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RESEARCH ARTICLE

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Demography, inequalities and Global Health Security Index as correlates of COVID-19 morbidity and mortality

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Abstract

Background: During a pandemic, the occurrence of infections and case fatality rates are expected to vary from one country to another due to several variables such as poverty, existing comorbidities, population density, access to health care, availability and quality of health system resources, and environmental factors.

Objectives: Our aim is to investigate the relationship between various demographic and socioeconomic factors and reported COVID-19 morbidity and mortality indicators in different countries. Also, to determine the position of the countries relative to each other in terms of three indicators including COVID-19 cases, deaths and tests.

Methods: Canonical correlation analysis is used to investigate the intercorrelations between independent variables and the COVID-19 cases and deaths for 92 countries. Countries' performances are measured by MULTIMOORA.

Results: Human Development Index, smoking habits, percentage of elderly population and test frequency are the most significant variables associated with COVID-19 morbidity and mortality according to our study findings. Singapore, New Zealand and Australia are the best performed countries.

Conclusions: Several significant and unexpected associations exist between socioeconomic factors and the COVID-19 cases and deaths. Singapore, New Zealand and Australia are surrounded by water, have been more successful in the pandemic process compared to other countries.

KEYWORDS
COVID-19 pandemic, demography, health policy, socioeconomic factors

Key points

- HDI, smoking habits, elderly population, and test frequency, were the most significant factors associated with COVID-19 mortality and morbidity
- Singapore, New Zealand, and Australia, that are surrounded by water, have better performance in the pandemic process than other countries
- Slovenia, Czech Republic, and Croatia have less favourable performance in the pandemic process compared to other countries

1 | INTRODUCTION

The pandemic risk has risen in the 21st century because of increased global travel and integration, urbanization, changes in land use, and greater exploitation of the natural environment.[1] Past experiences show that pandemics have serious effects on the global economy and create social chaos besides loss of lives.[2]

The COVID-19 pandemic has started as the infections of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in Wuhan, China in December 2019 and followed by occurrences of new cases in Thailand, Japan and the Republic of Korea in January.[3] WHO declared the outbreak of COVID-19 as a pandemic on 11 March 2020.

The rapid spread of the new infection causing high levels of morbidity and mortality in every country has overwhelmed health systems and caused the inevitable economic downturn. Governments have tried to keep mortality as low as possible and also manage the economic consequences of voluntary/mandated quarantine, lockdowns, closure of educational institutes or places of work, and isolation of households, towns, or cities.[4] According to an OECD economic evaluation report, the COVID-19 outbreak has already brought major economic disruption and GDP is expected to decrease by 2.4% in 2020.[5]

During a pandemic, the proportion of infected individuals and case fatality rates vary significantly from country to country. Study findings indicate that poverty, inequality, and social determinants of health create conditions for the transmission of infectious diseases and the discrepancy in health system capacity, political security, and socioeconomic risk can further contribute to unequal burdens of morbidity and mortality.[6,7] Stojkoski et al. (2020) state the importance of the socioeconomic determinants for developing policies aimed at preventing future health crises.[8] Khan et al. (2020) show that amount of health expenditure is positively associated with case fatalities.[9] Liu et al. (2020) indicate that elderly patients with COVID-19 are more likely to progress to severe disease.[10] Demenech et al. (2020) show an association between the Gini coefficient and COVID-19 incidence and mortality rates.[11] The Gini index determines the distribution of income among individuals or households, runs from zero to one hundred, with zero being complete equality and one hundred being complete inequality.[12]

As it is stated in various studies the case fatality rates are affected by several factors such as poverty, unemployment rates, education level, nutritional status, existing comorbidities, population density, access to health care, quality of health system resources and environmental factors.[13] Income is an indicator of access to economic resources available to purchase health-related goods and services.[14] In previous studies, it is emphasized that deaths during the pandemics are closely related to the income level of countries.[15,16] Low- and middle-income countries usually suffer from higher mortality rates in a pandemic due to high frequency of malnutrition and existing comorbidities, insufficient health care, lack of access to health care, and higher rates of virus transmission.[1] Education level, which is another measure that reflects social and economic characteristics relevant for health, is a significant predictor of mortality rates.[14] Life expectancy is a widely used measure for monitoring the evolution of mortality rate.[17] Human Development Index (HDI) is a composite measure that includes life expectancy, education, and per capita income indicators[18] which are used to rank countries by tiers of human development. The HDI is an indicator for countries' preparedness to respond effectively and efficiently to a health crisis, provide a convenient window into the impact of COVID-19 on households.[19-21] That is why we investigate the relationship between COVID-19 morbidity and mortality and countries' HDI.

Income inequality, frequently measured with the Gini coefficient,[17] is another important variable that is associated with the differences in exposure to the virus, susceptibility to disease, access to health care, and consequently affects mortality rates during the pandemics.[22] On the other hand, the level of preparedness and capacity to manage the pandemics that are summarized by Global Health Security (GHS) Index can help to understand different dynamics in different countries. GHS Index was developed after the outbreak of Ebola in 2014,[23] and used to evaluate the countries' capacity to manage the pandemics.[6] In our study, both measures are used as independent study variables.

In the early stages of the pandemic, several studies indicated that COVID-19 morbidity and mortality rates are significantly associated with older age, high number of comorbidities,[24] diabetes[25] and smoking.[26] Population density, which is related to physical distancing and the transmission of the disease, seems to be another significant factor during pandemics.[27] Based on the evidences from available literature these variables are included in this study.

All this evidence reflects the complex nature and multivariate dynamics of the pandemic. It is important to determine which variables are related to the better management of the pandemics and to be prepared for the next pandemics. Although several studies have investigated the relationship between COVID-19 and demographic, social and economic factors, studies discussing different variable combinations are still needed to determine interaction of the factors related to COVID-19. This research contributes to the literature for determining the probable predictors of varying COVID-19 morbidity and mortality rates in different countries. We compare data of 92 countries to determine key factors associated with increased cases and mortality rate of COVID-19. These data include country-specific socioeconomic factors, the health status of society, and the country's capability to prevent and mitigate pandemics. Furthermore, countries were ranked in terms of three indicators including COVID-19 cases, deaths, and tests and, their performances were evaluated. Countries are grouped as the countries with best conditions, less favourable, and the least favourable conditions according to their performance.

Therefore our aim in this study is to explore the complex relationship between 'COVID-19 indicators' (COVID-19 cases and deaths) and a group of 'independent variables' including demography, diabetes prevalence, probability of dying between ages 30 and 70, percentage of smoking, GINI index, HDI and Global Health Security Index (GHSI) in 92 countries. Moreover, to rank the countries according to their performances measured by MULTIMOORA method.

2 | METHODS

We conducted this descriptive study to investigate how various demographic and socioeconomic factors are associated with reported COVID-19 morbidity and mortality in different countries. We collected all data from various international open sources such as, Our World in Data, GHSI web site, World Bank, Human Development Data Center. Our study included the countries (*n* = 92) that have reported complete data regarding the study variables. We collected the latest available data (18th of December 2020) of all the variables for 92 countries.

Dependent and independent variables of the study are as follow:

- Dependent variables:
  - **Cases:** Confirmed cases of COVID-19 per million population[28]
  - **Deaths: Confirmed deaths** from COVID-19 per million population.[28]
- Independent variables:

- **GHSI (Global Health Security Index)**[23]: The GHSI calculated from 6 categories, 34 indicators, and 85 sub-indicators to assess a country's capability to prevent and mitigate epidemics and the pandemics.
- **GINI (GINI coefficient)**[29]: A measure of statistical dispersion intended to represent the income or wealth distribution of a nation's residents and is the most commonly used measurement of inequality.
- **Male smokers (%)**[28]**:** Percentage of male population who smoke.
- **Elderly population** (%)[28]: Percentage of people aged 65 or over.
- **Diabetes prevalence**[28]**:** Diabetes prevalence (as % of population aged 20 to 79) in 2017
- **Probability of dying between ages 30 and 70**[30]: (as % from any of cardiovascular disease, cancer, diabetes, or chronic respiratory diseases),
- **Population density**[28]**:** Number of people divided by land area, measured in square kilometres.
- **Tests per case**[28]: Tests conducted per new confirmed case of COVID-19.
- **HDI (Human Development Index)**[31]**:** This composite index is a measure for three dimensions of human development that include life expectancy, education and per capita income.[18]

Logarithmic, ln and square root transformations are used for some variables and multivariate normality assumption is provided for the research variables. We found that missing values are random, and replaced them with the mean values of each variable (Table 1). We performed Pearson's correlation analysis and the canonical correlation analysis (CCA) to investigate the intercorrelation between independent variables and the COVID-19 cases and deaths.

2.1 | Canonical correlation analysis

CCA is used to investigate the intercorrelation between independent variables and the COVID-19 cases and deaths. CCA aims to find a linear relationship between sets of multiple dependent and independent variables. It develops a weighted average of the variables from the first set and correlates with a weighted average of the variables from the second set. The weighted averages of the original variables are called canonical variates. A pair of canonical variates is also named as a *canonical root*. It finds the linear combination of independent variables, (X1, X2, etc.), and the linear combination of dependent variables (Y1, Y2, etc.), which maximizes the correlation. Each canonical function is con-

TABLE 1 Independent variables and correlations with COVID-19 indicators

			Correlation to dependent variables	
Independent variables	**Transform**	**Missing (*n*)**	**Cases**	**Deaths**
GHSI	-	-	0.240*	0.341**
GINI coefficient	Ln	10	−0.351**	−0.275**
Male smokers	Square root	6	0.601**	0.589**
Elderly population	Square root	-	0.498**	0.519**
Diabetes prevalence	Ln	-	0.275**	0.201
Probability of dying from chronic diseases	-	-	−0.355**	−0.280**
Tests per case	Ln	-	−0.364**	−0.550**
Population density	Ln	-	0.092	−0.106
HDI	-	-	0.653**	0.567**
Cases	Square root		-	0.845*
Deaths	Ln		0.845*	-

Abbreviations: GHSI, Global Health Security Index; HDI, Human Development Index.
*$p < 0.05$; **$p < 0.01$.

structed from the correlation between two canonical variates, one variate from the dependent variables and one from the independent variables. The number of canonical correlations equals the number of variables in the small set.[32] V_1 is the linear combination of the y variables. Let W_1 is a linear combination of the X variables. Let C_1 be the correlation between W_1 and V_1[33]:

$$W_1 = a_{11}X_1 + a_{12}X_2 + \ldots + a_{1p}X_p \tag{1}$$

$$V_1 = b_{11}y_1 + b_{12}y_2 + \ldots + b_{1q}y_q \tag{2}$$

The objective of canonical correlation is to estimate a_{11}, a_{12}, ... a_{1p} and b_{11}, b_{12}, ... b_{1q} such that C_1 is maximized. Equations (1) and (2) are canonical equations, W_1 and V_1 are the canonical variated and C_1 is the canonical correlation. This procedure is continued until the mth set of canonical roots. In summary, the objective of canonical correlation is to identify the m sets of canonical variates, (W_1, V_1), (W_2, V_2)...(W_m, V_m) such that the corresponding canonical correlations $C_1, C_2, \ldots, C_m$ are maximum and Corr $(V_j, V_k) = 0$, for all $j \neq k$, Corr$(W_j, W_k) = 0$, for all $j \neq k$ and Corr $(W_j, V_k) = 0$, for all $j \neq k$. CCA is an optimization problem with certain constraints. Redundancy analysis is used to fit the overall model. Redundancy index (R_d) indicates that measure of the variance of a variable explained by other variables in a given canonical correlation. It can be calculated for both dependent and independent variables. A redundancy index for the dependent variables demonstrates the amount of variance from dependent variables explained by the independent variables. It is calculated as:

$R_d =$ (average loading)^2 (canonical correlation)^2

If the index close to one shows that independent variable's variance being shared with the dependent variable, vice versa.

In CCA, there are three statistics available to determine the relative importance of variables in the study: standardized canonical coefficients, canonical loadings, and canonical cross-loadings. Canonical coefficients (R_c) are interpreted like regression coefficients. The squared canonical correlation coefficients ($\boldsymbol{R_c^2}$) indicate the proportion of variance common to the two groups of indicators. Canonical loading is the correlation between each variable and its canonical variate. Canonical cross-loadings are correlations between each variable and opposite canonical variate. To decide which variables are most important in a given pair of canonical variates, standardized canonical coefficients and/or canonical loadings are used. In most instances, however, the canonical loadings are used to interpret the meanings of canonical variates. Because of the multicollinearity problems, canonical cross-loadings directly measure the relative impact of each variable.[32]

Assumptions of CCA are linearity, multicollinearity (high multiple correlation between dependent or independent set), and multivariate normality.[32] We all checked the assumptions.

The primary aim of this research is to find the relationship between COVID-19 indicators and demographic and socioeconomic indicators using the CCA model (Figure 1). CCA is a multivariate analysis method to study the interrelationships between multiple dependent variables and multiple independent variables. When compared to other multivariate techniques, CCA has fewer rigid restrictions. For this reason, in situations with multiple dependent and independent variables, CCA is the most appropriate and powerful multivariate technique.[32]

2.2 | Country ranking with MULTIMOORA

After determining the effects of the socioeconomic variables on COVID-19 indicators, we ranked the countries according to these variables to provide broader information about them. MULTIMOORA (Multi-Objective Optimization by Ratio analysis plus Full Multiplicative Form), one of the MCDM (Multi-Criteria Decision-Making) methods, was used to make the rank objectively. MCDM approaches aim to find the best solution from the set of alternatives being evaluated according to objectives (criterias). Brauers and Zavadskas[34] introduced MOORA (Multi-Objective

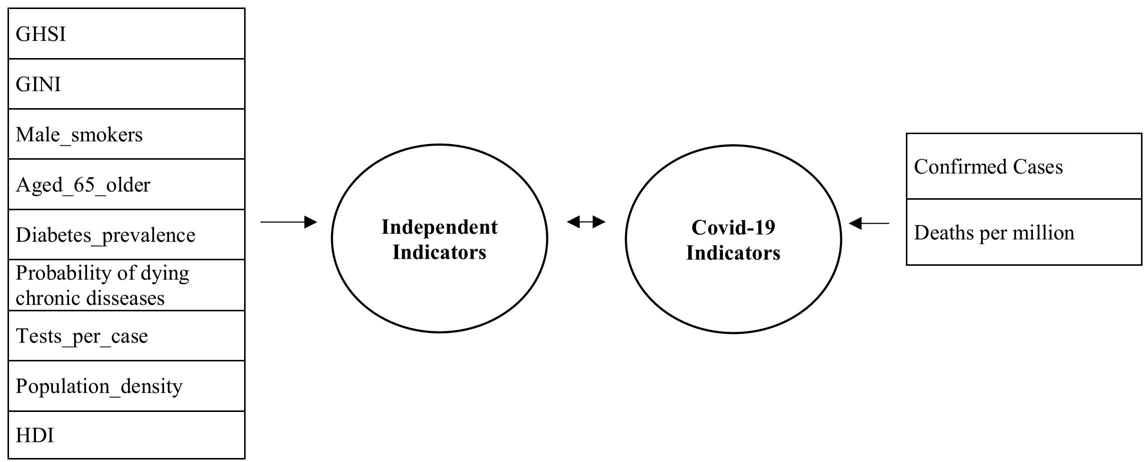

FIGURE 1 Study variables. GHSI, Global Health Security Index; HDI, Human Development Index

Optimization by Ratio analysis), which combines ratio and reference point approaches in 2006. In 2010, Brauers and Zavadskas[35] extended MOORA by adding a Full Multiplicative Form and applying Dominance Theory[36] to obtain a final ranking and call it MULTIMOORA. Thus, MULTIMOORA becomes a robust method for MCDM approaches.[37]

MOORA method begins with a decision matrix, X, where its elements, xij, denote *i*th alternative of *j*th objective (i = 1, 2, …,m and j = 1, 2,…, n). Ratio system is a data normalization method by comparing alternative of criteria to all values of the criteria:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^{2}}} \tag{3}$$

where x_{ij}^{*} denotes *i*th alternative of *j*th objective. For optimization, these responses are added in the case of maximization and subtracted in case of minimization:

$$y_{j}^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*} \tag{4}$$

where g = 1, … n denotes number of objectives to be maximized. An ordinal ranking in a descending order of the y_j^{*} shows the final preference.

The second part of MOORA is reference point theory is chosen with the Min–Max Metric of Tchebycheff as given by the following formula:

$$\min_{(j)} \left\{ \max_{(i)} \left| r_j - x_{ij}^{*}) \right| \right\} \tag{5}$$

This theory starts from the already normalized ratios as defined in the Equation (1).

Full Multiplicative Form method[35,36] embodies maximization as well as minimization of purely multiplicative utility function. The overall utility of the i-th alternative can be expressed as a dimensionless number:

$$U_i = \frac{A_i}{B_i} \tag{6}$$

where $A_i = \prod_{j=1}^{g} x_{ij}$, i = 1,2….n denotes the product of objectives of the i-th alternative to be maximized with g = 1,… m being the number of objectives to be maximized and $B_i = \prod_{j=g+1}^{m} x_{ij}$ denotes the product of objectives of the i-th alternative to be minimized with $m-g$ being the number of objectives to be minimized.

In MULTIMOORA, we used three COVID-19 indicators to rank the countries performances: COVID-19 cases (minimum the value better the performance of the country), deaths (minimum the value the better the performance of the country), and COVID-19 tests per case (maximum the value better the performance of the country). The decision matrix of the study contains our alternatives (92 countries) and objectives (3 COVID-19 variables). It has 276 elements. The decision matrix was translated into dimensionless ratios according to Equations (3) and (4) for Ratio System. Secondly, Equation (5) used the ratios obtained in Equation (3) to calculate the distances to the Reference Point of MOORA. Thirdly, the Full Multiplicative Form used the decision matrix to rank the countries. Finally, the final classification was made with dominance theory, and MULTIMOORA results were presented in Table 8. On the basis of the multi-criteria analysis, Brauers et al.[38] suggested dividing the countries into three groups. It could be called the groups as the best conditions countries (best performance), less favourable countries (medium performance), and the least favourable countries (low performance) for three COVID-19 indicators. The differences of other variables not used in MULTIMOORA according to the countries' groups were examined by one way analysis of variance (ANOVA).

The calculations were performed using the IBM SPSS 23 for CCA, one way ANOVA. MULTIMOORA is performed by R Studio 1.3.959 version using MCDA package.

3 | RESULTS

Table 1 presents the missing values, suitable transformations and correlation of independent variables with the dependent variables. Because CCA and correlation analysis require assumptions of normal distribution and a linear relationship between the dependent and independent variables, we transformed the data regarding to GINI, male smokers, elderly population, diabetes prevalence, test per case, population density, cases, and deaths indicators by logarithmic and squared root transformation.

One of the CCA assumptions is that the variables in both sets should have a significant level of correlation in themselves. The simple correlation between the indicators of confirmed COVID-19 cases and deaths is significant and high ($r = 0.845$; $p < 0.001$) as it is seen in Table 1. Table 1 also presents the correlations between COVID-19 indicators and independent variables. There are significant correlations between all independent variables and the COVID-19 indicators with the exception for population density. HDI, percentage of male smokers and elderly population are moderately and positively correlated with the COVID-19 cases (0.653, 0.601, and 0.498, respectively), while number of tests per case, probability of dying from chronic diseases, and GINI coefficient are negatively correlated (−0.364, −0.355, and −0.351, respectively). HDI, percentage of male smokers and the elderly population have significant moderate and positive correlation with the COVID-19 deaths (0.589, 0.567, and 0.510, respectively). COVID-19 deaths have a significant moderate negative correlation with tests per case (−0.550). The correlations between COVID-19 deaths and diabetes prevalence and COVID-19 deaths and population density are not significant.

Table 2 presents the simple linear correlations between the independent variables. There is a strong and significant positive correlation between male smokers prevalence and percentage of the elderly population ($r = 0.845$; $p < 0.001$), and also between the elderly population and HDI ($r = 0.770$; $p < 0.001$).

Findings of the Canonical Correlation tests of significance between COVID-19 indicators and independent variables across all detected canonical functions are presented in Table 3. They indicated that the canonical functions are collectively significant ($p < 0.001$); thus, it is possible to say that the two sets of indicators are correlated and dependent each other.

TABLE 2 Simple Linear Correlation between independent variables

	GHSI	GINI	Male smokers	Aged 65 older	Diabetes prevalence	Probability of dying from chronic disseases	Tests per_ case	Population density	HDI
GHSI	1	-	-	-	-	-	-	-	-
GINI	−0.110	1	-	-	-	-	-	-	-
Male smokers	0.401[b]	−0.399[b]	1	-	-	-	-	-	-
Aged 65 older	0.484[b]	−0.530[b]	0.845[b]	1	-	-	-	-	-
Diabetes prevalence	−0.133	−0.098	−0.079	−0.017	1	-	-	-	-
Probability of dyingFrom chronic diseases	−0.372[b]	0.265[a]	−0.307[b]	−0.464[b]	−0.078	1	-	-	-
Tests per case	−0.089	−0.027	−0.168	−0.122	0.096	−0.151	1	-	-
Population density	−0.037	−0.076	−0.119	−0.024	0.208[a]	−0.131	0.052	1	-
HDI	0.472[b]	−0.523[b]	0.676[b]	0.770[b]	0.344[b]	−0.606[b]	0.099	−0.0139	1

Abbreviations: GHSI, Global Health Security Index; HDI, Human Development Index.

[a]Correlation is significant at the 0.05 level (2-tailed).

[b]Correlation is significant at the 0.01 level (2-tailed).

TABLE 3 Canonical Correlation tests of significance

Statistics	Value	Approx. F statistics	p
Pillai's	1.135	11.945	$p < 0.001$
Hotelling's	4.048	17.99	$p < 0.001$
Wilk's lambda	0.143	14.791	$p < 0.001$
Roy's	0.777	-	-

TABLE 4 Summary of the canonical correlation analysis

	Independent variables	COVID-19 indicators
Number of variables	8	2
Extracted variance	35.1%	100%
Redundancy index (R_d)	22.8%	74.5%

Table 4 presents the summary statistics of CCA. As it is seen from the Table, 35.1% of canonical roots are covered by internal 'independent variables' variation and 100% of canonical roots are covered by 'COVID-19 Indicators' variation.

According to Redundancy index (R_d), 74.5% of changes in 'COVID-19 Indicators' can be predicted by studying changes in 'independent variables'. Also, 22.8% of changes in 'independent variables' can be predicted by changes in 'COVID-19 Indicators' (Table 4).

The next step was the estimation of the significance of CCA coefficients. As shown in Table 5, two orthogonal (uncorrelated) functions are resulted from the full CCA process and both functions are found to be significant ($p < 0.001$). The value for the first pairs of variates indicates that 77.8% of the variance between independent variables and COVID-19 Indicators are shared ($R_c = 0.88$) while the second pairs of variates share 35.8% of the variance ($R_c = 0.598$).

Computed values of the canonical loadings and the canonical cross-loadings for our data are presented in Tables 6 and 7 respectively.

According to Table 6, both the cases and deaths have strong positive correlations with the first variate (0.962 and 0.959, respectively). Among independent variables, HDI (0.727) and male smokers prevalence (0.709) have strong positive correlations with the first variate. Elderly population (0.608) and tests per case (−0.540) have moderate correlations with the first variate. Also, population density (0.597) and test per case (0.562) have positive moderate correlations with the second variate.

The square of canonical loading shows the proportion of variance that an observed variable linearly shares with a variate. Among COVID-19 indicators, the first variate explains 92.5% of the variance of cases and 92.0% of deaths. Among independent variables, the first variate explains 52.9% of the variance of HDI and 50.3% of male smokers prevalence (Table 6).

As it is seen from Table 7 the cross-loadings of cases and deaths are strongly correlated with the independent variables (0.849 and 0.845 respectively) in the first variate. That means 0.721 of the variance for confirmed COVID-19 cases and 0.714 of the variance for deaths can be predicted by changes in first variate. Among independent variables, HDI (0.641) and percentage of male smokers (0.625) have the highest correlations with the first variate of COVID-19 indicators. Percentage of elderly population (0.536) and tests per case (−0.476) have moderate correlations. All variables have weak correlations with the second variate.

Table 8 presents the rankings of the countries according to MULTIMOORA classified as best performance (holding ranks 1 to 31), medium performance (32–62) and low performance (63–92). As it is seen from the table, Slovenia, Czech Republic, and Croatia have the least favourable conditions while Singapore, New Zealand and Australia have the best. Countries with the best conditions had the lowest rates of male smokers and elderly population and HDI

TABLE 5 Overall fit of canonical correlation analysis

Canonical functions	Canonical correlations (R_c)	R_c^2	*F*	*P*
1	0.882	0.778	14.79	$p < 0.001$
2	0.598	0.358	5.70	$p < 0.001$

TABLE 6 Canonical loadings table

Functions	r_s		r_s^2	
COVID-19 indicators	Canonical Variable-1	Canonical Variable-2	1	2
Cases	**0.962**	0.271	**0.925**	0.073
Deaths	**0.959**	−0.285	**0.920**	0.081
Independent indicators				
GHSI	0.356	−0.294	0.127	0.086
GINI	−0.381	−0.226	0.145	0.051
Male smokers	**0.709**	0.034	**0.503**	0.001
Elderly population	**0.608**	−0.064	0.370	0.004
Diabetes prevalence	0.274	0.212	0.075	0.045
Probability of dying from chronic diseases	−0.385	−0.225	0.148	0.051
Tests per case	**−0.540**	**0.562**	0.292	0.316
Population density	0.010	**0.597**	0.000	0.356
HDI	**0.727**	0.251	**0.529**	0.063

Note: r_s and r_s^2 greater than |0.45| are bold.
Abbreviations: GHSI, Global Health Security Index; HDI, Human Development Index.

besides highest values for GINI. No statistically significant differences in diabetes prevalence, population density and probability of dying from chronic diseases are found according to the condition of the countries ($p > 0,05$).

4 | DISCUSSION

In this study, we investigated the association of a group of medical, social and economic variables with COVID-19 morbidity and mortality in 92 countries using CCA. In addition, we calculated countries' ranks relative to each other with MULTIMOORA method.

According to the summary statistics of CCA, 74.5% of changes in COVID-19 morbidity and mortality which we call ‘COVID-19 Indicators’ can be predicted by ‘Independent variables’. There are significant correlations between the COVID-19 indicators and independent variables except for the population density. Also, the correlation between COVID-19 deaths and diabetes prevalence is not significant.

The value obtained for CCA, (R_c = 77.8%) means a strong correlation between independent variables and COVID-19 indicators. CCA indicated that the number of COVID-19 cases and the deaths are positively correlated (r = 0.849 and r = 0.845, respectively). Among the independent variables, HDI and percentage of male smokers have the highest correlations (0.641; 0.625, respectively) and percentage of elderly population and tests per case (0.536; −0.476, respectively) have moderate correlations with COVID-19 indicators. The number of COVID-19 cases and mortality have risen as the HDI value, percentage of male smokers, and the elderly population increased, and have decreased as the number of tests per case decreased.

TABLE 7 Canonical cross-loadings

	Canonical cross-loadings		Shared variance (%)	
Correlations between COVID-19 indicators and independent variables				
	1	2	1	2
Cases	**0.849**	0.162	0.721	0.026
Deaths	**0.845**	−0.17	0.714	0.029
Correlations between independent variables and COVID-19 indicators				
GHSI	0.314	−0.176	0.099	0.031
GINI	−0.336	−0.135	0.113	0.018
Male smokers	**0.625**	0.020	0.391	0.000
Elderly population	**0.536**	−0.038	0.287	0.001
Diabetes prevalence	0.242	0.127	0.059	0.016
Probability of dying from chronic diseases	−0.339	−0.134	0.115	0.018
Tests per case	**−0.476**	0.336	0.227	0.113
Population density	0.009	0.357	0.000	0.127
HDI	**0.641**	0.150	0.411	0.023

Note: canonical cross-loadings greater than |0.45| are bold.
Abbreviations: GHSI, Global Health Security Index; HDI, Human Development Index.

Income indicators and life expectancy were reported as strong predictors of COVID-19 morbidity and mortality.[39,40] Some studies have indicated that high COVID-19 morbidity and mortality rates in developed countries are associated with high GDP and life expectancy.[41,42] On the other hand, Abedi et al. and Goutte, Péran, & Porcher reported that poorer and disadvantaged people are under high risk of COVID-19 mortality.[43,44] According to these studies, higher rates of COVID-19 mortality in districts with more disability and poverty were associated with working conditions and poverty.[43] However, considering the differences between countries, especially advanced age becomes more important determinant of COVID-19 mortality. Lawal (2021) reported life expectancy as one of the reasons of lower COVID-19 mortality rates in Africa.[40] Countries with high GDP are generally developed countries with advanced health systems, education systems, and high life expectancy. These countries are expected to cope the health problems better.[42]

The relationship between education and COVID-19 mortality rates is found to be important in some studies. Abedi et al. (2020) and Gouttea et al. (2020) reported significant relationships between education level and COVID-19 morbidity and mortality rates in different regions of a country with social-economic diversity.[43,44] Paradoxically, in this study, we found that countries with high HDI have higher number of COVID-19 cases and deaths. Our finding is similar to Chaudhry et al.'s who stated that countries with high per capita GDP have much more COVID-19 cases and deaths.[42] Countries with a high HDI are usually economically developed countries with high proportion of elderly population. The higher probability of morbidity and mortality from COVID-19 in the older populations during the early stages of the pandemic may be the underlying cause of the positive association between HDI and COVID-19 cases and deaths.

Smoking was identified as an important predictor for COVID-19 cases and deaths in many studies.[24,45,46] Hamidi et al. reported that countries with a higher percentage of smokers have higher mortality rates from COVID-19.[45] Vardavas and Nikitara explained smoking is most likely associated with the negative progression and adverse outcomes of COVID-19.[24] Cao et al. found that a doubling in the proportion of female smokers is associated with a significant increase in COVID-19 case fatality rates.[46] On the other hand, Cai (2020) stated that the current literature does not support smoking as a predisposing factor in men.[47] According to our study, male smoking is a strong correlate for both

TABLE 8 The Ranking of the 92 countries according to MULTIMOORA

Countries	Ratio system		Reference point		Multiplicative form		MultiMoora ranking
Singapore	0.2201779432	1	0.01392384	1	4,57E + 10	4	1
New Zealand	0.1584776685	2	0.07501601	3	6,77E + 11	3	**2**
Australia	0.1571128605	3	0.07319330	2	3,96E + 10	5	**3**
Fiji	0.0476674574	4	0.18658527	4	4,03E + 12	2	**4**
Vietnam	0.0432391605	5	0.19120402	5	8,02E + 13	1	**5**
Cuba	0.0057636485	6	0.22662274	7	7,27E + 09	9	**6**
Malawi	0.0026446830	7	0.23067112	12	1,17E + 10	6	**7**
Zambia	0.0021927354	8	0.22940019	9	2,43E + 09	12	**8**
Togo	0.0013071366	9	0.23202885	14	7,40E + 09	8	**9**
Rwanda	0.0010099606	10	0.23239463	21	8,45E + 09	7	**10**
Côte d'Ivoire	0.0007164367	11	0.23224584	17	5,20E + 09	10	**11**
South Korea	−0.0001215362	12	0.23238223	20	1,74E + 09	14	**12**
Mozambique	−0.0001860765	13	0.23356017	42	3,50E + 09	11	**13**
Nigeria	−0.0004223033	14	0.23396314	60	2,36E + 09	13	**14**
Uganda	−0.0008022375	15	0.23402514	66	1,40E + 09	15	**15**
Sri Lanka	−0.0015685244	18	0.23319439	32	1,01E + 09	16	**16**
Madagascar	−0.0010675531	16	0.23397554	63	8,35E + 08	17	**17**
Zimbabwe	−0.0013888388	17	0.23319439	33	7,40E + 08	18	**18**
Ghana	−0.0020339375	20	0.23332458	34	6,12E + 08	19	**19**
Ethiopia	−0.0019472322	19	0.23381435	53	3,97E + 08	20	**20**
Senegal	−0.0022808381	21	0.23373996	50	3,27E + 08	21	**21**
Japan	−0.0026740965	22	0.23349197	40	3,03E + 08	22	**22**
Malaysia	−0.0039716385	24	0.23362216	45	2,28E + 08	23	**23**
Kenya	−0.0039119058	23	0.23373996	49	1,38E + 08	24	**24**
Myanmar	−0.0051691823	26	0.23351057	41	1,04E + 08	25	**25**
Pakistan	−0.0050630707	25	0.23361596	44	9,93E + 07	26	**26**
Saudi Arabia	−0.0131121366	33	0.22013788	6	7,63E + 07	27	**27**
United Arab Emirates	−0.0240229745	39	0.22696372	8	5,94E + 07	28	**28**
Philippines	−0.0103175570	30	0.23301460	28	4,25E + 07	29	**29**
Bangladesh	−0.0069021147	27	0.23393215	59	4,08E + 07	30	**30**
Mauritania	−0.0070282848	28	0.23391355	58	4,01E + 07	31	**31**
Finland	−0.0126501857	32	0.23252482	22	3,73E + 07	32	**32**
Norway	−0.0143163815	35	0.23224584	18	3,68E + 07	33	**33**
Iceland	−0.0240601181	40	0.22957378	10	3,53E + 07	34	**34**
India	−0.0156653310	36	0.23225824	19	2,83E + 07	35	**35**
Indonesia	−0.0082609154	29	0.23419873	78	1,68E + 07	36	**36**
Kazakhstan	−0.0220380556	37	0.23207845	16	1,65E + 07	37	**37**
Jamaica	−0.0120003801	31	0.23384535	55	1,63E + 07	38	**38**
Namibia	−0.0140426731	34	0.23405614	69	9,35E + 06	39	**39**
Maldives	−0.0394296055	50	0.23263642	23	8,10E + 06	40	**40**

(Continues)

TABLE 8 (Continued)

Countries	Ratio system		Reference point		Multiplicative form		MultiMoora ranking
El Salvador	−0.0223336551	38	0.23364076	46	6,62E + 06	41	**41**
Denmark	−0.0408821533	52	0.23264881	24	4,82E + 06	42	**42**
Belarus	−0.0338611534	46	0.23333698	35	4,55E + 06	43	**43**
Qatar	−0.0731068768	66	0.23269841	25	4,18E + 06	44	**44**
Bahrain	−0.0846927676	70	0.23024954	11	3,78E + 06	45	**45**
Cyprus	−0.0323795220	44	0.23383295	54	3,53E + 06	46	**46**
Estonia	−0.0295723389	43	0.23380815	52	3,52E + 06	47	**47**
Ireland	−0.0517839176	60	0.23205985	15	3,43E + 06	48	**48**
Iraq	−0.0419602175	53	0.23292780	27	3,32E + 06	49	**49**
Latvia	−0.0358660876	47	0.23370276	47	2,40E + 06	50	**50**
Guatemala	−0.0286831569	41	0.23405614	68	2,24E + 06	51	**51**
Morocco	−0.0288307330	42	0.23411814	73	1,75E + 06	52	**52**
Kuwait	−0.0627396112	63	0.23318819	30	1,70E + 06	53	**53**
Russia	−0.0498307929	58	0.23339897	36	1,68E + 06	54	**54**
Israel	−0.0830300318	69	0.23194205	13	1,64E + 06	55	**55**
Greece	−0.0446234000	54	0.23372756	48	1,57E + 06	56	**56**
Malta	−0.0652300548	64	0.23279141	26	1,53E + 06	57	**57**
Canada	−0.0449423361	55	0.23376476	51	1,45E + 06	58	**58**
Germany	−0.0458272887	56	0.23388255	56	1,13E + 06	59	**59**
Dominican Republic	−0.0361512610	48	0.23411814	72	1,13E + 06	60	**60**
Libya	−0.0331734281	45	0.23424213	83	9,05E + 05	61	**61**
Paraguay	−0.0398636638	51	0.23418633	77	7,55E + 05	62	**62**
South Africa	−0.0507675494	59	0.23415533	75	5,29E + 05	63	**63**
Tunisia	−0.0388679166	49	0.23431033	90	5,18E + 05	64	**64**
Chile	−0.1031962953	78	0.23319439	31	4,93E + 05	65	**65**
Slovakia	−0.0548139300	61	0.23418013	76	4,55E + 05	66	**66**
United Kingdom	−0.1115587559	81	0.23345477	37	3,56E + 05	67	**67**
Iran	−0.0655962839	65	0.23419873	79	3,28E + 05	68	**68**
France	−0.1201135787	84	0.23347337	39	2,81E + 05	69	**69**
Luxembourg	−0.1460786522	89	0.23317579	29	2,68E + 05	70	**70**
Spain	−0.1298111403	87	0.23346097	38	2,49E + 05	71	**71**
Austria	−0.0922009931	74	0.23396934	61	2,45E + 05	72	**72**
Portugal	−0.0921600647	73	0.23396934	62	2,44E + 05	73	**73**
Ukraine	−0.0585557217	62	0.23429173	85	2,30E + 05	74	**74**
Netherlands	−0.0986612983	76	0.23397554	64	2,11E + 05	75	**75**
Lithuania	−0.0780605198	67	0.23421113	82	2,07E + 05	76	**76**
Hungary	−0.0996273287	77	0.23399414	65	2,03E + 05	77	**77**
Turkey	−0.0476069759	57	0.23440332	92	1,75E + 05	78	**78**
Mexico	−0.0809150766	68	0.23433512	91	1,65E + 05	79	**79**

TABLE 8 (Continued)

Countries	Ratio system		Reference point		Multiplicative form		MultiMoora ranking
Italy	−0.1260256647	86	0.23388875	57	1,65E + 05	80	**80**
Sweden	−0.1070878833	80	0.23407474	70	1,45E + 05	81	**81**
Romania	−0.0955861818	75	0.23420493	80	1,26E + 05	82	**82**
Switzerland	−0.1197565886	83	0.23407474	71	1,16E + 05	83	**83**
Serbia	−0.0865049646	71	0.23430413	89	1,14E + 05	84	**84**
Belgium	−0.1913728883	92	0.23360356	43	1,01E + 05	85	**85**
United States	−0.1418873567	88	0.23402514	67	9,18E + 04	86	**86**
Poland	−0.0908540517	72	0.23430413	88	9,00E + 04	87	**87**
Panama	−0.1254144000	85	0.23414913	74	8,64E + 04	88	**88**
Bulgaria	−0.1054323054	79	0.23430413	86	7,25E + 04	89	**89**
Croatia	−0.1169121714	82	0.23430413	87	5,47E + 04	90	**90**
Czech Republic	−0.1479270611	90	0.23421113	81	5,10E + 04	91	**91**
Slovenia	−0.1481494077	91	0.23427933	84	3,85E + 04	92	**92**

COVID-19 cases and deaths. Similar to our finding, higher risk of COVID-19 morbidity and mortality in men has been associated with higher smoking rates in Italy.[48]

The positive correlation between age and mortality is a well-known association that was also observed during this pandemic. According to a detailed report from the Chinese Center for Disease Control and Prevention, the overall case fatality rate was 2.3%, and increased to 8.0% for 70–79 years age group and 14.8% for 80 years and older.[49] Advancing age has been considered as a risk for COVID-19 morbidity and mortality in many studies.[4,42,50] Also, some clinical studies have explained a significant relationship between older age and disease severity of COVID-19.[26] Moreover, previous studies displayed that developed countries with a high proportion of the population over 65 have more COVID-19 cases and high case fatality rates.[40,41] According to CCA in this study, both cases and deaths are higher in populations where the proportion of the population aged 65 and over is higher. Arsalan et al. stated that developed countries such as Japan, Norway, Germany, Switzerland, Austria, Belgium, Denmark, Sweden, Netherlands, and Finland have the highest mortality risk due to their higher proportion of elderly population and countries including Ethiopia, Yemen, Sudan, Senegal have lower mortality risk due to their lower life expectancy and consequently lower proportion of elderly population.[41]

The number of diagnostic tests performed for case finding is an important variable that may influence the magnitude of identified COVID-19 morbidity. In this study, we found a negative relationship between tests per case and the COVID-19 cases and deaths. Chaudhry et al. (2020) reported that an increased scale of national testing was not associated with the number of critical cases, or deaths.[42] On the other hand, Cao et al. (2020) found the open testing policies are associated with a decrease in case fatality rate.[46]

It is known that the probability of dying between ages 30 and 70 from any chronic diseases is usually higher in low- and lower-middle-income countries[51] and income inequality influences a population's health status adversely.[52] However, some study findings indicate a threshold association of income inequality and mortality or little overall association.[53] The influence of income inequality on health is a complex issue and should be studied carefully. As revealed by the World Health Organization's Commission on Social Determinants of Health, extreme economic inequality drives other social inequalities.[54] Consequently, we were expecting that more people in societies with high GINI values would suffer from poor health and be more vulnerable to infectious diseases because of income inequality. But we found that both COVID-19 cases and deaths have a negative correlation with the probability of dying from chronic diseases and the GINI coefficient according to the results of CAA. The significant and positive correlation (r = 0.265,

$p < 0.05$, Table 2) between the GINI index and the probability of dying from chronic diseases supports this result. The correlation between COVID-19 frequency and probability of dying from chronic diseases and GINI is interesting. Fakhry reported that cardiovascular comorbidities were found as a major risk factor of COVID-19-related deaths.[39] However, Cao et al. (2020) and Lawal (2021) found a negative relationship between cardiovascular disease frequency and COVID-19 case fatality rate.[40,46] Lawal (2021) explained this negative relationship with the fact that countries, such as the United States, Italy, Spain, Japan, and China, with their better healthcare facilities, were able to slow down CVD deaths prior to COVID-19.[40] One other explanation of this paradox may be the unreported cases due to the insufficiency of the diagnostic tests in countries with high GINI values. Similar to our finding, underdiagnosed cases have been cited as one of the reasons why low-income countries have low AIDS cases.[55]

The GHS Index is a comprehensive assessment that ranks countries according to their level of preparedness for an epidemic or a pandemic. The GHS index for 195 countries was calculated as 40.2 on average and it was stated international preparedness for epidemics and the pandemics remains very weak.[56] Chaudhry et al. (2020), on the other hand, stated that every ten-unit increase in the GHS score is associated with a 55% increase in recovered cases.[42] In this study, GHSI was associated positively with COVID-19 cases and deaths.

Diabete is another variable that was identified as predictor for COVID-19 cases and deaths. The global diabetes epidemic, which is very strongly correlated with overweight and obesity, affects the majority of adult populations in most developed countries.[57] In this study, a weak positive correlation is found between diabetes and COVID-19 morbidity and mortality. Similar to our findings, Cao et al. also have reported a negative relationship between diabetes prevalence and case fatality rates,[46] while Lawal (2021) found no significant correlation.[40]

Quinn and Kumar emphasize that poverty, inequality, and social determinants of health create conditions for the transmission of infectious diseases, and existing health disparities or inequalities can further contribute to unequal burdens of morbidity and mortality.[7] Our study findings indicate that countries with high-income and improved health-related indicators could not succeed in controlling the COVID-19 pandemic. A World Bank report also stated that the COVID-19 cases and deaths are higher in developed countries.[27] Aged population structure may be one of the explanations of this finding. For example, many low-income African countries that have younger age population also have a lower frequency of severe COVID-19 cases.[46] Another explanation might be the timely determination of susceptible cases with much more contact tracing and testing. It is obvious that developed countries with better national surveillance systems have greater transparency in reporting and apply different techniques in the case and death detection and counting.[39,46] Increased human mobility due to the availability of travel and holiday opportunities in wealthier countries might also have a role in the increase of virus transmission.[42] On the other hand, these countries have implemented mitigation policies such as lockdowns, compulsory use of masks in public spaces to lower the incidence and mortality rate of COVID-19 cases. For example, Sebastiani et al. stated that the government measures prevented the rise of the epidemic in Italy.[58]

Dalglish (2020) and Emanuel et al. (2020), criticise the assumption that developed countries will have better health indicators in every situation due to better health systems they have. Dalglish (2020) stated that 'The pandemic has given the lie to the notion that expertise is concentrated in, or at least best channelled by, legacy powers and historically rich states'.. Moreover, the United States, Italy and the United Kingdom were considered the worst responders to the COVID-19 pandemic,[59] and they have faced an imbalance between supply and demand for medical resources such as hospital beds, intensive care beds, and ventilators.[50]

According to the results of the MULTIMOORA method, countries between 1st and 31st rankings have the best conditions, 32nd and 62nd have less favourable, 63rd and 92nd have the least favourable conditions with regard to COVID-19 indicators. Countries with the best conditions had the lowest rate of male smokers, rate of elderly population, GINI and HDI. Slovenia, Czech Republic, and Croatia have the least favourable conditions while Singapore, New Zealand and Australia have the best. New Zealand and Singapore, besides many other Asian countries have implemented strict control policies including extensive testing, tracing, and isolating of all cases (i.e., not just severe cases) from the start of the COVID-19 outbreak.[60] Moreover, New Zealand implemented strict lockdown policies and the closing of their borders.[61] Asia Pacific region, including New Zealand, Australia, and possibly Singapore have controlled coronavirus transmission more effectively than other countries.[62]

5 | CONCLUSIONS

Findings of this study indicates significant and unexpected associations between socioeconomic factors and the COVID-19 cases and deaths. According to the CCA results, the COVID-19 cases and mortality have risen as the HDI value, percentage of male smokers, and the elderly population increased, and have decreased as the number of tests per case decreased.

The most striking findings of our study are the positive correlation of HDI and GHSI, and the negative correlation of the probability of dying from chronic diseases and GINI index with the reported cases and deaths in the countries. These results show that improved indicators regarding economy and capability to prevent and mitigate epidemics and pandemics do not guarantee success in managing the COVID-19 pandemic. Results of the MULTIMOORA method indicates that Slovenia, Czech Republic, and Croatia are in the least favourable condition while Singapore, New Zealand, and Australia are in the best. Canada, Denmark, Germany, Ireland, and Norway have less favourable conditions. Three countries, Singapore, New Zealand and Australia, that are surrounded by water seem to be more successful during the pandemic compared to other countries by better implementing policies on physical distancing, wearing masks, staying at home, closing borders and testing practices.

5.1 | Limitations

Most important limitation of our study is its cross-sectional, descriptive nature and collection of data from open sources. Also, we did not investigate the role of some variables such as lockdowns, policies regarding mask use and social distancing. So, the statistical associations should be interpreted carefully.

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CONFLICT OF INTEREST

None declared.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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