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RETHINKING THE ROLE OF VASSINATIONS IN MITIGATING COVID-19 MORTALITY: A CROSS-NATIONAL SOCIOECONOMIC ANALYSIS

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Abstract

This study investigates the effectiveness of COVID-19 vaccination strategies in reducing mortality across a global sample of over 150 countries. A counterintuitive finding emerged: a positive correlation (r= .65) was observed between the percentage of fully vaccinated individuals and COVID-19 deaths in January 2022. Regression analysis, controlling for GDP per capita, confirmed this association, indicating a 0.7% increase in expected deaths per 100,000 with each 1% rise in full vaccination rates. These findings suggest that vaccination alone may not be sufficient to curb the pandemic's negative impacts. Socioeconomic and environmental factors, viral mutations, and technological disparities (e.g., ventilator availability) likely play a significant role in mortality rates between countries. The study concludes that a multifaceted approach encompassing vaccination alongside measures addressing these additional factors is crucial for mitigating the COVID-19 pandemic's spread and mortality.

Keywords: COVID-19; Vaccination Rates, Mortality Rates, Cross-National Analysis, Public Health Policy.
Classification: I18, I12, H51, O15, O54.

COVID-19 ÖLÜM ORANINI AZALTMADA AŞILANMANIN ROLÜNÜN YENİDEN DÜŞÜNÜLMESİ: ÜLKELERARARASI SOSYOEKONOMİK BİR ANALİZ

Öz

Bu çalışma, 150'den fazla ülkeden oluşan küresel bir örneklemde COVID-19 aşılama stratejilerinin ölüm oranını azaltmadaki etkinliğini araştırmaktadır. Sezgiye aykırı bir bulgu ortaya çıktı: Ocak 2022'de tam aşılanmış bireylerin yüzdesi ile COVID-19 ölümleri arasında pozitif bir korelasyon (r = .65) gözlemlendi. Kişi başına düşen GSYİH'yi kontrol eden regresyon analizi, bu ilişkiyi doğruladı ve tam aşılama oranlarında her %1 artışla 100.000 kişi başına beklenen ölümlerde %0,7'lik bir artış olduğunu gösterdi. Bu bulgular, aşılamanın tek başına salgının olumsuz etkilerini azaltmak için yeterli olmayabileceğini düşündürmektedir. Sosyoekonomik ve çevresel faktörler, viral mutasyonlar ve teknolojik farklılıklar (örneğin, ventilatör bulunabilirliği) muhtemelen ülkeler arasındaki ölüm oranlarında önemli bir rol oynamaktadır. Çalışma, aşılamanın yanı sıra bu ek faktörleri ele alan önlemleri de kapsayan çok yönlü bir yaklaşımın COVID-19 salgınının yayılmasını ve ölüm oranını azaltmak için hayati önem taşıdığı sonucuna varmıştır.

Anahtar Kelimeler: COVID-19, Aşılama Oranları, Ölüm Oranları, Ülkelerarası Analiz, Halk Sağlığı Politikası.
JEL Kodları: I18, I12, H51, O15, O54.

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1. INTRODUCTION

The COVID-19 pandemic, caused by the novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), continues to cast a long shadow on the socioeconomic landscape even as we navigate through 2022 (Bontempi et al., 2021; Bontempi and Coccia, 2021; Coccia, 2020, 2020a, 2020b, 2021; JHCSSE, 2022; Vinceti et al., 2021). The initial response in 2020 involved a global scramble to implement non-pharmaceutical interventions (NPIs) such as lockdowns and quarantines to curb the escalating crisis (JHCSSE, 2022). As 2021 and 2022 unfolded, the primary public health strategy transitioned towards widespread vaccination campaigns utilizing novel vaccine technologies based on viral vectors, protein subunits, and messenger RNA (Abbasi, 2020; Coccia, 2021, 2022, 2022a; Mayo Clinic, 2021). These vaccination programs were implemented with the optimistic goal of reducing COVID-19 transmission, facilitating a relaxation of NPIs, and maintaining a low basic reproduction number (R0). However, a critical question remains: to what extent are these novel vaccines demonstrably effective in significantly curtailing COVID-19 cases and deaths across diverse countries? Can they effectively control and potentially eradicate the pandemic's spread, thereby mitigating its detrimental societal impacts (Aldila et al., 2021; Coccia, 2021a; Prieto Cruriel et al., 2021; Saadi et al., 2021; Hoo and Soo, 1995)?

Efficient, government-orchestrated vaccination campaigns are paramount in significantly reducing community transmission rates and alleviating the burden on healthcare systems, as highlighted by Akamatsu et al. (2021) (Coccia, 2021b, 2021c, 2022a). Conversely, Shattock et al. (2021) propose that a comprehensive and swift vaccination rollout could expedite the relaxation of non-pharmaceutical interventions (NPIs). However, the emergence of new SARS-CoV-2 variants necessitates a reevaluation of control strategies due to the added complexities they introduce (Fontanet et al., 2021; Papanikolaou et al., 2021). These researchers advocate for a gradual, phased approach to easing restrictions to minimize population-level morbidity and mortality. Furthermore, a more rapid vaccination campaign could potentially mitigate the severity of the pandemic wave, allowing for greater flexibility in relaxing NPIs sooner (Shattock et al., 2021). Aldila et al. (2021) posit that achieving high vaccination coverage across a population could lead to COVID-19 eradication through herd immunity, indirectly protecting vulnerable individuals (Anderson et al., 2020; de Vlas and Coffeng, 2021; Randolph and Barreiro, 2020). However, Aschwanden (2020, 2021) challenges the feasibility of achieving herd immunity, labeling it a "misconception" due to the multitude of factors influencing COVID-19 transmission dynamics (cf., Moore et al., 2021).

The COVID-19 pandemic has exposed and exacerbated existing social disparities, significantly impacting mortality rates. A study by Seligman et al. (2021) analyzing US demographic data revealed an average COVID-19 death age of 71.6 years, with a near-even split between females and non-Hispanic whites. However, the data also highlighted a disproportionate burden on racial/ethnic minorities, individuals from lower socioeconomic backgrounds, those with less education, and veterans (Davies et al., 2021; Wolf et al., 2021).

In essence, stark racial/ethnic and socioeconomic disparities were evident. Racial/ethnic minorities and individuals of lower socioeconomic status experienced a higher mortality burden due to factors such as limited access to healthcare and education. Garber (2021) observed a rise in US COVID-19 mortality with increasing age, mirroring the overall pattern. Age-specific mortality rates were higher among groups already facing higher baseline mortality rates, such as non-Hispanic Black people, further reflected in projections of life expectancy.

Ackley et al. (2022) delved deeper into the US pandemic impact, uncovering a significant portion of excess deaths not directly attributed to COVID-19. Their model estimates suggest that in 2020, the US experienced approximately 438,386 excess deaths, with only 87.5% directly attributed to COVID-19. Geographical disparities were also evident, with regions like Mideast, Great Lakes, and New England reporting the most excess deaths, primarily in large metropolitan areas (Stokes et al., 2021).

Globally, comparable patterns emerged. Numerous countries had an increase in 2020 mortality rates, according to Sanmarchi et al. (2021). Excess mortality (EM) and confirmed COVID-19 mortality (CCM) differed significantly in a number of Latin American and Eastern European nations, including Mexico. Greece, on the other hand, displayed a mild EM that went above CCM. It's interesting to note that nations with negative EM were mostly in East Asia and had extremely low CCM. These results point to possible differences between countries in terms of testing, reporting procedures, and underlying causes of death (Islam et al., 2021). Islam et al. (2021) also brought attention to the fact that in 2020, high-income nations as a whole saw about one million extra fatalities. In the majority of the countries under study, men's age-standardized excess death rates were consistently greater than those of women. Excess mortality greatly outpaced recorded COVID-19 deaths in many countries, highlighting the necessity of evaluating excess mortality to fully comprehend the pandemic's effects. According to Kiang et al. (2020), the actual number of COVID-19-related deaths—both directly and indirectly—is probably far higher than the numbers that have been released.

These studies collectively underscore COVID-19 pandemic mortality as a multifaceted indicator intricately linked to demographics, socioeconomic determinants, healthcare access, and geographical location (Barnard et al., 2021; Garber, 2021; Islam et al., 2021; Stokes et al., 2021, 2021a; Woolf et al., 2021). The goal of the current study is to examine the links between vaccination rates and death rates in various nations within this complex setting. The goal of this research is to comprehend how many elements interact to affect the spread of pandemics and their effects on society. Best practices for handling the current and upcoming pandemics can be influenced by the findings (Coccia, 2019). This study is a component of a larger initiative that aims to pinpoint the fundamental causes of the dynamics of COVID-19 transmission and develop sensible policy measures for potential pandemics in the future (Coccia, 2020, 2020a, 2020c, 2021, 2022, 2022a).

2. EMPRICAL FRAMEWORK

2.1. Sample

This study's global sample size consists of N=151 nations. The sample size may be less for certain statistical analyses if there are missing data for some variables due to various confounding factors.

2.2. Measures for Statistical Analyses

This study's principal metric for gauging vaccination coverage is the percentage of a nation's population that achieved full vaccination against COVID-19 by January 11th, 2022. Although the data mostly reflects this particular date, due to difficulties with data gathering and reporting, there may be sporadic instances where information for specific countries comes from December 2021. It is crucial to acknowledge that this minor temporal discrepancy within a limited number of countries has a statistically insignificant impact when analyzing a large sample exceeding 100 units. The data encompasses all COVID-19 vaccine types administered globally, including those developed by Johnson and Johnson, Oxford/AstraZeneca, Pfizer/BioNTech, Sinopharm/Beijing, Sinovac, Sputnik V, and Moderna (Ritchie et al., 2020). Notably, each country has adopted a distinct combination of these vaccines within their national immunization strategies. (Source: Our World in Data, 2022)

GDP per Capita: In order to account for inflationary effects, GDP per capita data for the year 2020 is integrated in this analysis and expressed in constant 2010 US dollars. A country's total GDP is divided by its mid-year population to determine its GDP per capita. The GDP itself is a measure of the total monetary worth of all finished products and services produced over a given time period inside an economy. It is calculated by adding up all resident producers' gross value added, deducting any product taxes, and adding back any subsidies that were not included in the product value. It is significant to remember that depreciation of manufactured assets and depletion or deterioration of natural resources are not included in this computation. The data employed in this analysis are presented in constant 2010 US dollars to facilitate comparisons across countries while controlling for inflation. (Source: The World Bank, 2022)

Population Data: The population data used in this study complies with the de facto definition, which includes all people living inside a nation's borders, irrespective of their citizenship or legal status. Mid-year population estimates obtained from The World Bank (2022a) are represented by the values.

COVID-19 Deaths: This study incorporates data on the cumulative number of COVID-19 deaths reported in January 2022. This metric serves as a crucial indicator of the severity of this novel infectious disease's impact on various socioeconomic systems. Additionally, the study calculates the mortality rate per 100,000 people to enable comparative analysis between countries. (Source of data: JHCSSE, 2022).

2.3. Data Analysis Procedure and Model

The initial phase of the analysis involves the application of descriptive statistics to summarize the key characteristics of the data set. Specifically, the arithmetic mean and standard error of the mean will be employed to capture the central tendency and variability of the data, respectively. A critical step in the analysis involves assessing the normality of the distribution for each variable under investigation. This assessment will be conducted by examining the skewness and kurtosis coefficients. Skewness refers to the asymmetry of a distribution, while kurtosis indicates the degree to which the tails of the distribution differ from those of a normal distribution. If a variable exhibits a non-normal distribution, a logarithmic transformation will be applied to normalize the data. This transformation process is essential for ensuring that the underlying assumptions for subsequent parametric statistical tests are met. By normalizing the data, we enhance the reliability and validity of the analyses that follow (Coccia, 2018).

This study focuses on the following ratio of COVID-19 deaths calculated for all countries:

$$Mortality\ rate\ per\ 100\ 000\ people = \left(\frac{Total\ number\ of\ deaths\ from\ COVID-19\ at\ January\ 2022}{Total\ population\ in\ 2020}\right) \times 100\ 000$$

Following the initial descriptive analysis, the next stage delves into the relationships between the variables under investigation. To quantify the potential linear associations between the continuous variables, this study will primarily employ the Pearson correlation coefficient (r). This coefficient ranges in value from -1 to +1, with a value of 0 indicating no linear association, positive values signifying a positive correlation (variables move in the same direction), and negative values indicating a negative correlation (variables move in opposite directions). The strength of the association is reflected by the magnitude of the coefficient, with values closer to +1 or -1 representing stronger correlations. In this specific context, the The percentage of a nation's population that has received all recommended vaccinations against COVID-19 and the mortality rate (measured in deaths per 100,000 people) for each of the study's participating nations will be compared using the Pearson correlation coefficient. However, by including partial correlation, the study goes beyond a basic bivariate technique. This statistical method accounts for the possible confounding effect of a third variable, Gross Domestic Product (GDP) per capita, while also illuminating the direction and strength of a linear relationship between the aforementioned continuous variables. A confounding variable is one that is associated with both the independent and dependent variables, potentially masking or distorting the true relationship between them. By statistically controlling for GDP per capita's influence, partial correlation allows for a more refined understanding of the association between vaccination rates and mortality rates. This nuanced approach helps to isolate the unique effect of vaccination rates on mortality rates, independent of the potential influence of a nation's economic wealth.

These broad recommendations can be used to evaluate the correlation's strength:

$0.1 < | r | < 0.3$ … small/weak correlation

$0.3 < | r | < 0.5$ … medium/moderate correlation

$0.5 < | r |$ ……… large/strong correlation

Thirdly, using multiple regression analysis (independent variables or predictors), the value of two explanatory factors—the proportion of the population that has received the full COVID-19 vaccination and GDP per capita—is used to forecast the value of the mortality rate (dependent or response variable).

The log-log model definition is provided by:

$$\log y_{i,t} = \alpha_0 + \beta_1 \log x_{i,t} + \beta_2 \log z_{i,t-1} + u_{i,t} \qquad (1)$$

where:

$y_{i,t-}$ = Mortality rate of COVID-19 in January 2022.

$x_{i,t}$ = percentage of individuals who had all COVID-19 vaccinations in January 2022

$z_{i,t-1}$ = GDP per capita in 2020

$u_{i,t}$ = Error term

country $i=1, \ldots, n;$ $t=time$

Regression analysis was used in this investigation to carefully assess how well the model fits the observed data. To arrive to this conclusion, two crucial measures were examined: the standard error of the estimate and R-squared, which is also referred to as the coefficient of determination. R-squared measures the percentage of the dependent variable's variance that can be ascribed to the independent variables. In simpler terms, it reflects the percentage of the dependent variable's overall variability that the independent variables account for. Consequently, a higher R-squared value signifies a superior fit between the model and the data. To strengthen this assessment, the F-statistic, derived from the ANOVA table, was employed to test the overall effectiveness of the model fit. Furthermore, to gain a deeper understanding of the influence exerted by each independent variable on the dependent variable, unstandardized partial regression coefficients were examined. These coefficients isolate the impact of each independent variable while effectively controlling for the potential confounding effects of the other independent variables. This enables researchers to pinpoint the specific contribution of each variable to the dependent variable's behavior. Finally, t-tests were implemented to determine the statistical significance of each independent variable within the model. Statistical significance in this context implies that the relationship observed between the independent variable and the dependent variable is not merely due to chance, but rather reflects a genuine underlying association. By employing this comprehensive approach, the analysis effectively assessed the model's fit to the data and provided valuable insights into the relative influence of each independent variable.

3. RESULTS

The analysis's variables' summary statistics are shown in Table 1. Crucially, the table also shows that, in order to get a normal distribution, some variables underwent logarithmic transformation. This conversion guarantees that the information satisfies the presumptions of the statistical tests used thereafter, which are intended for data that is normally distributed.

Table 1. Descriptive statistics

Variables	N	Mean	Std. Error of Mean	Skewness	Kurtosis
GDPPC 2020, GDP per capita $	151	14,457.69	1,716.74	2.68	9.64
MOR2022, Mortality rate per 100 000 people (number)	151	111.43	9.75	1.33	1.69
VAC2022, Share % of people fully vaccinated	144	44.14	2.26	-0.13	-1.29
Log GDPPC2020	149	8.68	0.12	0.07	-0.90
LogMOR2022	151	3.82	0.13	-0.58	-0.68
LogVAC2022	144	3.40	0.09	-1.44	1.39

In the sample of N=144 nations, the bivariate Pearson link yields a positive coefficient r=.65 (p-value<0.01), indicating a substantial link between the percentage of persons fully vaccinated and the death rate per 100,000 people. This result is supported by table 3's partial correlation, which, after adjusting for the impact of GDP per capita, shows a moderate linear association between the continuous variables that were previously discussed (r partial =.44, p-value =.001).

Table 2. Bivariate correlation

Pearson Correlation	LogVAC2022	LogMOR2022
LogVAC2022	1	.646**
N	144	144

Note: MOR2022, Death per 100,000 persons in 2022; VAC2022, The percentage of individuals who received all recommended vaccinations in 2022; **The correlation is significant at the 0.01 level (1-tailed).

Table 3. Partial correlation

Control variable: GDPPC2020	Partial Correlation	LogVAC2022	LogMOR2022
	LogVAC2022	1	.443***
	N	135	135

Note: The variables that are significant at the 0.001 level (1-tailed) are the GDPPC 2020, GDP per capita; MOR2022, death rate per 100,000 persons in 2022; and VAC2022, share of people fully vaccinated in 2022.

The results shown in Table 4 require a more thorough analysis of the multivariate relationship, as Equation [1] illustrates. Two important explanatory factors are included in this equation: the GDP per capita in 2020 and the percentage of individuals who had the full COVID-19 vaccination in 2022. The multivariate analysis offers a more nuanced viewpoint by identifying the partial effects of one variable while controlling for the influence of the other, even though the original, simpler regression analyses can produce substantially comparable results.

Upon closer examination of the partial regression coefficients, several noteworthy findings become apparent. Counterintuitively, a 1% increase in the percentage of a nation's population that has received all recommended vaccinations (while maintaining a steady GDP per capita) is linked to a 0.7% increase in the anticipated COVID-19 death rate per 100,000 individuals. With a p-value of less than 0.001, this discovery, however, is statistically significant and suggests that there is little chance that this link is accidental. To investigate possible reasons for this unexpected result, more research is necessary. Determining whether this is a true causal relationship or whether this discovery could be influenced by other unmeasured factors is crucial.

On the other hand, a more logical pattern is suggested by the partial coefficient b2. Predicted COVID-19 death rate per 100,000 persons is predicted to rise by 0.2% for every 1% growth in GDP per capita (vaccination rates excluded). With a p-value less than 0.05, this link is likewise statistically significant. As with the earlier discovery, more research is advised to comprehend the mechanics behind this association.

With a p-value of less than 0.001, the F-statistic—which shows the ratio of explained variation to unexplained variance—indicates a high degree of statistical significance. This suggests that the data are well-fitted by the regression model as a whole. Stated differently, the variances in COVID-19 mortality rates are mostly explained by the combined impact of immunization rates and GDP per capita. The multiple regression model's R-squared value indicates that the two independent variables—vaccination rates and GDP per capita—can linearly explain roughly 53% of the variation in COVID-19 mortality rates. Even if this indicates a significant explanatory power, it's crucial to recognize that additional elements that the model does not account for could potentially be significant.

It is noteworthy that Figure 1 provides a restricted view of the model, showing the regression line for COVID-19 deaths per 100,000 persons based on the proportion of vaccinated individuals using a log-log model. For a thorough comprehension, it would be necessary to look at the regression lines for both independent variables and their interactions. A fuller picture of how vaccination rates, GDP per capita, and possibly their interaction affect COVID-19 death rates would be provided by this more comprehensive approach.

Table 4. Analysis of death rate in 2022 based on GDP per capita in 2020 and the number of persons who received all recommended vaccinations in 2022 using a log-log model [1].

	Simple Regression	Multiple regression
Constant α	0.754*	−0.542
(St. Err)	(0.325)	(0.665)
VAC2022, Coefficient β_1	0.917***	0.713***
(St. Err.)	(0.091)	(0.132)
GDPPC2020, Coefficient β_2	--	0.228*
(St. Err.)		(0.103)
R^2	.42	.43
(St. Err. of Estimate)	(1.23)	(1.22)
F	101.70***	52.80***

Note: MOR2022 (the mortality rate per 100,000 persons in 2022) is the dependent variable. This is the variable under investigation and the one that the other components help to explain. Explaining Factors: VAC2022 (Percentage of individuals who received the full COVID-19 vaccination in 2022) This is one element that could have an impact on death rates; Gross Domestic Product per capita in 2020, or GDPPC2020 This is an additional element that could affect death rates; Significance: VAC2022 (*** p-value<0.001): This suggests that the mortality rate and vaccination rate have a highly robust statistical association. A lower p-value suggests a higher significance. In this case, there's a very high probability that the observed effect of vaccination rate is not due to random chance. GDPPC2020 (* p-value<0.05): This shows a statistically significant, but less strong, relationship between GDP per capita and mortality rate.

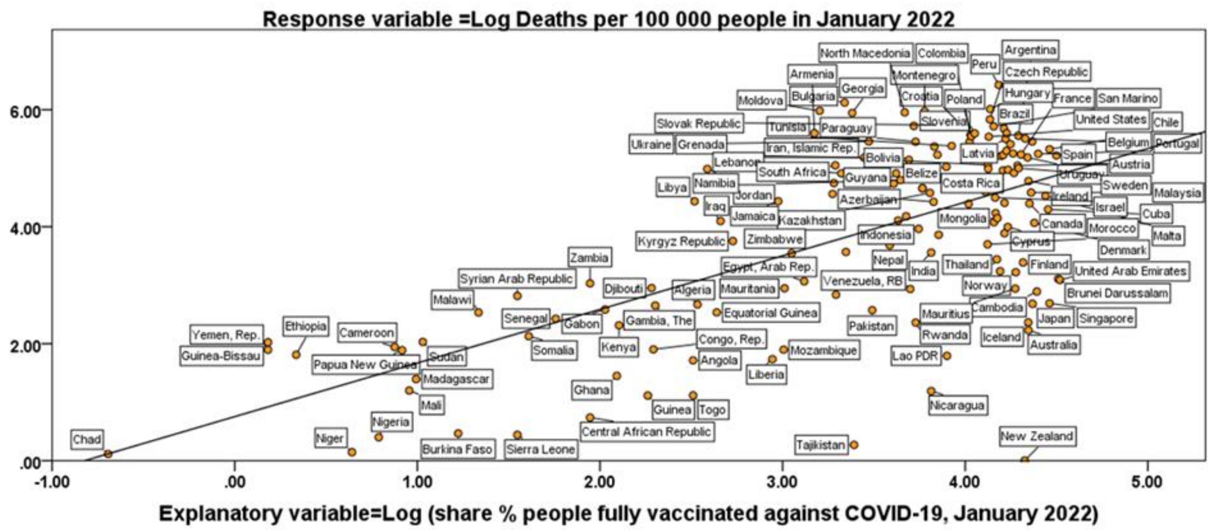

Figure 1. Relationship between the number of people vaccinated against COVID-19 (%) and the number of COVID-19 deaths per 100,000 people using a log-log model.

The study's results paint a nuanced picture, highlighting a critical point: while increasing vaccination rates is unquestionably a vital public health strategy, it may not be the sole factor in significantly curbing COVID-19 deaths. This underscores the intricate and multifaceted nature of the pandemic. A singular focus on boosting vaccination levels might not be enough to achieve the desired outcome. Here's why: the emergence and spread of new COVID-19 variants present a complex challenge with multiple dimensions. It's crucial to recognize that factors extending beyond vaccination rates, encompassing a wide range of environmental and socioeconomic conditions, significantly influence the dynamics of COVID-19 transmission. These multifaceted influences will be meticulously explored in the subsequent section of this analysis.

4. DISCUSSION

A significant relationship between vaccination rates and death rates was found by the investigation. Nations with higher rates of population immunization against COVID-19 have exhibited measurable reductions in the number of deaths per 100,000 individuals. The statistical significance of this link persisted even after accounting for GDP per capita, underscoring the independent impact of vaccination rates. One important finding from this study, though, is that immunization seems to be a required but insufficient condition to reduce COVID-19's harmful effects. The appearance and continued spread of viral strains with mutations highlight the intricate interactions between non-immunization elements that affect the disease's severity and ability to spread, even in populations with high vaccination rates.

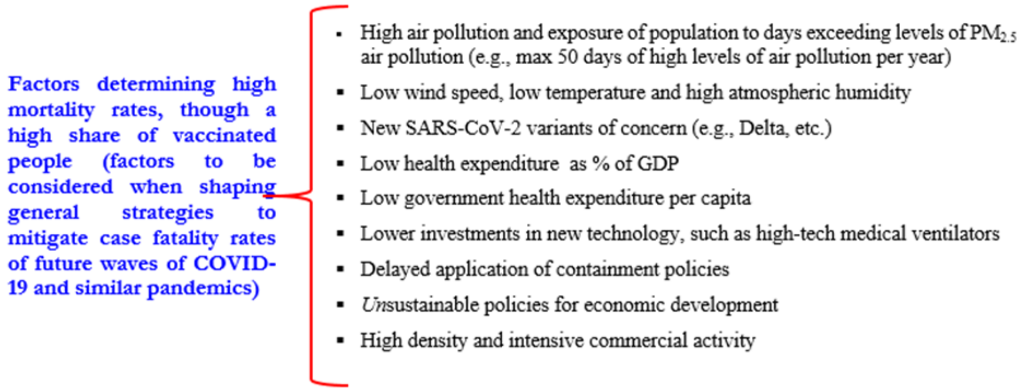

Figure 2. Factors contributing to high death rates, despite high vaccination rates throughout nations.

Considerations to be made while formulating general guidelines for managing pandemic outbreaks of novel viruses, including the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). The national commercial activity, high air pollution, high urban population density, lack of new technology (like non-invasive medical ventilation), low investments in the healthcare sector, and new variants all contribute to the unabated spread of COVID-19 throughout society (Figure 2).

A recent study by Coccia (2020a, 2020b, 2020c; Kargı and Coccia, 2024) examining data from Italian cities revealed a significant correlation between air pollution levels, geographic location, and COVID-19 case numbers. Cities exceeding annual air pollution limits for PM10 or ozone for more than 100 days displayed a higher incidence of cases. This trend was particularly concerning in inland (hinterland) areas bordering major urban centers. Hinterland locations with high air pollution and low wind speeds experienced a twofold increase in the average number of infected individuals in April 2020 compared to coastal cities with similar pollution levels but stronger winds. These findings highlight the potential influence of geospatial and environmental factors on the spread of COVID-19 and similar respiratory viruses. Building on this research, Coccia (2020a, 2022b, 2022c) emphasizes the importance of a healthy environment in mitigating COVID-19 infections and fatalities. Studies suggest an inverse relationship between air quality and COVID-19 mortality rates. In countries with lower COVID-19 fatalities, only an average of 72% of the population is exposed to air pollution exceeding World Health Organization (WHO) guidelines. Conversely, countries with higher mortality rates exhibit nearly 98% of their population breathing such polluted air. These observations suggest a potential protective effect of cleaner air. According to Coccia (2021), efforts for improving air quality should be given top priority in future pandemic preparedness plans, especially in rural and contaminated urban areas. Additionally, a review by Copat et al. (2020) examining several studies looking at the connection between air pollution and the transmission of COVID-19 indicates that certain pollutants, such as PM2.5 and NO2, may be involved in the virus's virulence and transmissibility. However, Coccia (2021) acknowledges the need for further research to solidify these connections, particularly regarding the exact mechanisms by which air pollution influences SARS-CoV-2 transmission dynamics and the broader societal impacts of such interactions.

New research points to a complicated relationship between wind patterns, air quality, and COVID-19 transmission. Research by Coccia (2020a) shows that air pollution levels and the spread of SARS-CoV-2 are positively correlated. On the other hand, high winds seem to be advantageous since they disperse pollutants, which may lead to a decrease in COVID-19 cases (Coccia, 2020b, 2021; Caliskan et al., 2020; Kargı et., 2023a, 2023b, 2023c). Stagnant air in urban environments acts as a trap for pollutants, potentially including viruses like SARS-CoV-2, which may contribute to higher COVID-

19 caseloads observed in certain European regions (Coccia, 2020a, 2020b, 2020c; 2021). Beyond pollutant dispersal, wind circulation might offer an additional layer of defense against viral transmission. Rosario et al. (2020) propose that wind not only removes pollutants but also increases viral exposure to sunlight, potentially hindering its spread. Supporting this hypothesis, Nicastro et al. (2021) conducted a spatial analysis examining the impact of ultraviolet (UV) light and solar radiation on SARS-CoV-2. Their research demonstrates that specific UV wavelengths have a potent inactivating effect on the virus's RNA. Notably, their findings suggest that midday summer sunlight in temperate regions can inactivate up to 63% of airborne viral particles within a matter of minutes.

Coccia's (2020a, 2020b) study on Italy revealed a correlation between population density and COVID-19 cases. Higher population density per square kilometer translates to a greater chance of interpersonal contact, potentially accelerating viral spread in cities, as confirmed by other research (Coccia, 2020a, 2021; Kargı, 2023, 2023a). Beyond population density, Bontempi and Coccia (2021) and Bontempi et al. (2021) identified a strong link between trade activity and COVID-19 spread. Their study on Italian provinces showed a significant positive correlation (average $r > 0.78$, p-value < 0.001) between import/export levels and confirmed cases over time. Similar findings emerged from a separate analysis of three European nations (Italy, France, Spain), further suggesting a positive association between trade and pandemic diffusion. This suggests that international trade data, encompassing economic, demographic, environmental, and climatic factors, might be a complex but valuable parameter when examining COVID-19 transmission dynamics.

New forms of the SARS-CoV-2 virus are constantly emerging as a result of mutations. The appearance of the Alpha (B.1.1.7) variant in the UK and the Beta (B.1.351) variant in South Africa was accompanied by a spike in COVID-19 cases in late 2020 (Fontanet et al., 2021). According to Fontanet et al. (2021) both variants showed spike protein mutations that increased transmission by an estimated 40–70%. In comparison to previous strains, the Alpha variation was not only more transmissible but also perhaps linked to a higher risk of death (61% increase), according to research by Davies et al. (2021). These results imply that Alpha may cause more serious illnesses in addition to spreading more quickly. Additional instances of how mutations might affect COVID-19 are the Delta (B.1.617.2) and Omicron (B.1.1.529) variants. Delta is thought to be almost twice as contagious as earlier variations and has the potential to cause more serious illness, especially in those who have not had a vaccination (Mayo Clinic, 2022). Vaccination appears to shorten the infectious period relative to unvaccinated persons, however breakthrough infections and transmission can still occur. Vaccines remain essential in preventing major illness even when their effectiveness against Delta may be marginally reduced (Mayo Clinic, 2022). Although the Omicron form is significantly more contagious than Delta, the extent of the illness it causes is still unknown (Mayo Clinic, 2022). Vaccination is still expected to be effective at preventing severe illness from Omicron, although breakthrough infections and transmission remain possibilities. The Alpha, Gamma, and Beta variants are currently less prevalent but continue to be monitored (Mayo Clinic, 2022). The Mu variant is also under observation. These evolving variants undoubtedly influence COVID-19 transmission dynamics and societal impacts.

A study by Coccia (2021e) suggests a link between healthcare spending and COVID-19 fatality rates. Countries with lower fatality rates tend to have higher average health expenditures, both as a percentage of GDP (7.6%) and per capita (around $2,300). Conversely, nations with higher COVID-19 death rates typically dedicate a smaller portion of their GDP (roughly 6%) to healthcare, with significantly lower per capita spending (around $243). This indicates a potential correlation between weak healthcare systems and higher COVID-19 mortality. Mechanical ventilators are a crucial technology in Intensive Care Units (ICUs) for critically ill patients, including those with COVID-19.

These devices help maintain proper oxygen and carbon dioxide levels by assisting patients who struggle to breathe on their own (IMARC, 2022). However, prolonged use of invasive mechanical ventilation can lead to complications like ventilator-associated lung injury. Non-invasive ventilation (NIV) offers a promising alternative to invasive methods. It delivers respiratory support without an invasive airway tube, improving patient comfort and potentially reducing costs (Soo Hoo, 2020, 2010). Newer NIV technology provides features like accurate airway pressure measurement, patient-triggered pressure assists, and improved humidification for enhanced comfort and airway clearance. Germany, a nation with a high number of ventilators (approximately 30,000 in 2020) despite a larger population (83.24 million), reported fewer COVID-19 deaths (117,318) compared to Argentina (120,019 deaths with a population of 45 million) (Our World in Data, 2022a; The World Bank, 2022a; JHCSSE, 2022). This case study supports the potential benefits of ventilator availability in mitigating COVID-19 mortality.

Scholars like Kapitsinis (2020) emphasize the importance of healthcare investment as a public policy tool to reduce COVID-19 mortality. Increased investment in hospital capacity, research and development of new technologies (vaccines, antivirals, innovative drugs), and high-tech medical devices can better equip nations to face future public health threats (Ardito et al., 2021; Coccia, 2017, 2017a, 2019, 2020).

CONCLUSIONS

The societal impact of COVID-19, particularly during an active pandemic, is demonstrably reflected in mortality rates (Lau et al., 2021; cf., Liu et al., 2021). Mitigating both mortality and case fatality rates remain paramount objectives for countries grappling with this global crisis (Coccia, 2020a, 2020d; Uçkaç et al., 2023, 2023a). Early pandemic responses largely relied on non-pharmaceutical interventions such as lockdowns (Coccia, 2020). However, by 2021 and 2022, mass vaccination campaigns emerged as the dominant global strategy.

This study explores the potential association between national vaccination rates and COVID-19 mortality. The findings suggest a nuanced relationship, where an increase in vaccination percentage is not necessarily correlated with a decrease in mortality across all countries. The authors posit that this complexity arises from the intricate interplay of factors influencing COVID-19 spread within diverse social and environmental contexts. While the study presents intriguing initial insights, it acknowledges several limitations that warrant consideration in future research.

First, the generalizability of the findings is hampered by the lack of availability to complete vaccination data for every nation. Second, not all possible confounding variables that could affect vaccination rates and death are taken into consideration in the study design. Prioritizing the control of these variables in future research can strengthen the study's conclusions and improve its causal inferences.

Thirdly, the lack of integrated socioeconomic data presents challenges for cross-country comparisons. Socioeconomic factors, as evidenced by research conducted by Angelopoulos et al. (2020) and Coccia (2018), can significantly influence mortality rates. Fourthly, future studies should incorporate data on country-specific healthcare investments, which can impact vaccination rates, healthcare management strategies, and ultimately, mortality outcomes.

Finally, the study's reliance on data from specific months necessitates caution when generalizing the results. Extending the analysis period and incorporating new data as it becomes available would strengthen the findings. Additionally, exploring a broader range of variables across countries would offer a more comprehensive understanding of the interaction between vaccination, mortality, and socioeconomic factors.

Despite the limitations, the study raises a critical point: achieving a significant reduction in COVID-19 mortality, controlling the pandemic, and mitigating its societal impacts might require a more multifaceted approach than solely relying on vaccination. More robust research endeavors are needed. This study underscores the importance of delving deeper into the complex interplay of factors driving pandemics within environmental and ecological contexts. Additionally, future research should consider the interactions between public health restrictions, vaccination efforts, and overall healthcare investments.

In conclusion, factors beyond purely medical considerations, encompassing social, economic, and innovation aspects, significantly influence COVID-19 mortality rates. Understanding these factors is paramount for effectively managing future pandemics and minimizing their negative impacts on public health, economies, and societies as a whole. Building upon these findings, future research should explore the relationships between the effects of pandemics on societies, healthcare systems, public health capacities, and national responses.

This study emphasizes the need for a multifaceted approach to managing future pandemics. Effective strategies should move beyond a solely vaccination-centric model and incorporate robust investments in healthcare systems, alongside comprehensive health, social, and economic crisis management policies. In order to lessen the diverse repercussions of pandemics on communities, it is essential to comprehend the intricate interactions between environmental and socioeconomic components. In the end, establishing ecosystems and socioeconomic systems that emphasize public health and general well-being can be achieved through conducting more research on socioeconomic issues, which can also help to inform and support the development of larger public health policies.

To further enhance our understanding of the societal impact of COVID-19 and inform effective pandemic management strategies, future research could explore the following areas:

- Long-term health consequences of COVID-19: Beyond mortality, investigating the long-term health implications of COVID-19 infections, such as chronic conditions and disabilities, is crucial for understanding the full scope of the pandemic's impact.

- Disparities in COVID-19 outcomes: Examining how factors like socioeconomic status, race, ethnicity, and geographic location influence COVID-19 outcomes can help identify vulnerable populations and inform targeted interventions.

- Mental health impacts of the pandemic: Assessing the psychological toll of COVID-19 on individuals and communities is essential for developing effective mental health support services.

- Economic consequences of pandemics: Analyzing the economic impacts of COVID-19, including job losses, business closures, and disruptions to supply chains, can inform policies aimed at mitigating economic damage and promoting recovery.

- Global cooperation and pandemic preparedness: Examining the role of international cooperation in addressing global health crises, such as COVID-19, can inform strategies for improving pandemic preparedness and response.

By addressing these areas, future research can contribute to a more comprehensive understanding of the societal impact of COVID-19 and inform the development of effective strategies for managing future pandemics.

Ethical Statement:

In the writing and publication processes of the study titled "*Rethinking the Role of Vaccinations in Mitigating COVID-19 Mortality: A Cross-National Analysis*," research and publication ethics have been strictly adhered to, and no data manipulation has been conducted. Ethics committee approval was not required for this study.

Contribution Statement:

The author of the study has contributed to all stages of the study, from writing to drafting, and has approved the final version after reviewing it.

Conflict of Interest Statement:

This study has not led to any individual or institutional/organizational conflict of interest.

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Extended Abstract

Rethinking the Role of Vaccinations in Mitigating COVID-19 Mortality: A Cross-National Socioeconomic Analysis

Aim: The COVID-19 pandemic has revealed significant vulnerabilities in public health systems, economies, and societal structures across the globe. This study investigates the factors contributing to COVID-19 mortality rates and transmission dynamics, focusing on the role of population density, trade activity, viral mutations, vaccination rates, and healthcare system capacity. By exploring these dimensions, the study aims to provide a nuanced understanding of the complex interplay between environmental, demographic, socioeconomic, and technological factors influencing pandemic outcomes. The ultimate goal is to inform more effective and equitable public health policies for current and future pandemics.

Method: This research synthesizes findings from multiple studies and datasets, incorporating diverse national contexts to evaluate key variables affecting COVID-19 mortality. The methodology includes an analysis of population density and trade activity as predictors of viral spread and examines the implications of healthcare expenditure and ventilator availability on mortality rates. The study also evaluates the impact of viral mutations—such as Alpha, Delta, and Omicron variants—on transmission dynamics and severity. Case studies comparing nations with varying healthcare capacities were utilized to provide deeper insights. Methodological limitations, including incomplete vaccination data, unaccounted confounding variables, and restricted timeframes, are discussed to guide future research.

Findings: Population density emerged as a primary factor influencing the spread of COVID-19. Studies by Coccia (2020a, 2020b) demonstrated that higher population densities significantly increased the likelihood of interpersonal contact, thereby accelerating transmission, particularly in urban areas. These findings align with research by Kargı (2023) and others, reinforcing the role of dense environments in facilitating viral spread. Trade activity also played a critical role, with studies highlighting a strong positive correlation between international trade levels and COVID-19 case counts. Bontempi and Coccia (2021) showed that Italian provinces with higher import/export activity had significantly elevated case numbers (average $r > 0.78$, p-value < 0.001), a trend corroborated by similar patterns observed in other European nations. These findings suggest that trade networks may act as conduits for viral transmission, amplifying the spread of infections across borders. Viral mutations further compounded the challenges of managing the pandemic. The Alpha (B.1.1.7) and Delta (B.1.617.2) variants exhibited higher transmissibility compared to earlier strains, with Alpha potentially increasing mortality by 61% (Davies et al., 2021). Vaccination campaigns significantly reduced severe disease outcomes but faced limitations due to varying efficacy across variants and the persistence of breakthrough infections. Despite these challenges, vaccination remains a critical tool for mitigating hospitalizations and deaths, particularly when complemented by robust public health measures. Healthcare system capacity and investment were strongly associated with mortality rates. Coccia (2021e) found that countries with higher health expenditures, averaging 7.6% of GDP or $2,300 per capita, reported lower fatality rates compared to nations with lower spending. Germany's case study, with 30,000 ventilators available for a population of 83.24 million, highlighted the benefits of adequate medical equipment in reducing COVID-19 deaths compared to Argentina, which experienced higher mortality with fewer resources.

Conclusion: The findings underscore the complexity of pandemic management, revealing that achieving substantial reductions in COVID-19 mortality requires a multifaceted approach. While vaccination remains vital, it is insufficient as a standalone strategy. Comprehensive public health policies must integrate healthcare investments, equitable resource distribution, and technological innovation to address the multifactorial drivers of pandemic outcomes. Future research is essential to fill existing gaps. Long-term studies should investigate the chronic health consequences of COVID-19, including conditions like long COVID and its impact on healthcare systems. Socioeconomic disparities must be further explored to identify vulnerable populations and inform targeted interventions. Additionally, the psychological toll of the pandemic on individuals and communities warrants greater attention, as mental health remains a critical component of societal resilience. Economic analyses should assess the broader impacts of pandemics, including disruptions to supply chains, job losses, and long-term recovery challenges. Global cooperation in addressing public health crises must also be prioritized, as international collaboration can enhance pandemic preparedness and response strategies. The study emphasizes that future pandemic management strategies must transcend vaccination-centric models, integrating robust investments in healthcare systems, innovative technologies, and comprehensive social and economic policies. Understanding the interplay between environmental, demographic, and socioeconomic factors is crucial for minimizing the adverse effects of pandemics. Ultimately, building resilient societies requires fostering ecosystems and socioeconomic systems that prioritize public health and well-being. By addressing the complex interdependencies of pandemic drivers, policymakers can develop adaptive responses that mitigate societal disruptions and safeguard public health. This study contributes to the growing body of

research on pandemic dynamics, highlighting the urgent need for holistic approaches to managing global health crises.