Scandinavian Journal of Public Health, 2022; 50: 810–818

ORIGINAL ARTICLE

Correlation between country-level numbers of COVID-19 cases and mortalities, and country-level characteristics: A global study

GEORGE N. OKOLI[1,2], CHRISTINE J. NEILSON[3] & AHMED M. ABOU-SETTA[1,4]

[1]George and Fay Yee Centre for Healthcare Innovation, Max Rady College of Medicine, Rady Faculty of Health Sciences, University of Manitoba, Canada, [2]College of Pharmacy, Rady Faculty of Health Sciences, University of Manitoba, Canada, [3]Neil John Maclean Health Sciences Library, University of Manitoba, Canada, and [4]Community Health Sciences, Rady Faculty of Health Sciences, University of Manitoba, Canada

Abstract

Background: Not much is known about correlations between country-level characteristics and country-level numbers of COVID-19 cases and mortalities. *Methods:* Using data from the World Health Organization and other international organisations, we summarised country-level COVID-19 case and mortality counts per 100,000 population, and COVID-19 case fatality rate from January 2020 to August 2021. We conducted adjusted linear regression analysis to assess relationships between these counts/rate and certain country-level characteristics. We reported adjusted regression coefficients, β and associated 95% confidence intervals. *Results:* There was a positive correlation between the number of cases and country-level male/female ratio, and positive correlations between the numbers of cases and mortalities and country-level proportion of 60+-year-olds, universal health coverage index of service coverage (UHC) and tourism. Country economic status correlated negatively with the numbers of cases and mortalities. COVID-19 case fatality rate was highest in Peru, South American region (9.2%), and lowest in Singapore, Western Pacific region (0.1%). A negative correlation was observed between case fatality rate and country-level male/female ratio, population density and economic status. These observations remained mostly among mid-/low-income countries, particularly a positive correlation between the number of cases and male/female ratio and proportion of 60+-year-olds. ***Conclusions:*** **Various country-level characteristics such as male/female ratio, proportion of older adults, country economic status, UHC and tourism appear to be correlated with the country-level number of COVID-19 cases and/or mortalities. Consideration of these characteristics may be necessary when designing country-level COVID-19 epidemiological studies and in comparing COVID-19 data between countries.**

Keywords: *COVID-19, country characteristics, cases, mortality, global health*

Introduction

Many individuals with COVID-19 display few or no symptoms, but some have severe illnesses, with associated high fatality rates, particularly among population subgroups at higher risk of complications such as older adults and individuals with certain chronic diseases [1,2].

Studies have explored individual- and population-based risk factors that may be associated with severe COVID-19 [3,4] and associated mortality [5,6]. Individual factors, such as age, comorbidity, socio-economic status and ethnicity, and population-level factors, such as health-system capacity and prevalence of some chronic diseases, have been suggested as potential risk factors [7–9]. While many risk factors have been identified and the extent of their relationship with COVID-19 are being gradually understood, the risk of COVID-19 is still evolving and varies within and across populations, with some advanced health-care systems observed to be

Correspondence: George N. Okoli, George and Fay Yee Centre for Healthcare Innovation, Max Rady College of Medicine, Rady Faculty of Health Sciences, University of Manitoba, 753 McDermot Avenue, Winnipeg, MB R3E 0T6, Canada. E-mail: George.Okoli@umanitoba.ca

Date received 14 May 2021; reviewed 29 March 2022; accepted 18 April 2022

DOI: 10.1177/14034948221098925
journals.sagepub.com/home/sjp
SAGE

overwhelmed by the disease [10]. Likewise, COVID-19-associated mortalities appear to be higher in some populations than others, even within regions with comparable health-care systems and demographics [11].

Despite increased understanding of COVID-19 individual- and population-level risk factors, not much has been done to investigate country-level characteristics that may be associated with COVID-19 case, mortality and case fatality rates. At the early stage of the pandemic, a cross-sectional study using publicly available data explored health-system factors associated with COVID-19 infection and mortality in Africa [12]. The authors suggested that response to the pandemic may be improved by identifying and addressing specific gaps in the funding of health-service delivery. About the same time, a country-level analysis measuring the impact of government actions, country preparedness and socio-economic factors on COVID-19 mortality concluded that low levels of national preparedness, scale of testing and population characteristics were associated with increased national case load and overall mortality [13].

Understanding the relationship between country-level characteristics and country-level COVID-19 infection and mortality could aid analysis and comparison of data from different countries and the development of more effective national public-health mitigation measures against the disease. In addition, the knowledge could be useful when dealing with future pandemics.

The objectives of this study were to summarise country-level COVID-19 case and mortality counts, determine case fatality rates and assess the correlation between these statistics and certain country-level characteristics.

Methods

We conducted a global study utilising publicly available country-level COVID-19, World Health Organization (WHO) data and other publicly available country-level data from the United Nations, the United States Central Intelligence Agency (CIA) and the World Bank. The data are all at the population level and are publicly available. The study period was from January 2020 to August 2021.

Data sources and covariates development

Cumulative country-level numbers of COVID-19 cases and mortalities per 100,000 population reported by the WHO member states (henceforth, countries) from January 2020 to August 2021 were obtained from the WHO COVID-19 Weekly Epidemiological Update dashboard – an online database that tracks confirmed COVID-19 cases and mortalities reported by countries from whenever each country started testing, documenting and reporting these statistics [14]. Counts primarily reflect laboratory-confirmed cases and mortalities based upon the WHO case definitions [14], although this may differ due to local adaptations. Case counts include both domestic and repatriated cases, with testing strategies and case detection, reporting practice and time to notifications and reporting of mortalities differing between countries. We extracted the data on 1 September 2021 and derived case fatality rate using cases and mortalities per 100,000 population (ratio of the number of mortalities to the number of cases multiplied by 100%).

We obtained country population count, population density (the number of people per unit area (km^2)) and age (proportions of 60+-year-olds and ⩽14-year-olds) and sex (ratio of males to females) structures for 2019 from the United Nations Statistics online database [15]. Population density was log transformed for a more normal distribution and to limit outliers. We utilised a modified version of the WHO country region classification by reclassifying some African countries grouped under the Eastern Mediterranean region (Egypt, Tunisia, Sudan) to the Africa region and, separating countries grouped under Europe into Eastern European countries and countries of the European Economic Area, and countries grouped under the Americas into South and North America. This reclassification was necessary for a better comparison between the grouped countries. We gathered information regarding each country's influenza pandemic preparedness plan (having versus not having a plan before 2020) [16], and data on cumulative numbers of probable or confirmed cases of Middle East respiratory syndrome (MERS) [17] and severe acute respiratory syndrome (SARS) [18] from the Emergencies, Preparedness and Response database of the WHO.

Data on country system of government were obtained from the CIA World Factbook [19] and were dichotomised into democratic governance and totalitarianism (communist, military, authoritarian, theocratic or absolute monarchy governance). We obtained each country's economic status (high, mid or low income) and the number of arrivals of international tourists in 2019 from the World Bank [20]. The World Bank defines these data on tourism to be 'the number of international inbound tourists (overnight visitors) who travel to a country other than their usual residence and outside their usual environment, for a period not exceeding 12 months, and whose main purpose in visiting is not for an activity remunerated from within the country visited' [20]. Using the tourism count, we derived tourism index (as a proxy for extent of tourism to a country) by dividing the number of tourists by country population. This index was then log transformed to obtain a more normally distributed tourism variable. Data on universal health coverage index of service coverage (UHC) for countries (based on a non-unit scale of 0 to 100, with higher being higher UHC) were obtained from the WHO UHC database, defined as 'the average coverage of essential services based on tracer interventions that include reproductive, maternal, and newborn and child health, infectious diseases, non-communicable diseases and service capacity and access, among the general and the most disadvantaged population' [21].

Outcomes

The primary outcomes were the numbers of COVID-19 cases and mortalities (deaths) per 100,000 population. The secondary outcome was the case fatality rate. These outcomes were all log transformed to obtain more normally distributed numbers and to limit outliers.

Model selection and data analysis

We synthesised country-level characteristics in a tabular form and presented the numbers of cases and mortalities as forest plots according to the modified WHO regions. Further, we presented case fatality rates as bar charts, also grouped according to the modified WHO regions. Binary variables were treated like dummy variables in the models (responses 0 or 1). We utilised the Akaike information criterion for multivariable linear regression model selection [22]. We assessed for non-linearity of models using the residual plot of fitted values versus residual values [23]. We assessed for heteroscedasticity graphically by checking for a funnel shape or a curve in the residual plot. We assessed for multicollinearity using the variance inflation factor (VIF), which is the ratio of variance of a predictor variable estimated coefficient in the full linear regression model to the variance of its estimated coefficient when fit on the outcome just by itself [24]. We utilised a VIF value >5 as an indicator of multicollinearity and discarded the predictor with such a VIF value. For our selected model, we included country-level characteristics: male/female ratio, proportion of 60+-year-olds, population density, UHC, tourism, pandemic preparedness plan, government, economic status and region. In addition to these country-level characteristics being readily available and publicly accessible, and therefore ideal for this study, we determined their relevance from reports of epidemiological and modelling studies on relationships between risk of COVID-19 infection and/or COVID-19 mortality, and sex and age [25], and population size [26], UHC and government [27], tourism [28] and pandemic preparedness and economic status [13]. We assessed these variables for effect modification. We calculated the crude regression coefficients (β) and the associated 95% confidence intervals (CIs) for the correlation between each of the variables and each of the outcomes. Using a multivariable linear regression model including all the variables, we calculated the adjusted regression coefficients (β) and the associated 95% CIs for the correlation between the variables and each of the outcomes. Having identified country economic status as a potential effect modifier, we conducted sensitivity analysis, repeating each multivariable analysis separately for high-, mid- or low-income countries. We implemented all statistical analyses in STATA v6 (StataCorp LP, College Station, TX).

Results

We included 130 countries in the analyses. The mean numbers of COVID-19 cases and mortalities per 100,000 population were 5148 (95% CI 4405–5891) and 94 (95% CI 78–110). The mean COVID-19 case fatality rate was 2 (95% CI 1.8–2.2). The assessed country-level characteristics are summarised in Table I.

Country-level numbers of COVID-19 cases and mortalities per 100,000 population by region

The numbers of COVID-19 cases and mortalities per 100,000 population varied across and within regions, with the highest point number of cases (18,371 per 100,000) recorded in the Eastern European region and the lowest (66 per 100,000) in the African region, and the highest point number of mortalities (601 per 100,000) recorded in the South American region and the lowest (1 per 100,000) in the African as well as the Eastern European and Western Pacific regions. In the African region, the lowest point number of cases (66 per 100,000) was recorded in Burkina Faso and the highest in Cabo Verde (6346 per 100,000), while the lowest point number of mortalities (1 per 100,000) was recorded in Burkina Faso and Benin, and the highest (198 per 100,000) recorded in Tunisia (Appendix 1). In the regions within European, the lowest point number of cases (181 per 100,000) was recorded in Tajikistan and the highest in Montenegro (18,371 per 100,000), both in the Eastern European region, while the lowest point number of mortalities (1 per 100,000) was also recorded in Tajikistan and the highest (308 per

Table I. Number (percentage) of the included countries across levels of the assessed country-level characteristics (*N*=130 countries).

Country characteristics	***n* (%)**
Number of COVID-19 cases per 100,000 population	
Less than the mean	70 (53.8)
More than the mean	60 (46.2)
Number of COVID-19 mortalities per 100,000 population	
Less than the mean	77 (59.2)
More than the mean	53 (40.8)
Case fatality rate	
Less than the mean	77 (59.2)
More than the mean	53 (40.8)
Male/female ratio	
Less than the mean	109 (83.4)
More than the mean	21 (16.6)
Proportion of 60+-year-olds	
Less than the mean	72 (55.4)
More than the mean	58 (44.6)
Population density	
Less than the mean	103 (79.2)
More than the mean	27 (20.8)
Universal health-care coverage	
Less than the mean	52 (40)
More than the mean	78 (60)
Tourism	
Less than the mean	94 (72.3)
More than the mean	36 (27.7)
Pandemic preparedness plan	
No	55 (42.3)
Yes	75 (57.7)
Government	
Democratic	115 (88.5)
Totalitarian	15 (11.5)
Region	
African Region	27 (20.8)
Eastern European Region	16 (12.3)
Eastern Mediterranean Region	10 (7.7)
European Economic Area	31 (23.8)
North America	3 (2.3)
South America	25 (19.2)
South-East Asia Region	7 (5.4)
Western Pacific Region	11 (8.5)
Country economic status	
Mid or low income	77 (59.2)
High income	53 (40.8)

100,000) recorded in Hungary (Appendix 2). In the regions within the Americas, the lowest point number of cases (140 per 100,000) was recorded in Nicaragua and the highest (11,759 per 100,000) in the USA, while the lowest point number of mortalities (3 per 100,000) was also recorded in Nicaragua and the highest (601 per 100,000) recorded in Peru, both in the South American region (Appendix 3). In the smaller regions (Western Pacific, South-East Asia and Eastern Mediterranean), overall, the lowest point number of cases (68 per 100,000) was recorded in New Zealand and the highest (16,017 per 100,000) recorded in Bahrain, while the lowest point number of mortalities (1 per 100,000) was recorded in New Zealand as well as in Singapore, and the highest (128 per 100,000) was recorded in Iran (Appendix 4).

Adjusted linear regression of country-level number of COVID-19 cases per 100,000 population against various country-level characteristics

There was a positive correlation between country-level number of COVID-19 cases and country-level male/female ratio (β=3.0; 95% CI 1.4–4.6), proportion of 60+-year-olds (β=1.1; 95% CI 0.5–1.7), UHC (β=2.0; 95% CI 0.5–3.4) and tourism (β=0.3; 95% CI 0.1–0.4; Table II). A negative correlation was observed between country-level number of COVID-19 cases and country-level economic status (β=−0.9; 95% CI −1.4 to −0.4; Table II). When analysed by country economic status, the observed correlations remained only among mid-/low-income countries but not among high-income countries; however, among high-income countries, a positive correlation was observed between the country-level number of COVID-19 cases and pandemic preparedness plan (β=1.0; 95% CI 0.1–2.0; Table II). There was no linear relationship/correlation observed for other assessed country-level characteristics.

Adjusted linear regression of country-level number of COVID-19 mortalities per 100,000 population against various country-level characteristics

There was a positive correlation between country-level number of COVID-19 mortalities and country-level proportion of 60+-year-olds (β=1.2; 95% CI 0.4–1.9), UHC (β=2.0; 95% CI 0.2–3.8) and tourism (β=0.2; 95% CI 0.0–0.4; Table II). A negative correlation was observed between country-level number of COVID-19 mortalities and economic status (β=−1.2; 95% CI −1.9 to −0.6; Table II). When analysed by country economic status, the observed correlation for proportion of 60+-year-olds remained only among mid-/low-income countries. In addition to these observed correlations, a positive correlation was also observed between country-level number of COVID-19 mortalities and country-level UHC (β=2.5; 95% CI 0.8–4.2) among the mid-/low-income countries and between country-level number of COVID-19 mortalities and country-level pandemic preparedness plan (β=1.5; 95% CI 0.1–2.8) among the high-income countries (Table II). There was no linear relationship/correlation observed for other assessed country-level characteristics.

Country-level COVID-19 case fatality rate

Country-level case fatality rate varied across regions, with similarities within some of the regions (Appendix

Table II. Linear regression of country-level numbers of COVID-19 cases and mortalities per 100,000 population and case fatality rates against various country-level characteristics.

Country characteristics	Overall (*N*=130 countries)		High income (*N*=53 countries)	Mid/low income (*N*=77 countries)
	Crude β (95% CI)	Adjusted β (95% CI)	Adjusted β (95% CI)	Adjusted β (95% CI)
Number of COVID-19 cases per 100,000 population				
Male/female ratio	0.8 (–0.7 to 2.4)	**3.0 (1.4–4.6)**	–0.3 (–2.9 to 2.3)	**3.2 (0.1–6.3)**
Proportion of 60+-year olds	**1.3 (0.9–1.6)**	**1.1 (0.5–1.7)**	–1.1 (–2.5 to 0.4)	**1.2 (0.6–1.8)**
Population density	0.1 (–0.1 to 0.3)	0.0 (–0.1 to 0.1)	0.1 (–0.0 to 0.3)	–0.0 (–0.2 to 0.2)
Universal health-care coverage	**4.3 (3.4–5.1)**	**2.0 (0.5–3.4)**	1 (–3.1 to 5.1)	**2.2 (0.7–3.6)**
Tourism	**0.6 (0.4–0.7)**	**0.3 (0.1–0.4)**	0.1 (–0.1 to 0.4)	**0.2 (0.1–0.4)**
Pandemic preparedness plan	**0.8 (0.3–1.3)**	–0.0 (–0.5 to 0.4)	**1 (0.1–2)**	–0.5 (–1 to 0.1)
Government	0.2 (–0.6 to 1)	–0.1 (–0.8 to 0.5)	–1.6 (–3.5 to 0.3)	–0.3 (–0.9 to 0.4)
Economic status	**1.1 (0.6–1.6)**	**–0.9 (–1.4 to −0.4)**	–	–
Number of COVID-19 mortalities per 100,000 population				
Male/female ratio	–1 (–2.7 to 0.6)	1.7 (–0.3 to 3.8)	–1.8 (–5.6 to 2)	0.7 (–3 to 4.4)
Proportion of 60+-year-olds	**1.3 (0.9 to 1.6)**	**1.2 (0.4–1.9)**	–1.1 (–3.2 to 1)	**1.2 (0.5–1.9)**
Population density	–0.0 (–0.3 to 0.2)	–0.1 (–0.3 to 0.7)	0.1 (–0.2 to 0.3)	–0.1 (–0.4 to 0.1)
Universal health-care coverage	**3.7 (2.6–4.7)**	**2.0 (0.2–3.8)**	–1.7 (–7.7 to 4.4)	**2.5 (0.8–4.2)**
Tourism	**0.4 (0.3–0.6)**	**0.2 (0.01–0.4)**	–0.0 (–0.4 to 0.4)	0.2 (–0.1 to 0.4)
Pandemic preparedness plan	**0.8 (0.3–1.4)**	0.2 (–0.4 to 0.8)	**1.5 (0.1–2.8)**	–0.3 (–0.9 to 0.4)
Government	–0.4 (–1.2 to 0.5)	–0.3 (–1.2 to 0.6)	–1.8 (–4.6 to 1)	–0.6 (–1.4 to 0.2)
Economic status	0.6 (0.0–1.1)	**–1.2 (–1.9 to −0.6)**	–	–
COVID-19 case fatality rates (%)				
Male/female ratio	**–1.9 (–2.6 to −1.2)**	**–1.2 (–2.2 to −0.2)**	–1.6 (–3.5 to 0.4)	**–2.4 (–4.5 to −0.4)**
Proportion of 60+-year-olds	0.0 (–0.2 to 0.2)	0.1 (–0.3 to 0.4)	–0.1 (–1.2 to 1)	0.0 (–0.4 to 0.4)
Population density	**–0.2 (–0.3 to −0.1)**	**–0.1 (–0.2 to −0.0)**	–0.1 (–0.2 to 0.1)	–0.1 (–0.2 to 0.0)
Universal health-care coverage	**–0.6 (–1.2 to −0.0)**	0.0 (–0.9 to 0.9)	–2.7 (–5.8 to 0.4)	0.3 (–0.7 to 1.2)
Tourism	**–0.1 (–0.2 to −0.1)**	–0.1 (–0.2 to 0.0)	–0.1 (–0.3 to 0.1)	–0.1 (–0.2 to 0.0)
Pandemic preparedness plan	–0.0 (–0.3 to 0.2)	0.2 (–0.1 to 0.5)	0.4 (–0.3 to 1.1)	0.2 (–0.2 to 0.5)
Government	**–0.6 (–1 to −0.2)**	–0.1 (–0.6 to 0.3)	–0.2 (–1.6 to 1.3)	–0.3 (–0.8 to 0.1)
Economic status	**–0.5 (–0.7 to −0.3)**	**–0.4 (–0.7 to −0.0)**	–	–

Statistically significant results are shown in bold.

β: regression coefficient; CI: confidence interval.

5). The highest case fatality rate was recorded in the South American region (9.2%) and the lowest in the Western Pacific region (0.1%). We observed a negative correlation between country-level COVID-19 case fatality rate and country-level male/female ratio (β=−1.2; 95% CI −2.2 to −0.3), population density (β=−0.1; 95% CI −0.2 to −0.0) and economic status (β=−0.4; 95% CI −0.7 to −0.0; Table II). When analysed by country economic status, the observed correlation for country-level male/female ratio only remained among mid-/low-income countries, but none of the correlations were observed among the high-income countries (Table II). There was no linear relationship/correlation observed for other assessed country-level characteristics.

Discussion

We summarised country-level numbers of COVID-19 cases and mortalities per 100,000 population from January 2020 to August 2021 and assessed the relationship between these numbers and some country-level characteristics. We calculated country-level COVID-19 case fatality rate and assessed the relationship between the rate and the country-level characteristics.

Our findings suggest that the country-level number of COVID-19 cases increases with increasing country-level male/female ratio, proportion of 60+-year-olds, UHC and tourism and decreases with higher country economic status. Our findings also suggest that the country-level number of COVID-19 mortalities increases with increasing country-level proportion of 60+-year-olds and tourism and decreases with higher country economic status. Further, it was suggestive that the country-level COVID-19 case fatality rate decreases with increasing country-level male/female ratio, population density and economic status. These findings appeared to be modified by country-level economic status and largely remained only among mid-/low-income countries, especially for country-level number of COVID-19 cases. In addition, a higher country-level number of COVID-19 cases was observed among only high-income countries that have a pandemic preparedness plan, suggestively due to the effect of higher testing capacities and priorities of the more affluent countries who also mostly have a pandemic preparedness plan.

Our findings should be interpreted with caution considering that the country-level numbers of COVID-19 cases and mortalities and the associated case fatality rates were all crude estimates not standardised by country-level population age structure. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) responsible for COVID-19 could infect the young and the old at a similar rate, but still manifest and cause more severe morbidity and mortality among older adults [25]. A higher mortality rate among older adults is therefore an important reason to standardise for age. There were possible inconsistencies in the definitions of COVID-19 cases and mortality and in data-collection processes within and across countries. For example, it is not clear exactly how each country defines COVID-19 cases and mortalities, and while case and mortality counts primarily reflect laboratory-confirmed COVID-19 cases and mortalities based upon the WHO case definitions, some departures likely existed within and across countries due to local adaptations. Moreover, laboratory tests are likely to differ, and therefore diagnostic test accuracy may differ as well. Inclusion of individuals with respiratory symptoms but not laboratory confirmed for COVID-19 would mean false counting and over-counting of cases, wrongly classified mortality and potentially a false lower case fatality rate. While case counts included both domestic and repatriated cases, reporting practices and time to case notification and reporting of deaths likely differ between countries. It is also not clear when each country started collating and reporting data to the WHO and the inconsistencies in data collection that may have evolved over time. Further, there were no data on the proportions of COVID-19 cases and mortalities that had a chronic disease and the level of severity. This is important considering that certain chronic diseases (particularly immunodeficiency or immunosuppressive diseases and medications for treatment) may increase susceptibility to infection because of a weakened immune system and may increase the risk of mortality from COVID-19 [29]. In addition, our study period included periods when COVID-19 vaccination became available, with proportions of the vaccinated likely differing between countries. Vaccination is also likely to influence cases and mortalities during this period, with potentially reduced numbers of cases and mortalities likely to be observed in populations with high vaccination rates compared with those with low vaccination rates. These and many other potentially relevant issues may likely have impacted the case and mortality counts for our study, with likely under- or overestimation of the true case and mortality counts and case fatality rates, depending on the issue type. We could not determine any of these with certainty.

Nevertheless, the positive correlations observed between country-level number of COVID-19 cases and country-level male/female ratio and proportion of 60+-year-olds and the positive correlation between country-level number of COVID-19 mortalities and country-level proportion of 60+-year-olds reflect the findings from prior studies which suggested that being male and an older adult were risk factors for COVID-19 infection, severity and death [30]. While sex and age biases have been observed with COVID-19 severity in many populations since the onset of the pandemic, not much is known regarding the observed positive correlation between country-level number of COVID-19 cases and country-level male/female ratio and proportion of 60+-year-olds, in particular as observed among only mid-/low-income countries. Intersectional analysis may be needed to understand these observations, although it is likely that socio-economic differences may play a role. It may also be that males are more complacent compared with females with regards to the reality, transmissibility and severity of COVID-19 in mid-/low-income countries, and high prevalence of chronic diseases, poor nutrition and less optimal public-health mitigation strategies may explain the observed correlation with proportion of 60+-year-olds among the mid-/low-income countries. Further, the positive correlations observed between country-level number of COVID-19 cases and tourism and between country-level number of COVID-19 mortalities and tourism may reflect the role of trans-border travelling in spreading the infection, particularly with respect to asymptomatic infected persons unknowingly transporting the disease from one country to another. This may have negated initial public health measures to reduce transmission within countries and increased local infections and strain on health systems irrespective of how advanced a health system may be. It is therefore suggestive that perhaps high touristic countries would have better controlled trans-border infection transmissions had they acted quicker than they did to enact pandemic preparedness plans and border controls. This is especially necessary during epidemics of highly infectious diseases such as COVID-19 and has a higher chance of limiting the spread of infection [31,32]. That said, it is also important to balance the need for border control with the need for keeping the flow of international trade/commerce, and perhaps just a more stringent earlier introduction of screening of international passengers might have been helpful [32]. The positive correlation observed between country-level number of COVID-19 cases and country-level UHC may be explained by the fact that countries with higher UHC (the advanced health systems) are also the ones that have the capacity to screen, test, track and document cases of infections more accurately, and therefore are more likely to report cases and mortalities than countries with lower UHC. It could also be interpreted as confirmation of the impact of differences in COVID-19 testing regimes across countries. Further, the observed negative correlation between country-level case fatality rate and country-level population density was a surprise finding and may suggest that the relationship between population density and COVID-19 infection or mortality may be influenced by other factors, including country economic status, infection control strategies and policies, and health-system capacity [26]. While studies have shown that increased COVID-19 infection transmission is more likely within cities with higher population densities [33–35], evidence is still accumulating regarding the relationship between COVID-19 mortality and population density. This knowledge would aid more understanding of our finding.

Pana et al. explored country-level determinants of country-level mean COVID-19 mortality rates using data from 37 countries during the early stage of the pandemic. They found that international travel was directly associated with COVID-19 mortality slope, and they concluded that very early restrictions on international travel should have been considered to prevent COVID-19-related deaths [36]. Goodyear-Smit et al. explored the relationship between the perceived strength of countries' primary-care system and COVID-19 mortality in an online survey of a convenience sample of primary health-care experts and, similar to our findings, concluded that countries having a pandemic preparedness plan and a strong health system did not necessarily experience lower COVID-19 mortality rates [37]. Similarly, the authors suggested that the important immediate responses should have included limiting COVID-19 entry across borders, as doing so would limit imported infections, alleviate the burden on hospitals and minimise deaths. These findings are in line with our findings regarding the correlation between the number of country-level COVID-19 cases and country-level tourism and UHC and between the number of country-level COVID-19 mortalities and country-level tourism and UHC, and support the notion of a likely positive effect that early border controls would have made to the speed of the infection. At the early stage of the pandemic, Okeahalam et al. examined factors associated with COVID-19 infections and mortality in Africa using publicly available data [12]. Just as we found, they reported a positive association between country-level UHC and the risk of COVID-19 deaths. Furthermore, Petti and Cowling explored the ecological association between influenza and COVID-19 mortality rates in European countries and concluded that common significant determinants of both COVID-19 and influenza mortality rates included life expectancy, influenza vaccination in the elderly, number of hospital beds per population unit and crude cardiovascular disease mortality rate [7]. However, the study did not examine any of the country-level characteristics that we assessed.

Our study has limitations, including inherent limitations of administrative health databases [38] and the weaknesses that may be unique to the WHO COVID-19 database. First, the database does not capture information on laboratory tests used in confirming COVID-19 cases and how cases were defined by countries, including any changes that may have been made to case definition during the study period. This information would have supported sensitivity analyses, particularly with regards to confirmatory test type in countries. Second, it was not clear how countries reported COVID-19 cases and mortalities to the WHO and whether the COVID-19 database is updated retrospectively with previously unreported mortality counts. As such, the case and mortality counts utilised in this study may be under- or over-reported, but we cannot say with certainty, although these counts are most likely under-reported, especially for countries whose health systems are still evolving. In addition, data validity may be compromised by systematic or personnel errors, considering that the WHO COVID-19 database has not been validated, and therefore the completeness and quality of the data are not yet established. Cases and mortalities were not reported for some countries, and it was not clear whether those countries have the capacity to test their population and track COVID-19-associated mortalities. Furthermore, the relationships that we assessed only considered the covariates included in the models, and as such, there are likely residual confounding due to unmeasured confounders such as effects of policies, knowledge, attitudes and practices, social and physical determinants of health, including housing and the natural environment, and barriers to accessing health services. In addition, a paucity of the data meant that we could not explore potential relationships within geographical regions, despite the distributions of the country-level characteristics suggesting that the relationships we found may differ across the regions.

Nevertheless, our study has some merits, including utilisation of data from known global authorities and international organisations, and data standardisation by using the same year WHO country-level population estimates and the World Bank tourism counts for each country. We also employed an appropriate and clear methodological framework in the conduct and reporting of this study.

Conclusions

Various country-level characteristics such as male/female ratio, proportion of older adults, country economic status, UHC and tourism appear to be correlated with country-level number of COVID-19 cases and/or mortalities. Consideration of these characteristics may be necessary when designing country-level COVID-19 studies and when comparing COVID-19 data between countries. This study forms the basis for further evaluations of the relationships between country-level characteristics and country-level numbers of COVID-19 cases and mortalities. With COVID-19 vaccines now available, future studies should assess the relationship between vaccination coverage and country-level numbers of COVID-19 cases and mortalities.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

ORCID iD

George N. Okoli https://orcid.org/0000-0002-6437-930X

Supplemental material

Supplemental material for this article is available online.

References

[1] Clark A, Jit M, Warren-Gash C, et al. Global, regional, and national estimates of the population at increased risk of severe COVID-19 due to underlying health conditions in 2020: A modelling study. *Lancet Glob Health* 2020;8:E1003–17.
[2] Onder G, Rezza G and Brusaferro S. Case-Fatality Rate and Characteristics of Patients Dying in Relation to COVID-19 in Italy. *JAMA* 2020;323:1775–6.
[3] Islam MZ, Riaz BK, Islam A, et al. Risk factors associated with morbidity and mortality outcomes of COVID-19 patients on the 28th day of the disease course: a retrospective cohort study in Bangladesh. *Epidemiol Infect* 2020;148:e263.
[4] Liu T, Liang W, Zhong H, et al. Risk factors associated with COVID-19 infection: a retrospective cohort study based on contacts tracing. *Emerg Microbes Infect* 2020;9:1546–53.
[5] Jin J, Agarwala N, Kundu P, et al. Individual and community-level risk for COVID-19 mortality in the United States. *Nat Med* 2021;27:264–9.
[6] Rosenthal N, Cao Z, Gundrum J, et al. Risk factors associated with in-hospital mortality in a US national sample of patients with COVID-19. *JAMA Netw Open* 2020;3:e2029058.
[7] Petti S and Cowling BJ. Ecologic association between influenza and COVID-19 mortality rates in European countries. *Epidemiol Infect* 2020;148:e209.
[8] Varkey RS, Joy J, Sarmah G, et al. Socioeconomic determinants of COVID-19 in Asian countries: an empirical analysis. *J Public Aff*. Epub ahead of print 23 October 2020. DOI: 10.1002/pa.2532.
[9] Abrams EM and Szefler SJ. COVID-19 and the impact of social determinants of health. *Lancet Respir Med* 2020;8:659–61.
[10] Haldane V, De Foo C, Abdalla SM, et al. Health systems resilience in managing the COVID-19 pandemic: lessons from 28 countries. *Nat Med* 2021;27:964–80.
[11] Bilinski A and Emanuel EJ. COVID-19 and excess all-cause mortality in the US and 18 comparison countries. *JAMA* 2020;324:2100–2.
[12] Okeahalam C, Williams V and Otwombe K. Factors associated with COVID-19 infections and mortality in Africa: a cross-sectional study using publicly available data. *BMJ Open* 2020;10:e042750.
[13] Chaudhry R, Dranitsaris G, Mubashir T, et al. A country level analysis measuring the impact of government actions, country preparedness and socioeconomic factors on COVID-19 mortality and related health outcomes. *EClinicalMedicine* 2020;25:100464.
[14] World Health Organization. *WHO COVID-19 dashboard*. Geneva: World Health Organization.
[15] United Nations Statistics Division. Popular statistical tables, country (area) and regional profiles: population, surface area and density, https://data.un.org/default.aspx (accessed 4 August 2021).
[16] World Health Organization. National Plans for Pandemic Preparedness and Risk Management. *WHO Strategic Partnership for International Health Regulations (2005) and Health Security (SPH)*. Geneva: World Health Organization.
[17] World Health Organization. *Middle East respiratory syndrome coronavirus (MERS-CoV)*. *Health Topics*. Geneva: World Health Organization.
[18] World Health Organization. *Cumulative number of reported probable cases of SARS. Emergencies preparedness, response*. Geneva: World Health Organization.
[19] Central Intelligence Agency. *The world fact nook*. Washington, DC: Central Intelligence Agency.
[20] World Bank. *International tourism, number of arrivals (World Tourism Organization, Yearbook of Tourism Statistics, Compendium of Tourism Statistics and data files)*. *World Bank Open Data*. Washington, DC: World Bank.
[21] World Health Organization. *Index of service coverage Global Health Observatory data repository*. Geneva: World Health Organization.
[22] Portet S. A primer on model selection using the Akaike information criterion. *Infect Dis Model* 2020;5:111–28.
[23] Feng C, Li LH and Sadeghpour A. A comparison of residual diagnosis tools for diagnosing regression models for count data. *BMC Med Res Methodol* 2020;20.
[24] Shrestha N. Detecting multicollinearity in regression analysis. *Am J Appl Math Stat* 2020;8:39–42.
[25] Yanez ND, Weiss NS, Romand JA, et al. COVID-19 mortality risk for older men and women. *BMC Public Health* 2020;20.

[26] Martins PR. Relationship between population density and COVID-19 incidence and mortality estimates: a county-level analysis. *J Infect Public Health* 2021;14:1087–8.

[27] Duong DB, King AJ, Grepin KA, et al. Strengthening national capacities for pandemic preparedness: a cross-country analysis of COVID-19 cases and deaths. *Health Policy Plan* 2022;37:55–64.

[28] Russell TW, Wu JT, Clifford S, et al. Effect of internationally imported cases on internal spread of COVID-19: a mathematical modelling study. *Lancet Public Health* 2021;6:e12–e20.

[29] Semenzato L, Botton J, Drouin J, et al. Chronic diseases, health conditions and risk of COVID-19-related hospitalization and in-hospital mortality during the first wave of the epidemic in France: a cohort study of 66 million people. *Lancet Reg Health Eur* 2021;8:100158.

[30] Wingert A, Pillay J, Gates M, et al. Risk factors for severity of COVID-19: a rapid review to inform vaccine prioritisation in Canada. *BMJ Open* 2021;11:e044684.

[31] Chinazzi M, Davis JT, Ajelli M, et al. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science* 2020;368:395–400.

[32] Burns J, Movsisyan A, Stratil JM, et al. Travel-related control measures to contain the COVID-19 pandemic: a rapid review. *Cochrane Database Syst Rev* 2020;10:CD013717.

[33] Chen D, Hu CC, Su FF, et al. Exposure to SARS-CoV-2 in a high transmission setting increases the risk of severe COVID-19 compared with exposure to a low transmission setting? *J Travel Med* 2020;27.

[34] Ilardi A, Chieffi S, Iavarone A, et al. SARS-CoV-2 in Italy: population density correlates with morbidity and mortality. *Jpn J Infect Dis* 2021;74:61–64. DOI: 10.7883/yoken.JJID.2020.200.

[35] Wong DWS and Li Y. Spreading of COVID-19: Density matters. *PLoS One* 2020;15:e0242398.

[36] Pana TA, Bhattacharya S, Gamble DT, et al. Country-level determinants of the severity of the first global wave of the COVID-19 pandemic: an ecological study. *BMJ Open* 2021;11:e042034.

[37] Goodyear-Smith F, Kinder K, Mannie C, et al. Relationship between the perceived strength of countries' primary care system and COVID-19 mortality: an international survey study. *BJGP Open* 2020;4:bjgpopen20X101129.

[38] Haut ER, Pronovost PJ and Schneider EB. Limitations of administrative databases. *JAMA* 2012;307:2589; author reply 2589–90.