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The impact of COVID-19 vaccination coverage on reducing disease burden: A data-driven analysis comparing higher income and lower income countries

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ABSTRACT

COVID-19 (coronavirus disease 2019) vaccination remains a key preventive measure against the current pandemic. As of March 25, 2022, the World Health Organization (WHO) reported 476,374,234 confirmed cases of COVID-19 and more than six million deaths globally. Our motivation in this study was to examine differences in COVID-19 burden between countries (in terms of incidence and mortality), with the goal of answering whether countries with different income levels have different proportions of fully vaccinated individuals per 100,000 populations, whether this results in differences (on average) in COVID-19-specific incidence, mortality, and vaccination coverage, and whether vaccinations reduce the rate of infections and deaths caused by COVID-19. We performed simple one-way ANOVA (analysis of variance) tests as well as Spearman rank correlation analyses. Our results demonstrated that COVID-19 vaccination rates were low in low-income countries (LICs) and lower-middle-income countries (LMICs), and that the rates of recorded cases and deaths were the lowest in these countries as well (almost certainly due to low surveillance rates). In contrast, COVID-19 vaccination rates were high in high-income countries (HICs) and upper-middle-income countries (UMICs), and these countries also showed the highest rates of recorded cases and deaths. The country-level proportion of people receiving COVID-19 vaccines was statistically significantly and negatively correlated with COVID-19 descriptives in HICs and showed negative weak-to-moderate correlations in lower and middle-income countries. However, there is no proof that this association is causative in nature. Our findings inform research directions, policy initiatives, and medical guidelines.

1. Introduction

COVID-19 (coronavirus disease 2019) is a severe infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pathogen (Ortiz-Prado et al., 2020), a novel coronavirus; this is one of the deadliest viruses emerging in the past 100 years and has caused a global pandemic on an unprecedented scale. COVID-19 was first reported in late December 2019 in Wuhan, China (the capital city of Hubei province and one of the largest cities in central China). The virus and illness were unknown prior to this (Khan et al., 2020).

Published epidemiological and mechanistic data have shown that COVID-19 primarily spreads via respiratory droplets, direct contact with infected people, and contact with contaminated objects (Huang et al., 2020; Burke et al., 2020; Chan et al., 2020; Li et al., 2020; Liu et al., 2020). This virus has infected hundreds of millions of individuals worldwide. As of February 26, 2022, the WHO has reported over 430 million confirmed COVID-19 cases worldwide as well as over 5.9 million deaths (WHO, 2022). The COVID-19 pandemic has greatly affected the world population, and these effects appear to differ by country and region. Quarantine and lockdown procedures as well as individual precautions (such as social distancing, wearing facemasks, hand hygiene, and limiting interpersonal contact to outdoor settings) have been widely implemented during this pandemic, though with substantial pushback from citizens and various stakeholders.

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The pandemic's effects are far-reaching and complex and will not disappear soon. The lives of millions of individuals have been severely affected throughout the world. Moreover, the impacts of this disease are cascading and far-reaching, including reported climate impacts (i.e., precipitation, maximum and minimum temperatures) (Nundy et al., 2021). The detrimental influence of COVID-19 on economies, daily life, and social engagement, among other factors, has resulted in moderate to severe psychological and well-being impacts for many people (Cao et al., 2020).

Several researchers have concentrated their efforts on publishing articles focusing on different sectors of society that have been severely (and often differentially) affected by COVID-19 (Nundy et al., 2021; El-Rashidy et al., 2021; Shahzad et al., 2021). Such studies have revealed that COVID-19 has had a broad impact that goes far beyond its direct influence on mortality and morbidity (Nundy et al., 2021). For example, the pandemic has resulted in substantial negative impacts on the global economy due to lockdowns, curfews, and border closures, and has likewise resulted in negative adverse economic effects at the state and regional levels (such as leading to a decrease in supply and demand with regard to goods and services) (El-Rashidy et al., 2021; Shahzad et al., 2021). Unexpected impacts vary from one field to another (e.g., the economy and medical system) and include negative adverse effects on health as well as social, economic, and political consequences that have had a significant detrimental impact on everyday life. The pandemic has strongly and adversely affected the global economy as well as country-specific and regional economies on the micro and macro levels (Gu and Wang, 2020).

The world's developing countries represent 85% of the world's population; however, only 21% of pandemic deaths have been reported in these countries, likely due to a lack of sufficient surveillance (Schellekens and Sourrouille, 2020). Because of this remarkable disparity, our study focused on the impact of vaccinations on pandemic outcomes, such as morbidity and mortality. Our goal was to provide insight into answering questions as to whether different country-specific income levels result in differences (on average) in COVID-19 descriptives (i.e., incidence, mortality, vaccination coverage) and whether vaccinations reduce the rates of infections and deaths caused by COVID-19. We used World Bank income classifications, dividing countries into high-income countries (HICs), upper-middle-income countries (UMICs), lower-middle-income countries (LMICs), and low-income countries (LICS) (Lindsey et al., 2020).

1.1. COVID-19 by country-level income groupings

According to medical and policy experts, the residents of the world's poorest economies have been and continue to be disproportionately affected by the coronavirus pandemic; moreover, unless these individuals receive adequate assistance, hunger levels will skyrocket and political unrest may rise in some nations (WBG, 2022b). A brief summary of statistics pertaining to this topic is shown in Table 1, which reports the cumulative numbers of COVID-19 confirmed cases and deaths by World Bank income groupings as of February 26, 2022.

Severe COVID-19 outbreaks have spread to almost every country worldwide. Moreover, approximately 5.9 million individuals have died of COVID-19, with the highest number of deaths reported in HICs (incidence: 2,250,511 [38%] per 100,00 population; mortality: 447.842 deaths per 100,000 population), followed by UMICs (incidence: 2,630,933 [44%] per 100,000 population; mortality: 636.685 deaths per 100,000 population), LMICs (incidence: 991,304 [17%] per 100,000 population; mortality: 277.271 deaths per 100,000 population), and LICs (incidence: 42,459 [1%] per 100,000 population; mortality: 19.467 deaths per 100,000 population). Although nations with relatively high vaccination rates (e.g., HICs) have relatively low reported rates of transmission, the virus is still circulating at extremely high rates within these countries. In response to an increase in the number of new cases and deaths, certain European countries (such as Germany and Austria) are tightening restrictions, with a focus on people who have not yet been vaccinated (Siebert, 1997).

Table 1: Characteristics and COVID-19-specific information by country income-level grouping

Characteristics	HICs	UMICs	LMICs	LICs
Population	1,214,930,230	2,513,672,790	3,330,652,550	665,149,040
GNI per capita in USD	>12,695	4,096-12,695	1,046-4,095	<1,046
Cases (total cumulative)	232,383,113	125,735,555	69,247,951	1,840,018
Deaths (total cumulative)	2,250,511	2,630,933	991,304	42,458
Total vaccine doses	221,986,317,4	5,088,683,829	297,834,159,6	116,724,715
Total vaccine doses per 100 population	184.1	172.89	100.817	17.013
Fully vaccinated persons per 100 population	70.84	70.6	43.79	9.19

COVID-19, coronavirus disease 2019; GNI, gross national income; HICs, high-income countries; LICs, low-income countries; LMICs, lower-middle-income countries; UMICs, upper-middle-income countries; USD, US dollars

1.2. COVID-19 vaccinations

According to the WHO, there have been 476,374,234 confirmed cases of COVID-19 and more than six million deaths worldwide as of March 25, 2022. Approximately 60.9% of the world's population has received at least one COVID-19 vaccine, and approximately 10.92 billion vaccine doses have been administered in total (WHO, 2020). Accordingly, the WHO has developed a plan of action based on the values of justice and ethics in order to ensure an equal distribution of COVID-19

vaccinations and to determine the ideal period for administering these vaccinations (Duan et al., 2021). In addition, the WHO, the European Commission, and the French government have developed COVAX (COVID-19 Global Access), a worldwide risk-sharing structure for COVID-19 vaccine procurement and distribution, to increase access to COVID-19 diagnostics, medicines, and vaccinations. Approximately 78 HICs and economies have agreed to participate in the COVAX initiative (Andersson et al., 2021). COVAX has been shown to be the most effective strategy for controlling adverse effects on public health associated with the pandemic as well as the resulting economic consequences thereof (Wouters et al., 2021). A successful rollout of COVID-19 vaccines and prioritizing universal and equal access to vaccination may be our strongest hope for putting the pandemic and its devastating consequences behind us. Vaccines have been produced in mass, are proven to be highly effective, and have already been administered effectively in a range of countries throughout the world. Table 2 presents basic information regarding the most effective vaccinations that have been developed, tested, and produced to date.

Table 2: Examples of COVID-19 vaccines authorized by the WHO

Vaccine	Date of vaccine authorization
Pfizer/BioNTech Comirnaty	Dec 31, 2020
SII/COVISHIELD and AstraZeneca/AZD1222	Feb. 16, 2021
Janssen/Ad26.COV2.S	Mar. 12, 2021
Moderna (mRNA 1273)	Apr. 30, 2021
Sinopharm	Jun. 21, 2021
Bharat Biotech BBV152 COVAXIN	Nov. 3, 2021

COVID-19, coronavirus disease 2019; WHO, World Health Organization

Policy-level dilemmas in administering the distribution of COVID-19 vaccines have produced truly shocking inequalities that have disproportionately impacted the world's most vulnerable people (Klugman and Moore, 2020). Hence, adopted vaccination strategies have become a critical public affairs issue worldwide. Various challenges and controversies have emerged with regard to the most effective strategies to confront the pandemic on a global scale (Harris and Moss, 2021).

Vaccination coverage is currently below 10% in seven countries in the eastern Mediterranean region, and only approximately 10% of the population in LICs have received at least one dose. Whereas more than 80% of COVID-19 vaccines have been distributed within wealthy countries, LICs (which are mostly located in Africa) have received only 0.6% of the total vaccines distributed to date Moreover, 83% of eligible people in HICs have had at least one vaccine dose, whereas only 21% of the eligible population in LICs (on average) have received one vaccine dose (Franco-Paredes et al., 2021). Despite success within large-scale development and manufacturing, a dangerous gap in vaccine coverage still exists between the richest and the poorest countries For example, at the time when some rich countries began to explore the possibility of deploying booster doses of the vaccine in order to protect their populations more comprehensively, most of the populations of developing countries had not yet received even their first dose. There are urgent and complex challenges facing the industry as well as governing and regulatory bodies in making these vaccinations available globally. From both an ethical and practical published health perspective, it is critical that all individuals, not just the wealthy, are protected. Moreover, achieving large-scale economic recovery will not be achieved without ending the health crisis and effectively and uniformly administering vaccines on a global scale (Mathieu et al., 2021).

Inequities in the production and distribution of vaccines have given way to the emergence of deadly mutations that have had a devastating effect on millions of people throughout the world on an individual, family, community, and societal level (Ye et al., 2022). This is especially true in LICs, which have received the smallest number of vaccines as compared with middle and higher income countries. Moreover, a recent new mutation (i.e., a new coronavirus strain) has prompted countries, even those already implementing advanced vaccination programs, to reimpose stricter public health measures, and some countries have returned to implementing travel restrictions. In addition, the ongoing pandemic is deepening disparities in economic benchmarks, with dire consequences on a personal and financial level that impact everyone at all levels of the economy. Moreover, the unfair distribution of vaccines is not just a moral attack but is self-defeating economically and epidemiologically (Delabouglise and Boni, 2020) because it prolongs the duration of the crisis, the economic downturn, and the anguish of everyone affected by it. For these reasons, economists and policymakers stress that a new level of international support must focus on a strengthened coordination strategy, backed by sufficient funding, with the goal of effective implementation of vaccination programs in order to vaccinate the global population on a sufficient (ideally universal) scale.

We note that the worsening of the epidemiological scenario is not related to the rate of vaccine coverage as much as it is affected by the easing of prevention and containment measures prior to reaching a minimum level of vaccine coverage (Leung et al., 2021; Kiem et al., 2021). Vaccines reduce infection risk and particularly reduce severe disease and the need for treatment in

hospitals. Subject matter experts are concerned that the aggravation of the epidemiological situation in some countries will lead to a reversal in economic breakthroughs that were paved by the containment of the virus in countries that recorded high rates of vaccination coverage, which in turn prompted United Nations member states to start easing restrictions imposed on movement during the first pandemic waves (Bahl et al., 2021; Andre et al., 2008).

Containing the COVID-19 pandemic requires implementing critical control measures, including the use of facemasks, physical distancing, contact tracing, and isolation protocols. The development and implementation of vaccines are critically important measures in effectively controlling the COVID-19 pandemic, as vaccines have been proven to reduce disease-related morbidity and mortality (Andre et al., 2008). Several studies have investigated the association between macro-socioeconomic parameters and the global allocation of COVID-19 vaccines with a higher GNP (gross national product) per capita linked to higher immunization rates (Wu et al., 2020; Hughes et al., 2021) and several studies on COVID-19 vaccine equality have focused on vaccine access (i.e., domestic vaccination policies) in countries with varying income levels (Andersson et al., 2021; Yusuf et al., 2021; Duan et al., 2021).

This study specifically investigated the impact of COVID-19 vaccination coverage on reducing disease burden (measured in terms of morbidity and mortality), with country income level as a mediating factor. This study evaluated data up to January 2022, and included data for all variants of concern.

2. Material and methods

2.1. Data sources for epidemiologic data on COVID-19

COVID-19 epidemiological data available as of January 22, 2020, were retrieved from the publicly available open source database, Our World in Data (Tregoning et al., 2021). Our World in Data aggregates the most up-to-date statistics on the coronavirus pandemic reported by governments and health agencies worldwide, including with regard to COVID-19-specific variables (such as incidence, mortality, and vaccination coverage statistics). Data on country income levels were obtained from the World Bank (Ritchie et al., 2020). This secondary analysis of publicly available, aggregated, and anonymized data did not require ethics review board approval or obtaining participant informed consent.

2.2. Statistical hypotheses and analyses

Considering income groups based on the aforementioned World Bank classification scheme, we tested the null hypothesis that populations classified within four country-level economic groupings would be equally affected with regard to COVID-19 descriptives (i.e., incidence, mortality, vaccine coverage). We proposed the following hypothesis:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 \quad (1)$$

$$H_A: Not\ all\ \mu_j\ are\ equal, j = 1, 2, 3, 4 \quad (2)$$

In other words, we aimed to determine whether the four aforementioned country-level income groupings-LICS, LMICs, UMICs, and HICs-differed in terms of the mean number of deaths, the mean number of cases, and the mean number of vaccine doses that were administered in total in these countries. We aimed to answer whether different country-level income levels resulted in differences in the numbers of COVID-19 cases and deaths as well as in differences in the numbers of administered doses.

Hence, we calculated descriptive statistics to determine the differences in the average number of cases and deaths across groups of countries with different income levels. We performed simple one-way ANOVA (analysis of variance) tests using the aforementioned COVID-19 descriptives as dependent variables and "country income classifications" as predictive factors. The results of the Kolmogorov-Smirnov test for normality of variances and Levene's test for homogeneity of variances indicated that the data satisfied the ANOVA assumptions for normality and homogeneity of variances (P-value>0.05). Moreover, to quantify associations between vaccination and COVID-19 burden, we presented scatter diagrams and calculated the parameter ρ as well as population correlation coefficients in order to measure the direction and strength of the linear relationship between vaccination and various COVID-19 descriptives.

3. Results

The ANOVA results presented in Table 3 demonstrated a statistically significant difference among the World Bank income groupings in terms of incident cases (F=210.958, P=0.001), new deaths (F=545.824, P=0.001), new deaths per million populations (F=363.833, p=0.001), and new vaccinations (F=280.822, p=0.001). Post-hoc tests for the homogenous subsets revealed that all groups showed statistically significantly different means (P<0.0001). Differences were found between countries in all income groupings. In other words, we found differences in the daily averages with regard to new confirmed cases, deaths, deaths per million populations, and new vaccinations; accordingly, the different country-level income groupings could be ordered as follows (as summarized in Table 3):

1. Incident cases: HICs (mean=229,833, CI: 206,635, 253,033), UMICs (mean=126,171, CI: 120,284, 132,058), LMICs, (mean=95,772, CI: 88,821, 102,723), LICS (mean=2,481, CI: 2,295, 2,667)
2. New deaths: UMICs (mean=3,132, CI: 3,009, 3,255), HICs (mean=2,753, CI: 2,589, 2,918), LMICs

(mean=1,656, CI: 21,560, 1,754), and LICS (mean=57, CI: 53, 61),

3. New deaths per million populations: HICs (mean=2.2664, CI: 2.1309, 2.4019), UMICs) mean=1.2461, CI: 1.1971, 1.2950), LMICs) mean=0.4973, CI: 0.4682, 20.5265), LICS mean=0.0856, CI: 0.0796, 0.0917).
4. New vaccinations: UMICs) mean=11,382,795, CI: 10,599,499, 12,166,091), LMICs) mean=8,422,846, CI: 7,770,571, 9,075,121), HICs) mean=5,193,267, CI: 4,949,817, 5,436,717), and LICS) mean=279,863, CI: 616,030, 343,697)

Table 3: COVID-19 incidence, mortality, and vaccination rates stratified by country income level

COVID-19 statistics		N	Mean	Std. Dev.	Std. Error	95% CI for the mean		F (p-value)
						Lower bound	Upper bound	
New cases	LICs	695	2481	2494.723	94.63	2294.97	2666.56	210.96 (0.000)
	LMICs	727	95772	95466.412	3540.65	88820.87	102723.16	
	UMICs	727	126171	80851.560	2998.63	120284.40	132058.39	
	HICs	727	229833	318613.701	11816.73	206634.50	253032.57	
New deaths	LICs	695	57	54.384	2.06	52.86	60.96	545.82 (0.000)
	LMICs	727	1656	1333.451	49.46	1559.36	1753.54	
	UMICs	727	3132	1690.257	62.69	3009.11	3255.25	
	HICs	727	2753	2261.035	83.8	2588.59	2917.85	
New deaths per million	LICs	695	0.0856	0.08172	0.00310	0.0796	.0917	363.83 (0.000)
	LMICs	727	0.4973	0.40037	0.01485	0.4682	.5265	
	UMICs	727	1.2461	0.67241	0.02494	1.1971	1.2950	
	HICs	727	2.2664	1.86095	0.06902	2.1309	2.4019	
New vaccinations	LICs	315	279863	575808.817	32443.151	216029.69	343696.59	280.82 (0.000)
	LMICs	367	8422846	6354436.575	331698.89	7770570.87	9075120.53	
	UMICs	386	11382795	7827155.413	398391.72	10599498.99	12166090.6	
	HICs	412	5193267	2513794.038	123845.74	4949817.33	5436717.49	

CI, confidence interval; COVID-19, coronavirus disease 2019; HICs, high-income countries; LICs, low-income countries; LMICs, lower-middle-income countries; UMICs, upper-middle-income countries

Fig. 1 illustrates how trends in COVID-19 infections have changed over time. The general reported trend with regard to infection rates showed an increase over time among HICs, followed by similar but less pronounced patterns in UMICs, LMICs, and LICs. We note that, in the period spanning April to June 2021, incident cases were highest among individuals in LICs. Moreover, since October 2021, the data suggest that the monthly reported numbers of confirmed COVID-19 cases are the highest HICs, except for during the period between April and May 2021 (when the highest number of cases was reported in upper-middle-income countries). The number of incident cases steadily increased until January 2022.

Moreover, three pandemic waves are shown during the period spanning January 2020 to January 2022 (i.e., in January, May, and August 2021). In January 2022, one year after vaccination campaigns were started around the world, COVID-19 cases in HICs, UMICs, and LICs reached their highest monthly rates since the beginning of the pandemic (i.e., with the spread of the Omicron variant). The LMICs reached their highest rates in May 2021.

Fig. 2 suggests that the highest number of deaths in HICs occurred in April 2020, January 2021, and December 2021. In UMICs, the highest numbers of deaths were recorded in July 2020, January 2021, and April 2021. In LMICs, the highest numbers of deaths occurred in September 2020, May 2021, and August 2021. The LIC grouping experienced the lowest number of deaths during the study period, likely due to inadequate surveillance.

Fig. 3 suggests that vaccination coverage has varied and continues to vary widely by country-level income grouping. Vaccine coverage in HICs started early, showing a stable rate in December 2020 that continued an overall rising trend at a regular pace until January 2022. In UMICs, vaccination campaigns began in December 2020 and reached a climax in July 2021, with the vaccination of a total of 7,218,75,842 people. In LMICs, vaccination campaigns began in December 2020 and showed an increasing rate until September 2021. As expected, the LIC grouping had the lowest number of distributed vaccinations.

Fig. 4 illustrates the reported incident numbers of confirmed COVID-19 deaths per million population according to income-level country groupings as reported from January 22, 2020, to December 16, 2021. The data reported herein suggest that HICs recorded a noticeable increase in the number of new deaths since the beginning of the pandemic and until the end of May 2021. Following this time point, the number of new deaths began to decline. This was again followed by a new wave of the pandemic, spiking in the period between mid-October 2020 to mid-May 2021. This wave then subsided until mid-August 2021, with a new wave starting at the end of 2021.

Fig. 4 also indicates that UMICs reported higher average mortality (for example, new deaths per million population=9.03 on January 2020) as compared with HICs, and this trend was evident from the end of July 2020 until October 9, 2020. The number of deaths in UMICs continued to increase (though below the average mortality in HICs) until the period from July 2021 to August 5, 2020; hence, the curve for UMICs is consistently at a lower level than that for HICs. Moreover, the death curves for LMICs and LICs were always lower than those for HICs and UMICs, likely due to inadequate surveillance.

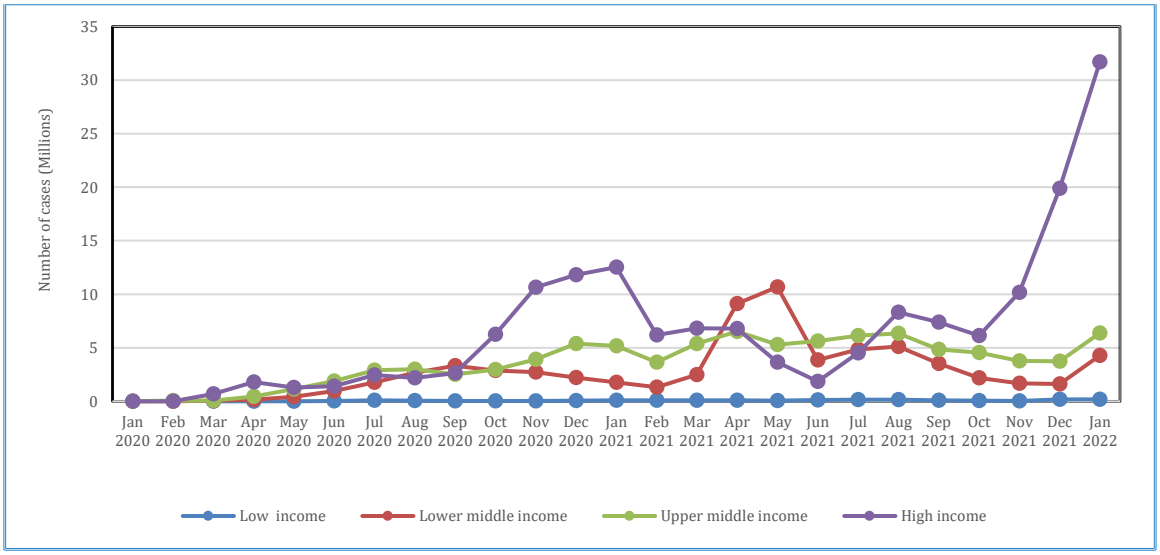

Fig. 1: Confirmed cases by country income level, January 2020 to January 2022

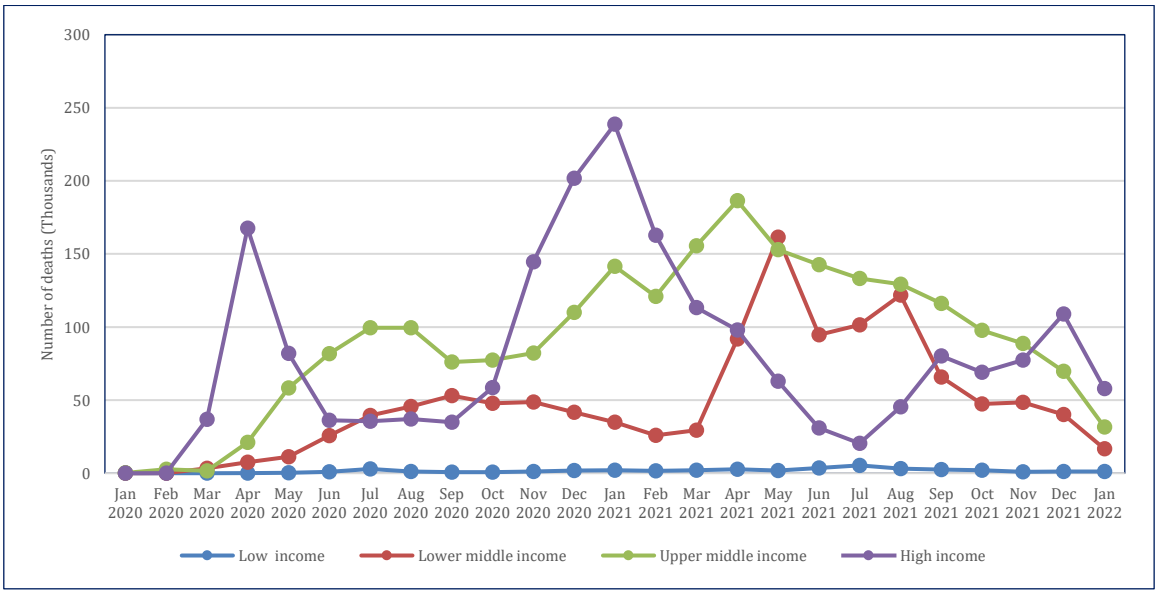

Fig. 2: Deaths by country income-level grouping, January 2020 to January 2022

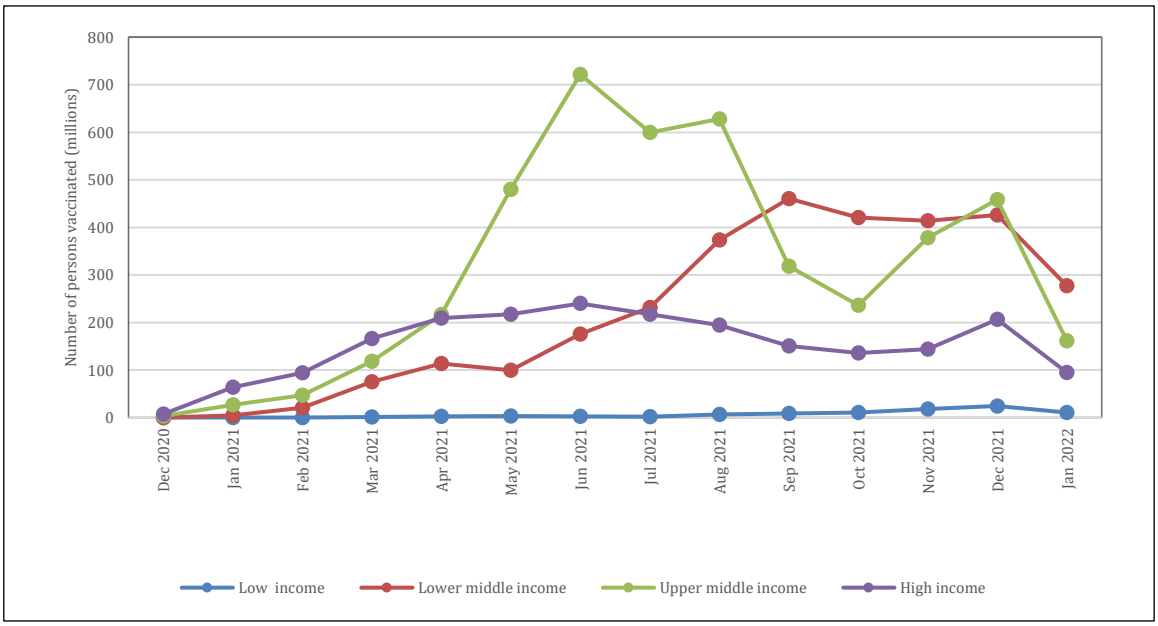

Fig. 3: Comparison of vaccination coverage by country-level income groupings

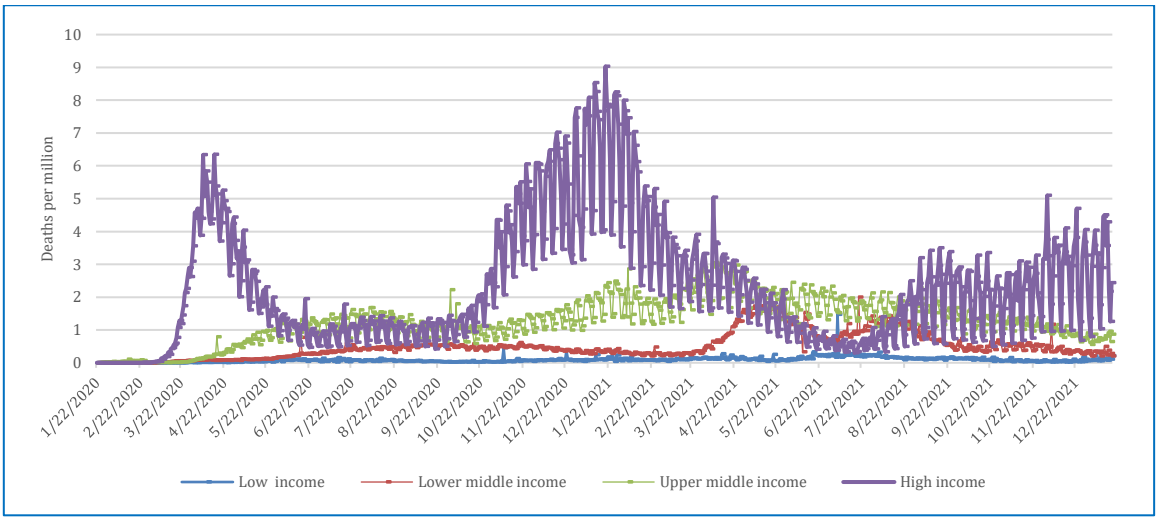

Fig. 4: New deaths per million populations, January 2020 to December 2021

We examined associations between vaccinations and COVID-19 mortality using a one-month lag within time series data on vaccinations, evaluated in association with mortality statistics. We analyzed datasets for countries in the four aforementioned income groupings—LICS, LMICs, UMICs, and HICs. The associations were measured using non-parametric Spearman's rank correlation coefficients (Table 4). The estimated correlation coefficient for HICs was r=-0.947, suggesting a strong, negative association between deaths and vaccinationsin HICs. The estimated correlation coefficient for UMICs was r=-0.65, suggesting a moderately statistically significant, negative association between deaths and vaccinationsin UMICs. The data also suggested a weak, statistically insignificant, negative association between deaths and vaccinationsin LMICs (r=-0.133), and a moderately statistically significant, negative association between deaths and vaccinationsin LICs (r=-0.673).

Table 4: Spearman rank correlation coefficients for the numbers of COVID-19 deaths according to monthly vaccinations, lagged by one month.

Country income grouping	Correlation coefficients
HICs	-0.947*
UMICs	-0.65*
LMICs	0.133
LICs	-0.673*

COVID-19, coronavirus disease 2019; HICs, high-income countries; LICs, low-income countries; LMICs, lower-middle-income countries; UMICs, upper-middle-income countries; *Statistically significant correlation at the 0.01 level

In terms of elucidating the contribution of vaccines in reducing the pandemic burden in terms of mortality, cross-correlations between vaccinations and mortality data show that changes in vaccine coverage in HICs were statistically significantly associated with the number of deaths reported in these countries. As shown in Fig. 5, the estimated linear model providing a good fit to the developed data is as follows:

$$\textit{Monthly deaths} = 216{,}792.9 - 0.001 * (\textit{monthly vaccinations lagged by one month})$$

This model, which included lagged effects, explained 89.7% of the observed variance in COVID-19 deaths. The results also show that mortality statistics showed low to moderate correlations with countries' vaccination coverage rates, as demonstrated in Figs. 6-8.

4. Discussion

In the study reported herein, we used F-tests to evaluate hypotheses evaluating different measures of COVID-19 burden. Our results suggest rejecting the null hypothesis for all evaluated variables (see Table 3). In other words, we conclude that there is a statistically significant variation in the number of incident cases between country-level economic groupings. Moreover, we conclude that the statistical evidence seems to support that UMICs have a high average COVID-19 burden rate in terms of incidence and mortality, followed by corresponding rates in HICs, LMICs, and LICs.

We analyzed datasets in countries classified into four income groups (LICs, LMICs, UMICs, and HICs). Although substantial efforts have been made to achieve a degree of protection that will limit the spread of the virus and the generation of new variants (WBG, 2022a), the current pandemic situation remains unclear. Statistical analysis of the study data evaluated herein showed that general trends in terms of cases of coronavirus infection as well as COVID-19 deaths for the four income groupings have been increasing from the beginning of the pandemic until January 2022 (Figs. 1-3).

The findings reported herein may be differentially affected by the characteristics of vaccination campaigns in lower income countries (Karn et al., 2021), which have low levels of

vaccination coverage. In addition, vaccination campaigns in poor countries have been nearly uniformly disrupted due to various logistical, societal, and infrastructure-based problems, including a lack of political commitment, a lack of security, and a wide range of logistical challenges (Sheikh et al., 2021).

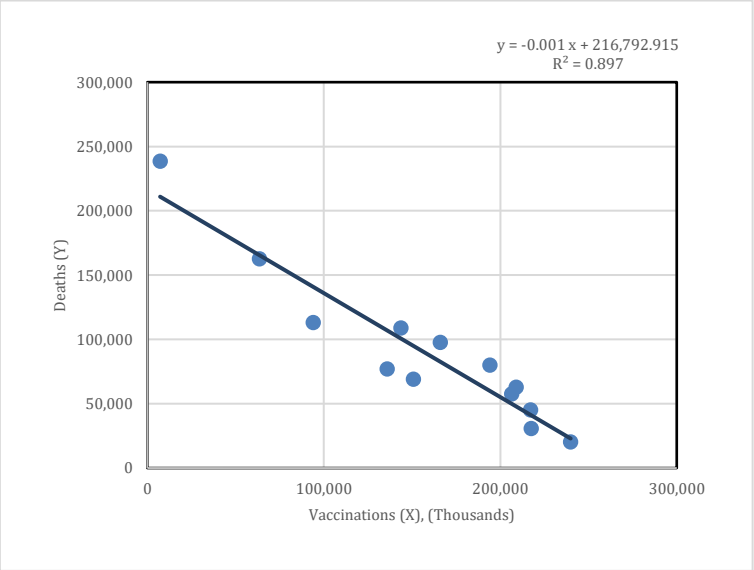

Fig. 5: Scatter plot of COVID-19 (coronavirus disease 2019) deaths vs. vaccinationsin high-income countries (HICs)

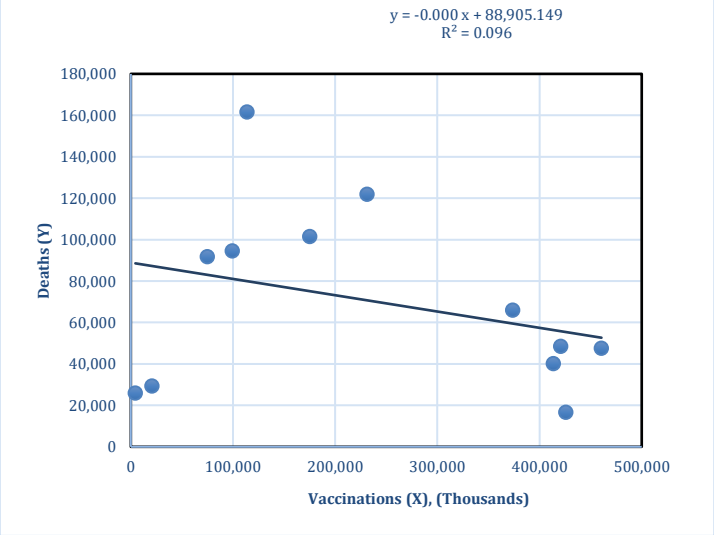

Fig. 6: Scatter plot of COVID-19 (coronavirus disease 2019) deaths vs. vaccinationsin lower-middle-income countries (LMICs)

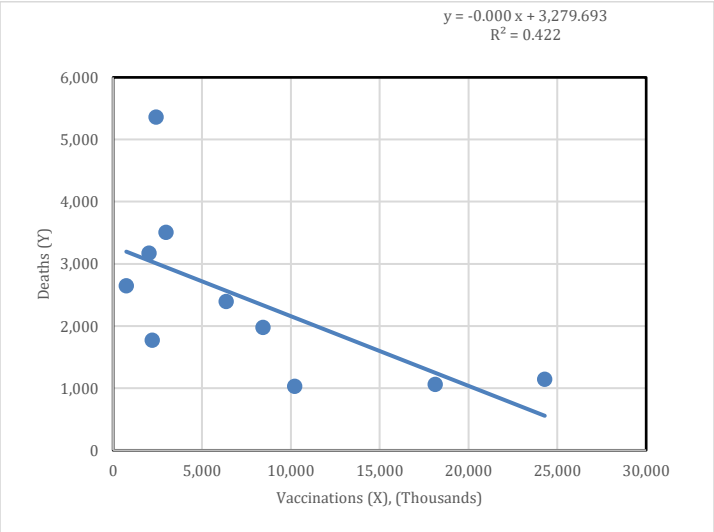

Fig. 7: Scatter plot of COVID-19 (coronavirus disease 2019) deaths vs. vaccinationsin low-income-countries (LICs)

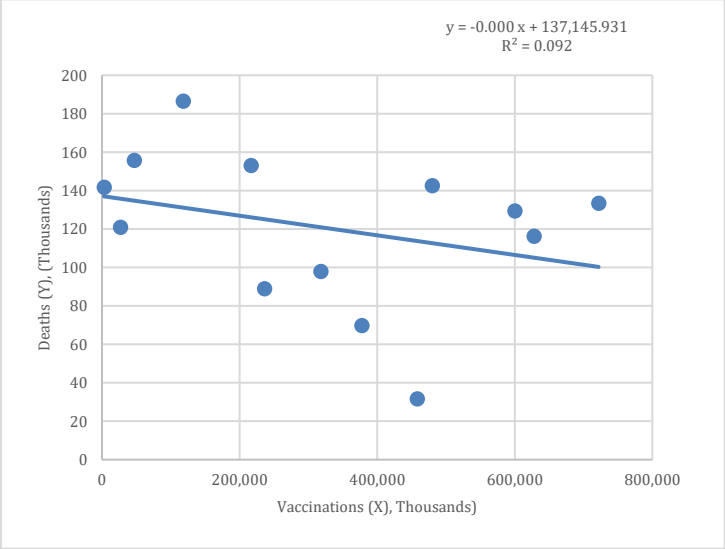

Fig. 8: Scatter plot of COVID-19 (coronavirus disease 2019) deaths vs. vaccinationsin upper middle-income countries (UMICs)

However, LICs and LMICs recorded low numbers of cases and deaths, almost certainly due to inadequate surveillance. As for higher income countries, although their citizens generally received early vaccination and the level of vaccine coverage reached a high rate in these countries, the rates of COVID-19 infection (transmission) as well as the associated mortality rates in these countries were also high.

According to our data analysis, the burden of disease was higher in higher income countriesthan in lower incomes countries, perhaps due to varying environmental and social conditions and vaccination levels in the respective populations. These trends are tied not only to the size of local populations but also to disease reproduction numbers (i.e., the mean number of secondary cases expected from an initial case in a susceptible population).

Citing this alleged imbalance as a justification, it is fruitful to mentionthat activists and more impartial policy experts alike contend that practically all diseases prevalent in LIC nations have been "neglected," (Coker et al., 2008) and that the pharmaceutical industry has invested essentially nothing in research and development with regard to these ailments in recent years (Stevens, 2004).

With regard to HICs, our data support the notion that a relationship between country-level vaccination rate and COVID-19 mortality exists (p-value<0.001) and is strongly negative (Fig. 5). In contrast, the association between deaths and vaccinationsin lower income countries seems to be weak (Figs. 6-8). This could be explained by the fact that in populations with high levels of vaccination coverage, the transmission of the virus drops dramatically following effective vaccine campaigns, though the COVID-19 virus can exceed the potency of vaccines to some extent. However, poor countries are still far from reaching that threshold. In the US, vaccination was found to be associated with a reduction in COVID-19 deaths during the first five months of vaccine availability (Gupta et al., 2021).

The reported linear model, describing the association between deaths and vaccination coverage lagged by one month (Fig. 5), provides a good fit for the data evaluated herein. The interpretation of this model is that increasing the monthly vaccination rate while keeping other factors constant, will reduce the death rate. Although this suggestion is in line with the general rule that COVID-19 vaccines reduce the risk of SARS-CoV-2 infection and the resulting death rate, our results suggest that LICs and LMICs have the least access to vaccines, though (likely underreported) death rates remain low in LICs and LMICs (Figs. 6-8). UMICs have the highest reported COVID-19 death rates, followed by HICs, LMICs, and LICs. COVID-19 deaths in HICs are at a peak. We note that the highest number of new deaths per million population (at a rate of 9.03 new deaths) was reported in January 2021 (Fig. 4).

This study has some limitations. First, due to a lack of comprehensive testing, the number of confirmed cases may be lower than the true number of cases in some countries. Second, the number of verified deaths in some countries was lower than the actual number of deaths. This is due to a lack of adequate testing and difficulties in determining causes of death, among other factors. Finally, we conclude that there is a high, statistically significant association between the burden of COVID-19 and inequalities in vaccine distribution. However, this study was not designed to assess causality, and there is no evidence that this relationship is causal in nature.

5. Conclusion

Although our data-driven analysis, which compares higher income and lower income countries, suggests that UMICs experienced the greatest losses to COVID-19, followed by HICs, LMICs, and LICs. We note that huge inequalities in access to pharmaceutical production infrastructure

and vaccine markets dominated by wealthy countries strongly affect vaccine deployment and ultimately vaccination coverage due to the current global vaccine allocation structure. While wealthy nations dominate global vaccine manufacturing, many impoverished nations, particularly in Africa, remain reliant on foreign donations. In these poor countries, COVID-19 cases and deaths have increased the vulnerability of the poor, who have lost precarious jobs, cannot afford to work from home because they rely on the street for income, and often lack access to healthcare and emergency aid. Currently, while some rich countries are removing restrictions due to the efficacy of their vaccine campaigns, vaccination rates in African countries are still low, with vaccine coverage in LICs reaching 15% (as compared to approximately 80% in HICs and UMICs). Hence, we predict that COVID-19 will likely continue to disproportionately affect lower-income countries due to low vaccination rates and we believe that it is highly likely that the disease will become endemic to poor countries in the future. Our findings provide data guiding initiatives that could attempt to mitigate these projected trends.

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Compliance with ethical standards

Conflict of interest

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

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