva, L.F. Pires, Evidence that high temperatures and intermediate relative humidity might favor the spread of COVID-19 in tropical climate: a case study for the most affected Brazilian cities, Sci. Total Environ. (2020) 139090.
[5] P. Brenton, V. Chemutai, Trade Responses to the COVID-19 Crisis in Africa, World Bank, 2020.
[6] G. Cepaluni, M. Dorsch, R. Branyiczki, Political Regimes and Deaths in the Early Stages of the COVID-19 Pandemic, Available at SSRN (2020) 3586767.
[7] M. Dell, B.F. Jones, B.A. Olken, *Climate Change and Economic Growth: Evidence from the Last Half Century* (No. w14132), National Bureau of Economic Research, 2008.
[8] M. Dell, B.F. Jones, B.A. Olken, Temperature shocks and economic growth: evidence from the last half century, Am. Econ. J. 4 (3) (2012) 66–95.
[9] Diop, B.Z., Ngom, M., Biyong, C.P., & Biyong, J.N.P. (2020). Predicting Covid-19's spread in Africa: rural and relatively young population may limit the spread and severity. MedRxiv.
[10] A.R. Falsey, E.E. Walsh, Viral pneumonia in older adults, Clin. Infect. Dis. 42 (4) (2006) 518–524.
[11] M.R. Farzanegan, M. Feizi, H.F. Gholipour, Globalization and Outbreak of COVID-19: An Empirical Analysis, 2020 Joint Discussion Paper Series in Economics.
[12] Fernandes, N. (2020). Economic effects of coronavirus outbreak (COVID-19) on the world economy. Available at SSRN 3557504.
[13] C.B. Frey, C. Chen, G. Presidente, Democracy, culture, and contagion: political regimes and countries responsiveness to Covid-19, Covid Econ. 18 (2020) 222–238.
[14] G. Gavazzi, F. Herrmann, K.-H. Krause, Aging and infectious diseases in the developing world, Clin. Infect. Dis. 39 (1) (2004) 83–91.
[15] W.O. Kermack, A.G. McKendrick, A contribution to the mathematical theory of epidemics, Proc. R. Soc, Lond. Ser. A 115 (772) (1927) 700–721.
[16] W.O. Kermack, A.G. McKendrick, Contributions to the mathematical theory of epidemics. II.—The problem of endemicity, Proc. R. Soc, Lond. Ser. A 138 (834) (1932) 55–83.

[17] W.O. Kermack, A.G. McKendrick, Contributions to the mathematical theory of epidemics. III.—Further studies of the problem of endemicity, Proc. R. Soc, Lond. Ser. A 141 (843) (1933) 94–122.
[18] K. Liu, Y. Chen, R. Lin, K. Han, Clinical features of COVID-19 in elderly patients: a comparison with young and middle-aged patients, J. Infect. (2020).
[19] P. Lloyd-Sherlock, S. Ebrahim, L. Geffen, M. McKee, Bearing the brunt of covid-19: older people in low and middle income countries, Br. Medic. J. Publishing Group (2020).
[20] Y. Ma, Y. Zhao, J. Liu, X. He, B. Wang, S. Fu, B. Luo, Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China, Sci. Total Environ. 724 (2020) 138226.
[21] M. Maliszewska, A. Mattoo, D. Van Der Mensbrugghe, The Potential Impact of COVID-19 on GDP and Trade: A Preliminary Assessment, The World Bank, 2020.
[22] C.-J. Neiderud, How urbanization affects the epidemiology of emerging infectious diseases, Infect. Ecol. Epidemiol. 5 (1) (2015) 27060.
[23] D.N. Prata, W. Rodrigues, P.H. Bermejo, Temperature significantly changes COVID-19 transmission in (sub) tropical cities of Brazil, Sci. Total Environ. (2020) 138862.
[24] H. Qi, S. Xiao, R. Shi, M.P. Ward, Y. Chen, W. Tu, Z. Zhang, COVID-19 transmission in Mainland China is associated with temperature and humidity: a time-series analysis, Sci. Total Environ. (2020) 138778.
[25] S. Riddell, S. Goldie, A. Hill, D. Eagles, T.W. Drew, The effect of temperature on persistence of SARS-CoV-2 on common surfaces, Virol. J. 17 (2020) 2–7 October 2020.
[26] P. Ssentongo, A.E. Ssentongo, E.S. Heilbrunn, D.M. Ba, V.M. Chinchilli, Association of cardiovascular disease and 10 other pre-existing comorbidities with COVID-19 mortality: a systematic review and meta-analysis, PLoS One 15 (8) (2020) e0238215.
[27] Shi, P., Dong, Y., Yan, H., Li, X., Zhao, C., Liu, W., Xi, S. (2020). The impact of temperature and absolute humidity on the coronavirus disease 2019 (COVID-19) outbreak-evidence from China. MedRxiv.
[28] Squalli, J. (2020). Evaluating the determinants of COVID-19 mortality: a cross-country study. MedRxiv.
[29] Wang, M., Jiang, A., Gong, L., Luo, L., Guo, W., & Li, C. (n.d.). Temperature significantly change COVID-19 transmission in 429 cities. medRxiv. 2020.
[30] Y. Zhu, J. Xie, Association between ambient temperature and COVID-19 infection in 122 cities from China, Sci. Total Environ. (2020) 138201.
[31] J. Machhi, J. Herskovitz, A.M. Senan, D. Dutta, B. Nath, M.D Oleynikov, W.R. Blomberg, D.D Meigs, M. Hasan, M. Patel, P. Kline, The natural history, pathobiology, and clinical manifestations of SARS-CoV-2 infections, J. Neuroimmune Pharmacol 15 (3) (2020) 359–386.
[32] B.W. di Mauro, Macroeconomics of the flu, in: R. Baldwin, B.W. Di Mauro (Eds.), Economics in the Time of COVID-19, A VoxEU.org Book, 2020, pp. 31–55 https://voxeu.org/system/files/epublication/COVID-19.pdf accessed on July 3 2022.