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Modelling the Relationship Between COVID-19 Vaccination and Cases/Deaths: Evidence from a Large Panel of Countries.

Matthew Biniyam Kursah[1*], Isaac Appiah-Otoo[2] & Faith Umborja Umborgati[3]

[1]Department of Geography Education, University of Education Winneba (UEW), Winneba, Ghana

[2]College of Management Science, Chengdu University of Technology, Chengdu, China

[3]Department of Health Administration and Education, University of Education Winneba (UEW), Winneba, Ghana

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abstract

This study examined the relationships between COVID-19 vaccinations, on the one hand, and COVID-19 cases and attributable deaths, on the other hand. This information is needed to fully inform public health decision-making on interventions, an area that has not been explored. The study used a sample of 84 countries, categorised into Africa (19), Asia (23), Europe (26), South America (8) and North America (8), spanning 01 January 2021 to 02 November 2022. This study employed the feasible generalised least squares (GLS) estimator for the analysis. The results showed that an increase in vaccination reduced the number of cases and deaths. The regional findings showed that vaccination reduced the number of cases in Europe and South America. It also reduced the number of cases in Africa, but the difference was not statistically significant. Also, vaccination significantly reduces deaths in all regions except Asia. The findings of this study suggest that vaccination is likely the best way to end this pandemic. It provides supporting evidence that vaccination is critical for reducing COVID-19 cases and even more so for preventing deaths among infected individuals. Also, vaccination has yielded greater health benefits in reducing cases and deaths in some regions of the world than others. Thus, continuously improving vaccine coverage and monitoring outcomes will be critical to translating efficacious vaccines into desirable health impacts. Accordingly, policies promoting vaccination, such as vaccine production in additional countries and financial or other incentives to reduce hesitancy, should be encouraged by the World Health Organisation (WHO), countries, and states.

1. Introduction

In late 2019, a new severe acute respiratory syndrome coronavirus, later named COVID-19, emerged, which was declared a pandemic in early 2020 by the World Health Organisation (WHO). Some countries, especially in Europe, North America and Asia, experienced the third and fourth waves of the virus, while others even experienced the fifth wave with deadly consequences. Generally, the virus continues to spread at an alarming rate worldwide (Adekunle et al., 2020; WHO, 2024). The main diffusion channels involved are human-to-human transmission, which is energised by temperature, air pollution and other environmental factors (Coccia, 2020).

To facilitate effective interventions, studies have been conducted to explore the spatial dynamics of the virus and the enabling factors involved (Bashir et al., 2020a; Bashir et al., 2020b; Cunningham, 2021; Killerby et al., 2020; Magazzino et al., 2021; Mehmood et al., 2021). Generally, there is consensus that increasing COVID-19 cases are likely to result in more attributable deaths (Adekunle et al., 2020; Appiah-Otoo & Kursah, 2021). With a panel of 232 countries, Appiah-Otoo and Kursah (2021) showed that cases significantly increase deaths at the global and regional levels. The study noted that a 1% increase in cases led to a 0.78% increase in deaths at the global level. Regionally, a 1% increase in cases led to a 0.90% increase in deaths in the Americas, 0.88% (Southeast Asia), 0.72% (Europe), 0.67% (Eastern Mediterranean), 0.65% (Africa) and 0.52% in the Western Pacific.

* Corresponding author.
E-mail address: mkursah@uew.edu.gh (M.B. Kursah).

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This implies a variation in the number of confirmed cases and deaths globally. Studies have also shown that the virus cases and deaths are not universal even within a country. In the Chinese provinces, an increase in cases of 1% increased deaths by ~0.10% to ~1.71% (Sarkodie & Owusu, 2020). A detailed analysis of COVID-19 cases and deaths using geo-visualisation techniques has also been conducted (Kodge, 2020). These models can help policymakers adopt the best strategies for mitigating the virus by tailoring control measures to the areas that need them most, which is critical for effective containment (Aslam et al., 2021).

The links between COVID-19 cases and deaths and pollution proxies have also been examined (Bashir et al., 2020a; Bashir et al., 2020b; Coccia, 2020; Magazzino et al., 2021). For example, Bashir et al (2020a) reported that the presence and severity of PM_{10}, $PM_{2.5}$, sulphur dioxide and nitrogen dioxide were significantly correlated with cases and deaths. Moreover, $PM_{2.5}$ and NO_2 are the most significant pollutants that cause COVID-19 deaths (Magazzino et al., 2021). Additionally, cities with high air pollution and low wind speeds had greater COVID-19 transmission (Coccia, 2020). Thus, reducing human exposure to pollutants is an effective COVID-19 mitigation strategy. The average temperature, minimum temperature and air quality have also been found to have significant associations with COVID-19 cases and deaths (Bashir et al., 2020b).

Studies have also examined how race/ethnicity and social inequities explain disparities in COVID-19 cases (Moore et al., 2020). For instance, health and social inequities have led to more cases of severe illness and deaths among minorities (Adeniji et al., 2021; Moore et al., 2020). This is because the population has faced significant socioeconomic inequalities (Adeniji et al., 2021). In the United States of America (USA), non-Hispanic black and Hispanic individuals were disproportionately represented in virus infections (Adeniji et al., 2021; Killerby et al., 2020). This is because this population had lower household income, lower rates of private insurance and uninsured persons, and a greater likelihood of living in multifamily housing and neighbourhoods with higher rates of poverty and overcrowding. These socioeconomic factors drive COVID-19 case counts and severity (Adeniji et al., 2021; Stokes et al., 2020). Additionally, these individuals are at a higher risk of death (Killerby et al., 2020; Moore et al., 2020; Stokes et al., 2020). In a USA study, Cunningham (2021) reported that physical activity also decreased the number of COVID-19 cases and the number of deaths. This is due to health benefits such as boosting the immune system through body exercise or activity.

Owing to variations in virus case counts, countries have adopted many and sometimes varied measures to combat the COVID-19 virus. Some of the measures used in managing the spread of the virus were quarantine, testing, isolation and travel bans. These measures have received scientific research (Ahmadi et al., 2020; Huang et al., 2021; Jabłońska et al., 2021; Lee et al., 2021). For example, a higher percentage of foreign travellers accelerated the peak of COVID-19 transmission (Jabłońska et al., 2021). Therefore, reducing individual movements and transits was key in fighting the virus. This justified the frequent lockdowns, quarantines and travel bans in most countries as COVID-19 mitigation strategies.

With time, attention shifted from the lockdown and related strategies due to negative economic spill-over effects. The emphasis on these measures has also dwindled due to the sustainability of the lockdowns and the resurgence of the virus in countries that initially applied the lockdown measures. These countries initially recorded fewer COVID-19 infections and lower mortalities. However, many of these countries, such as Peru, had higher mortality rates after the initial low case counts (Rentería et al., 2021). In late 2021 and early 2022, there was a reliance on vaccinating the general population as a control measure to fight the virus, even though a great source of information exists that highlights a growing hesitancy towards vaccines in some countries (BBC, 2021; Troiano & Nardi, 2021). However, few studies to date have assessed the impact of COVID-19 vaccination on case and death counts at a large scale to inform policymakers about the intervention's efficacy.

This study examines the statistical relationships between vaccination and COVID-19 cases and deaths using a global dataset of 84 countries (Appendix 1). The relationships between COVID-19 vaccination, cases and deaths in the 84 countries were examined using the feasible generalised least squares (GLS) estimator. The link between the socioeconomic indicators of human welfare/policies, such as population density, poverty rate, diabetes incidence, testing and stringency, and COVID-19 cases and deaths, are used as a control variable in the analysis. This will help fashion effective policy decisions to combat the virus. This study contributes to the knowledge of the dynamics of COVID-19 after two years of vaccination in 84 countries where data are available. The analysis of the effects of the vaccination programme on the case and death counts is needed to fully inform public health decision-making on the intervention, which has not been explored.

2. Methodology

2.1 Study Countries and regions

The study countries were 84 from five (5) regions corresponding to the five (5) major continents, Africa, Asia, Europe, North America and South America (Figure 1). The 84 countries and regions are shown in Appendix 1. There were 19 countries in Africa, 23 in Asia, 26 in Europe, eight (8) in North America and eight (8) in South America. These countries were chosen because of data availability. The countries were generally spread across the five regions to give a balanced assessment of the study.

2.2 Data

Datasets from 84 countries, further categorised into Africa (19), Asia (23), Europe (26), South America (8) and North America (8), spanning 01 January 2021 to 02 November 2022, were used based on data availability. Appendix 1 shows the country list. Datasets consisting of cases per 100 of the population, deaths per 100 of the population and people vaccinated per 100 of the population were used. From the literature review, we considered population density, the poverty rate (percent of people classified as poor), diabetes prevalence as a proxy for health conditions, testing per 100 people and stringency (government interventions such as lockdowns, social distancing and stay-at-home policies).

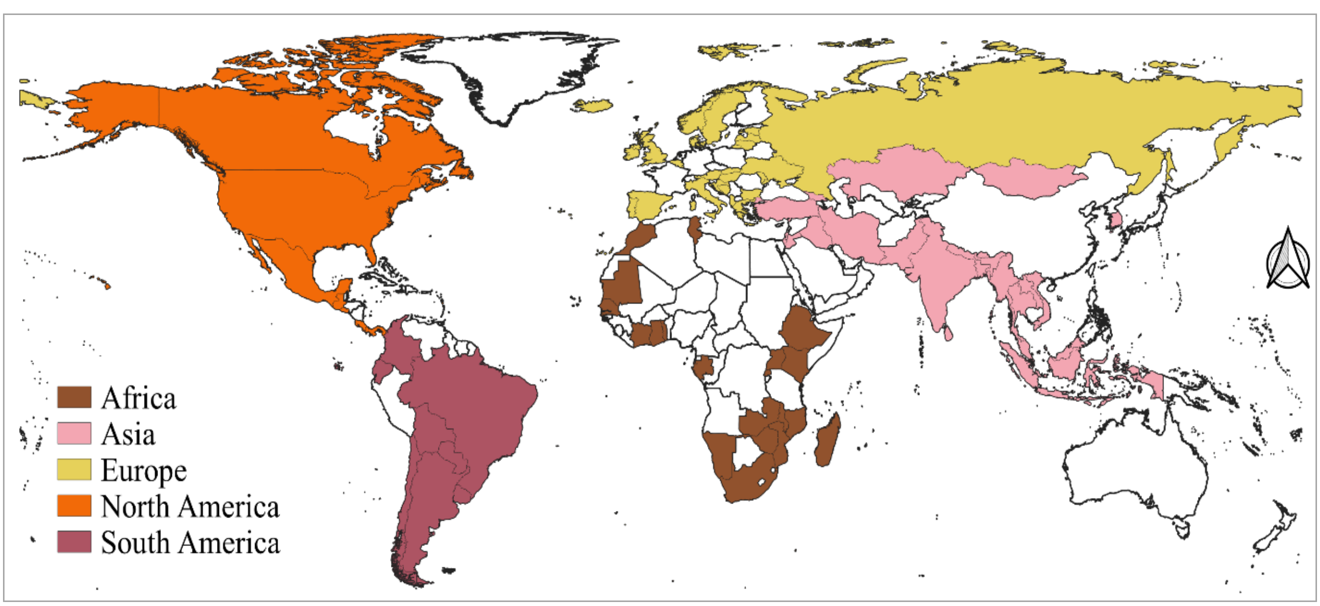

Figure 1: The countries and regions in the study

The COVID-19 data were acquired from the World Health Organisation (WHO) (WHO, 2024) dashboard[1] and the vaccination, population, and socioeconomic datasets from Our World in Data (Our World in Data, 2024) database[2].

The stringency was measured as an index. The stringency index, developed by the Oxford COVID-19 Government Response Tracker (OxCGRT), provides a systematic method to track states' and countries' responses to COVID-19 using nine stringency indicators (Hale et al., 2021a; Hale et al., 2021b). The indicators are school closings, workplace closings, cancellations of public events, restrictions on gathering size, closed public transport, stay-at-home requirements, public information campaigns, restrictions on internal movement, and restrictions on international travel. These indicators were combined into a series of novel indices. The stringency index (SI) was then computed as

$$SI = \frac{1}{k}\sum_{j=1}^{k} l_j \quad (1)$$

where k is the number of component indicators, and I_j is the sub-index score for an individual indicator. The output is a value depicting a country's stringency index, which can be compared with indices of other countries (Hale et al., 2021a; Hale et al., 2021b). Countries with favourable stringency indices depict those that adopted more stringent COVID-19 and what were then normally referred to as "social distancing" measures. With this index, countries can be ranked based on the level of stringency, comprising an overall score from indicators such as school closings, workplace closings, cancellations of public events, restrictions on gathering size, closed public transport, stay-at-home requirements, public information campaigns, restrictions on internal movement, and restrictions on international travel.

2.1. Empirical model

This study employed the feasible generalised least squares (GLS) estimator for the analysis. The technique produces excellent findings since it solves cross-sectional dependence issues (Fomby et al., 1984). The models are expressed in Equation (2) for cases and Equation (3) for deaths:

$$\ln cases_{it} = b_o + b_1 \ln vac_{it} + b_2 \ln pop_{it} + b_3 \ln pov_{it} + b_4 \ln dbp_{it} + b_5 \ln test_{it} + b_6 \ln str_{it} + \varepsilon_{it} \quad (2)$$

$$\ln deaths_{it} = b_o + b_1 \ln vac_{it} + b_2 \ln pop_{it} + b_3 \ln pov_{it} + b_4 \ln dbp_{it} + b_5 \ln test_{it} + b_6 \ln str_{it} + \varepsilon_{it} \quad (3)$$

where $\ln cases_{it}$ is the number of cases, $\ln deaths_{it}$ is the number of deaths, $\ln vac_{it}$ is the number of vaccinations, $\ln pop_{it}$ denotes the population density, $\ln pov_{it}$ is the poverty rate, $\ln dbp_{it}$ is the diabetes incidence, $\ln test_{it}$ is the number of tests and $\ln str_{it}$ is the stringency index. The parameter b_o is a constant, while $b_1 - b_6$ denotes the long-run elasticity estimates of the explanatory variables for cases and deaths. The subscripts i and t indicate countries and time, respectively while ε_{it} is the error term of each observation. The goal of this study is to estimate b_1. It is expected that b_1 will have a significant negative effect on cases and deaths because vaccination is seen as a COVID-19 combat strategy.

3. Results

Table 1 shows the correlation analysis for the cases and deaths. The highest correlation coefficient is 0.7 (for cases and deaths), which is below the conventionally accepted threshold of 0.8 to conclude that the variables suffer multicollinearity effects. Thus, we can conclude that the study does not suffer from any multicollinearity challenges. Consequently, all variables can be used in the model for analysing the relationship between COVID-19 vaccination and cases/deaths.

The pair of coefficients shows that COVID-19 cases and deaths were the most correlated, with a coefficient of 0.712 (Table 1). This means that COVID-19 deaths increase with rising cases. Table 1 also shows that other variables, except COVID-19 cases and deaths, have very weak positive or negative relationships not exceeding a coefficient of 0.7.

One other revealing information from the data is that testing for the COVID-19 virus was moderately and positively associated with vaccinations. This implies that a higher testing rate somehow encouraged vaccination. If a higher number of people get tested for the virus, the education about the need for vaccinations could be enhanced, hence more people would be more likely to get vaccinated. Also, the testing rate was moderately and negatively correlated with population density, poverty and stringency. The population density and poverty are mutually congruent and together influence the education and accessibility, or even willingness to get vaccinated against COVID-19. The denial of the virus's existence is more likely among these segments of the population compared to the more educated, enlightened and wealthy ones.

Table 1: Matrix of correlations

Variables	lncases	lndeaths	lnvac	Lnpop	lnpov	lndpb	lnstr	lntest
lncases	1.000							
lndeaths	0.712	1.000						
lnvac	0.249	-0.026	1.000					
lnpop	-0.119	-0.225	0.043	1.000				
lnpov	-0.442	-0.240	-0.286	-0.020	1.000			
lndpb	-0.061	-0.051	0.077	0.149	-0.111	1.000		
lnstr	-0.140	0.086	-0.343	0.065	0.116	0.136	1.000	
lntest	0.662	0.383	0.324	0.045	-0.542	-0.113	-0.035	1.000

Incases (Cases), Indeaths (Deaths), Invac (Vaccination), Inpop (Population density), Inpov (Poverty), Indbp (Diabetes incidence), Instr (Stringency index) and Intest (Testing)

Source: The Authors (2025)

The highest variance inflation factor (VIF) results are shown in Tables 2 and 3. Multicollinearity is suggested when VIF > 5 (Daoud, 2017; Sahana et al., 2020). Thus, Tables 2 and 3 suggest that this study is free from multicollinearity issues.

Table 2: Variance inflation factor (cases)

Variable	VIF
lntest	1.666
lnpov	1.590
lnvac	1.361
lnstr	1.229
lndpb	1.144
lnpop	1.042
Mean VIF	1.339

Source: The Authors (2025)

Table 3: Variance inflation factor (deaths)

Variables	VIF
lntest	1.607
lnpov	1.523
lnvac	1.326
lnstr	1.205
lndpb	1.140
lnpop	1.030
Mean VIF	1.305

Source: The Authors (2025)

[1] https://covid19.who.int/ (retrieved 3 November 2022)
[2] https://ourworldindata.org/ (retrieved 3 November 2022)

3.1 Feasible generalised least squares estimate

Table 4 presents the results with COVID-19 cases as the dependent variable. The full sample results of the 84 countries show that vaccination has a negative impact on cases. At the regional level, however, there were variations. Vaccination significantly reduces the number of cases in Europe and South America. Vaccination also reduces COVID-19 cases in Africa, but, not statistically significant. It had minimal effects in North America. However, this is not the case in Asia, as the coefficient is 0.059. A 1% unit change in vaccination will cause a change of -0.003% for the full sample, -0.013% in Africa, 0.059% in Asia, -0.070% in Europe, 0.002% in North America and -0.178% in South America.

This means that vaccinations against COVID-19 are more likely to reduce the number of cases in South America and Europe than in the 84 countries combined. It also reduced COVID-19 cases in South America, Europe and Africa more than the other regions. For Asia and North America, vaccination did not reduce COVID-19 cases. This might not be surprising as the USA (North America) witnessed one of the most publicised COVID-19 vaccination hesitancy that even took a highly political dimension between the Republicans and the Democrats. The accuracy of COVID-19 data from some Asian giants was in doubt during the pandemic peaks. If that were the case, it could explain the contrary results of Asia.

In Table 5, the deaths are used as the dependent variable. The results show that vaccination has a negative and significant effect on deaths for the full sample. This means that vaccination against COVID-19 reduced death occurrence in the 84 countries. On a regional basis, vaccinations significantly reduced deaths in Africa (-0.112), Europe (-0.216), North America (-0.189) and South America (-0.171). Like in the number of cases (Table 4), the contrary outcome is in Asia. Thus, vaccinations against COVID-19 significantly reduced deaths in all regions except Asia. A 1% unit change in vaccination caused a change of -0.139% for the full sample, -0.112% in Africa, 0.066% in Asia, -0.216% in Europe, -0.189% in North America and -0.171% in South America. Thus, vaccinations had a greater effect on mortality (Table 5) than COVID-19 cases (Table 4).

3,2 Robustness Analysis

3.2.1 Fixed effects estimates

The fixed effects (FE) model, which accounts for country-specific characteristics, was employed to verify the validity of our findings. The results in Tables 6 and 7 are largely consistent with the previous results, except for the full sample results in Table 6.

Table 4: GLS results (cases)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
Vaccination	-0.0032	-0.0134	0.0593***	-0.0701***	0.0024	-0.1781***
	(0.007)	(0.017)	(0.015)	(0.013)	(0.016)	(0.013)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.4641***	-1.9883***	-3.6903***	1.7424***	-6.6001***	-1.7020***
	(0.1031)	(0.4081)	(0.2544)	(0.1862)	(0.4622)	(0.3813)

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: The Authors (2025)

Table 5: GLS results (deaths)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
Vaccination	-0.1393***	-0.1123***	0.0661***	-0.2164***	-0.1890***	-0.1711***
	(0.007)	(0.020)	(0.016)	(0.012)	(0.016)	(0.014)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-7.5712***	-8.2303***	-11.666***	-6.5632***	-16.814***	-12.113***
	(0.114)	(0.500)	(0.279)	(0.178)	(0.503)	(0.389)

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: The Authors (2025)

Table 6: Fixed effects results (cases)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
lnvac	-0.041***	0.008	0.074***	-0.128***	-0.004	-0.145***
	(0.007)	(0.017)	(0.014)	(0.012)	(0.016)	(0.012)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.571***	-1.970***	-2.110***	2.770***	-2.514***	0.230
	(0.116)	(0.523)	(0.259)	(0.178)	(0.341)	(0.226)

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: The Authors (2025)

Table 7: Fixed effects results (deaths)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
lnvac	-0.102***	-0.064***	0.103***	-0.255***	-0.183***	-0.105***
	(0.007)	(0.019)	(0.015)	(0.011)	(0.015)	(0.013)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-8.624***	-10.811***	-11.893***	-5.815***	-8.046***	-9.787***
	(0.117)	(0.596)	(0.274)	(0.167)	(0.363)	(0.234)

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Source: The Authors (2025)

Table 8: GLS results (cases excluding leading vaccinated countries)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
lnvac	0.014**	0.009	0.112***	-0.076***	0.032*	-0.186***
	(0.007)	(0.016)	(0.016)	(0.013)	(0.017)	(0.014)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.637***	-2.957***	-4.100***	1.798***	-8.180***	-4.436***
	(0.107)	(0.398)	(0.262)	(0.187)	(0.555)	(0.514)

Standard errors in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: The Authors (2025)

Table 9: GLS results (deaths excluding leading vaccinated countries)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Full sample	Africa	Asia	Europe	North America	South America
lnvac	-0.133***	-0.109***	0.117***	-0.219***	-0.170***	-0.196***
	(0.008)	(0.020)	(0.017)	(0.012)	(0.017)	(0.015)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-7.724***	-8.695***	-12.260***	-6.542***	-17.366***	-13.213***
	(0.119)	(0.510)	(0.285)	(0.180)	(0.588)	(0.529)
Observations	15604	1371	4147	6403	1430	2253

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Source: The Authors (2025)

3.2.2 Dropping the leading vaccinated countries

In this section, we present the results without the leading vaccinated countries, such as the United States of America, Russia, India, Argentina, and Rwanda, and re-estimated the previous results. The results of Table 8 and Table 9 remain stable, except for the full sample and North America results in Table 8.

4. Discussions

This study examined the relationship between vaccination on the one hand and COVID-19 cases and deaths on the other hand. The feasible generalised least squares (GLS) estimator was used for the analysis. The rate of vaccination had a negative relationship with cases and deaths. This negative relationship implies that vaccination reduces both cases and deaths. By applying the feasible generalised least squares estimator, the results showed that an increase in vaccination of 1% reduces cases by -0.003%, implying that vaccination reduces COVID-19 cases. Thus, vaccination empowers individuals to generate antibodies that diminish infection levels, making them immune. This finding supports the argument that vaccination plays an essential role in combating diseases (Kolff et al., 2018). Therefore, people who are vaccinated against COVID-19 are much less likely to transmit the virus to others (Juno & Wheatley, 2021; Levine-Tiefenbrun et al., 2021) or have reduced COVID-19 transmission (Shah et al., 2021) or reduced total number of new COVID-19 cases (Chen et al., 2022) or less likely to contract the virus. The results in this study also affirm earlier studies, noting that vaccination against COVID-19 reduces the risk of infection and hastens the viral clearance in patients (Wilder-Smith, 2022) or that there is a positive effect of taking the COVID-19 vaccination, and not taking it doubles the risk of developing long-term COVID-19 complications (Xie et al., 2024). Another study found that COVID-19 cases were lower for household members of vaccinated healthcare workers compared with their unvaccinated counterparts (Shah et al., 2021). However, other studies have been sceptical about the effects of vaccination on caseload. For example, Wilder-Smith (2022) has noted that the effects of vaccination on reducing COVID-19 transmission are minimal. Another study has gone much further to warn that the association of the reduction of COVID-19 cases to vaccination may be overly stated (Franco-Paredes, 2022). The differences in the timing of the studies may explain the varying outcomes as they were conducted quite early in the vaccination era.

The regional findings of COVID-19 cases and vaccination showed that vaccination reduced the number of cases in all regions except Asia. It also reduced the number of cases in South America and Europe compared to the 84 countries combined. Vaccination also reduced COVID-19 cases in South America, Europe and Africa more than in the other regions. It had very minimal effects in North America. The findings of this study suggest that vaccination is likely the best way to end this pandemic, albeit with varying intensity. A more localised and detailed study of the exceptional outcomes for Asia is recommended.

The results of the feasible generalised least squares estimator showed that an increase in vaccination of 1% reduced deaths by -0.139%, implying that vaccination reduces the chance of deaths. Thus, vaccination empowers individuals to generate antibodies that diminish long-term complications and resultant deaths. This concords with a study that has found that emergency care or hospitalisation due to COVID-19-related illness was lower in fully vaccinated patients compared with unvaccinated counterparts (Bahl et al., 2021). Also, patients vaccinated against COVID-19 were less likely to develop long COVID-19-related complications following infection, regardless of the changes in the virus over time or variant (Xie et al., 2024). It has also been found that COVID-19 vaccination is associated with a reduction in the number of COVID-19-related hospitalisations (Shah et al., 2021), meaning those infected even after being vaccinated were less likely to be hospitalised. Also, as vaccination has increased regionally, emergency care or hospitalisations of fully vaccinated people have remained low and happen much less regularly than in unvaccinated individuals (Bahl et al., 2021). However, the study opined that where hospital-based treatment was required, elderly patients with significant comorbidities are at high risk for severe outcomes whether vaccinated or not (Bahl et al., 2021). This implies that age and comorbidities of the patients are also key variables in the survival of COVID-19 patients.

On a regional basis, the results showed that vaccination has a negative and significant effect on deaths for the 84 countries combined. This means that vaccination against COVID-19 reduced deaths witnessed in the 84 countries. Vaccinations significantly reduced deaths in Africa (-0.112), Europe (-0.216), North America (-0.189) and South America (-0.171). Thus, vaccinations against COVID-19 significantly reduced deaths in all regions except Asia. A 1% unit change in vaccination led to a change of -0.139% for all 84 countries combined, -0.112% in Africa, -0.216% in Europe, -0.189% in North America and -0.171% in South America. Like in the number of cases (Table 4), the contrary outcome is in Asia.

Comparing the impacts of COVID-19 vaccination on cases and deaths, the feasible generalised least squares estimator results showed that an increase in vaccination of 1% reduces cases by -0.003% and deaths by -0.139%, implying that vaccination reduces the chance of deaths more than 40-fold compared to cases. The reduction is statistically significant for deaths than for cases. Thus, vaccination generally had a greater effect on deaths or mortality (Table 5) than on cases (Table 4). On a regional basis, vaccination reduces cases and deaths in Africa by -0.013 and -0.112, respectively. It is -0.070 and -0.216 in Europe, and 0.002 and -0.189 in North America. For South

America, the impact of vaccination on COVID-19 cases and deaths is similar. It is also similar in Asia, but vaccination did not reduce either cases or deaths.

The results of this study have provided supporting evidence that vaccination is critical for reducing COVID-19 cases and even more critical to preventing deaths. However, vaccination has yielded significant health benefits in reducing cases and deaths in certain regions of the world more than others. Thus, continuous improvement in vaccine coverage and monitoring of the outcomes will be critical to converting efficacious vaccines into desired health outcomes.

More testing was associated with higher cases and deaths; however, minimal on the latter. It implies that more testing encourages vaccinations. If more people get tested for COVID-19, the awareness of the virus and the need to get vaccinated can be boosted, hence a higher number of people would be more likely to get vaccinated. More testing rates had a negative and moderate relationship with population density and poverty. Generally, the latter two variables (population density and poverty) are not mutually congruent, and together influence the education, awareness, accessibility or even willingness to get the vaccination against the COVID-19 virus. The denial of the virus's existence is more likely among these segments of the population compared to the more educated, enlightened and wealthy ones. The more intriguing outcome is the positive linear relationship between cases and deaths and the stringency index (measured by stringency policies such as restrictions on mobility, lockdowns and travel restrictions). On the hinge side, it is explainable. Due to the negative impacts of the stringency policies on the economy, governments used these measures rather reactively. Thus, the restrictions on mobility and travel bans were imposed when cases and deaths rose and eased when cases and deaths declined. This tallies with the findings of Bennett (Bennett, 2021).

Although vaccination reduced cases and deaths, as shown in this study, a good proportion of the general public was hesitant to take the vaccine because of factors such as ethnicity, working status, religiosity, politics, gender, age, education and income status, which influenced one's acceptance or unwillingness to take the vaccine (Troiano & Nardi, 2021). Common reasons assigned for the unwillingness to take the vaccine include concerns about the safety of the vaccines because they were produced in haste/rush and could have medium- to long-term negative effects on one's health. Additionally, some believe that a vaccine is not needed because COVID-19 is harmless (BBC, 2021; Troiano & Nardi, 2021). Other reasons include trust issues and doubts about the efficacy of the vaccine, belief that they were already immune, doubts concerning the provenance of the vaccines and being anti-vaccine in general (Troiano & Nardi, 2021). Much needs to be done in this respect to convince the public to receive vaccines. The state of Ohio (USA) placed a cash prize of one million dollars (US$) for recipients of COVID-19 vaccines as part of a weekly lottery launched to encourage the public to receive the vaccines[3]**.** Only those who received the vaccine were eligible for the lottery draw. Similar strategies can be adopted elsewhere.

The study has contributed to improving our understanding of the relationship between COVID-19 vaccinations, cases and deaths and will inform future public health policies and strategies. It also adds to the knowledge of the dynamics of COVID-19 vaccinations from 84 countries across the globe with high vaccination rates and where data were available. This analysis on the effects of the COVID-19 vaccination programme on the case and death counts is needed to fully inform public health decision-making on the intervention, which has not been explored. The link between the socio-economic indicators of human welfare/policies, such as population density, poverty rate, testing and stringency on the one hand and cases and deaths on the other was also examined. This will help fashion effective policy decisions to combat the virus. Moreover, it will add to the body of literature on COVID-19 in general.

5. Conclusion

In this study, relationships between COVID-19 vaccination, cases and deaths in 84 countries across all continents were examined using the feasible generalised least squares (GLS) estimator. Vaccination was found to reduce cases and deaths; a 1% increase in vaccination reduced COVID-19 cases by -0.003% and deaths by -0.139%, implying a greater impact on deaths than cases, more than 40 times. Thus, vaccination could be a useful tool to combat the COVID-19 pandemic. To do this, the majority of the population must be encouraged to take the vaccine since there have been reported cases of high hesitancy among the public due to influencing factors such as ethnicity, politics, religiosity, working status, gender, age, education, and income status. Financial and other reward schemes could be instituted to encourage the public to take the vaccine. The Ohio (USA) weekly lottery reward prize for recipients of COVID-19 vaccines is one of such policies to encourage vaccinations. Similar reward schemes can be instituted in other countries and states/regions to boost vaccination programmes. More efforts are also needed to engage the public and provide accurate information on vaccines, thereby countering doubts, misinformation, and misconceptions about COVID-19 vaccines and their side effects. Producing vaccines in additional countries could further improve access and affordability, especially for developing nations. Other reasons for high hesitancy include anxieties about vaccine safety (due to rushed development and potential medium- to long-term health effects), doubts about efficacy, perceptions that COVID-19 is harmless, beliefs in prior immunity, and general anti-vaccine sentiments. To dramatically increase vaccination rates, policymakers must address these concerns.

The study focused on 84 countries for which data were available. Thus, future studies should extend the scope of this study to include more countries when data are available. Additionally, as more people are vaccinated over time, future studies should examine the effects when more data become available. Finally, future studies should examine the channels via which vaccination influences cases. The findings of the study will help improve our understanding of the COVID-19 vaccination and inform future public health policies and strategies. The study also adds to the knowledge of the dynamics of COVID-19 vaccinations globally. The analysis of the impacts of the vaccination programme on the case and death counts is needed to fully inform public health decision-making on the intervention, and refinement and/or readjustment as the case may be.

6. Appendix 1

List of the 84 countries used in the study.

Africa: Côte d'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Madagascar, Malawi, Mauritania, Morocco, Mozambique, Namibia, Rwanda, Senegal, South Africa, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.

Asia: Bangladesh, Bhutan, Georgia, India, Indonesia, Iran, Iraq, Israel, Jordan, Kazakhstan, Laos, Malaysia, Mongolia, Myanmar, Nepal, Palestine, Pakistan, Sri Lanka, South Korea, Thailand, Timor, Turkey, and Vietnam.

Europe: Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Denmark, Estonia, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Norway, Portugal, Russia, Slovakia, Sweden, Spain, Ukraine, and the United Kingdom (UK).

North America: Canada, Costa Rica, the Dominican Republic, El Salvador, Guatemala, Mexico, Panama, and the United States of America (USA).

South America: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, and Uruguay.

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The data were acquired from the World Health Organisation's Dashboard at https://covid19.who.int/ and Our World in Data at https://ourworldindata.org/

Authors' contributions

MBK was involved in the conceptualisation, writing, reviewing, editing, analysis, data curation, software, validation and proofreading of the manuscript. IA-O: Conceptualisation, writing, reviewing, editing, analysis, data curation, software, validation and proofreading of the manuscript. FUU: Conceptualisation, writing, reviewing, editing, analysis, data curation, validation and proofreading of the manuscript. We then discussed the write-up page by page to approve the manuscript.

Statements and declarations

Ethical considerations

Not applicable since we used only publicly available data.

[3] https://www.bbc.com/news/world-us-canada-57096039

Consent to participate
Not applicable. This research did not require any ethical approval, as we did not use data from individuals or animals. Additionally, all the datasets we used are publicly and freely downloadable.

Consent for publication
Not applicable

Conflicts of interest
The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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Data availability
The data used are freely accessible at the World Health Organisation's Dashboard at https://covid19.who.int/ and *Our World in Data* at https://ourworldindata.org/

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