International Journal of Community Medicine and Public Health
Malakasuka PN et al. Int J Community Med Public Health. 2025 Dec;12(12):5487-5496
http://www.ijcmph.com
pISSN 2394-6032 | eISSN 2394-6040

DOI: https://dx.doi.org/10.18203/2394-6040.ijcmph20254020

Original Research Article

Advanced panel data models in examining the impact of COVID-19 vaccines on the number of deaths in Sub-Saharan Africa

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Received: 23 June 2025
Revised: 11 October 2025
Accepted: 13 November 2025

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ABSTRACT

Background: The invention of vaccines to fight COVID-19 pandemic has been a great technical triumph as the pandemic became a big challenge around the globe. This study aimed to examine the impact of COVID-19 vaccines on the number of deaths in Sub-Saharan Africa.
Methods: The study employed advanced panel data model to evaluate the impact of COVID-19 vaccine from January 2020 to December 2023. The models used are pooled OLS regression, fixed and random effect models. The control factors investigated along with vaccine are COVID-19 cases, number of people vaccinated, cardiovascular death rate, population density and GDP per capita.
Results: The data findings from pooled regression, fixed and random effect models gave R Square of 0.99229, 0.97607 and 0.98307 respectively. Also, the results gave the root mean square error of 2088.69, 22637.08, 13301.06 for pooled regression, fixed and random effect model respectively. The three models indicate that vaccination is the substantial answer in minimizing the number of COVID-19 deaths in Sub-Saharan Africa.
Conclusions: The study found vaccine to be the most scientific strategy to combat the COVID-19 pandemic. There is a need for governments in Sub-Saharan Africa to invest more on vaccination programmes to safeguard people on the future pandemic eruption.

Keywords: COVID-19, Fixed effect, Pooled OLS regression, Random effect, Vaccine

INTRODUCTION

COVID-19 was expanded globally from Wuhan, China's 7th most crowded city all over China at the end of 2019 and was then transferred to a growing number of countries.[6] In March 2020 the World Health Organization (WHO) declared the COVID-19 virus a global contagion.[29] A couple of statistical models have been employed to study the impact of COVID-19 vaccines on the relentlessness of the pandemic and deaths in the world.[28] Sub-Saharan Africa faces complications in securing COVID-19 vaccines. Investigation by mode show that merchantable transactions and COVAX supply reflect the need while higher-income republics in the constituency tend to obtain vaccines without divulging their source.[27] Africans face duple hazard on life expectancy due to poverty and constrained vaccine access. The COVID-19 contagion triggered the crude death rate in South Africa to escalate from 8.7 deaths per 1000 people in 2020 to 11.6 deaths per 1000 people in 2021.[14] Mathematical compartmental model was developed to measure the impact of injection agendas on curtailing the liability of COVID-19 in DR Congo, Kenya and Rwanda in view of the third wave of the COVID-19 pandemic. Overall, vaccination had a higher impact in tumbling COVID-19 deaths from established cases likened to those from symptomatic cases.18 Diverse regression procedures such as LSTM, Prophet and SVR were used to predict COVID-19 eruption. The prophet algorithm specified a correlation of -0.521 in the United

Kingdom and -0.774 in the United States between the numbers of vaccinated people and deceases.[7] Generalized linear mixed model was employed to cognize the consequence of vaccination on case–fatality ratios. The mean case–fatality ratios of COVID-19 had reduced by 69.0 percent in the top 20 vaccinated countries, 26.5 percent in the rest of the world and 7.6 percent in Sub-Saharan Africa.[9]

Polynomial regression model in Asian nations revealed COVID-19 cases to be reduced by up to 74.89 percent upon vaccination and the death rate to be reduced to 75.31 percent after receiving the subsequent dose of vaccination.[24]

Negative binomial regression was employed to analyse causes associated with vaccination coverage and summarizes improvement made in rolling out COVID-19 vaccinations in the African region in 2022.[16] The impact of vaccination on the COVID-19 pandemic was evaluated by means of logistic regression model in 50 U.S. states. The outcome showed that serum usage had substantial negative correlations with numbers of COVID-19 deaths with $r=-0.19$. The study displayed that the death rate of the unvaccinated COVID-19 populace was 11 times higher than that of the vaccinated COVID-19 population.[20]

African region recorded the lowest vaccination rate, less than 30 percent, during the current coronavirus disease 2019 pandemic. This is principally owing to the legacy of medical exploitation and misinformation operations, which have caused distrust in medical organizations and healthcare benefactors in some African groups.[26] Logistic regression was used to analyse the usefulness of vaccines for people of dissimilar age groups in Europe. The results revealed the overall vaccine effectiveness to be 74, 76, 63 and 63 percent among those aged 30-44, 45-59, 60-74 and ≥75 years respectively.13 The real-life impact of vaccination on COVID-19 death, with adjustment for SARS-CoV-2 variants spread and other factors was evaluated across Europe and Israel using non-linear Poisson mixed regression models.

The analysis discovered that vaccination efficacy in terms of safety against deaths was found to be 72 percent with a lower lessening in the number of deaths for B.1.1.7 vs non-B.1.1.7 variants.[11] Agent-based model of COVID-19 was used in a representative Sub-Saharan Africa countries setting to inspect whether subnational prioritization might affect the accumulative two-year impact on disease conduction and burden of a vaccination movement. Urban prioritization averted more contaminations in only a slightest situation when internal immigration rates were low and vaccination started by day 30 of an outburst. Rural prioritization was the optimum strategy for all other scenarios.[25]

Linear regression, logistic regression, least absolute shrinkage and selection operator, multilayer perceptron and support vector regression were applied to determine COVID-19 vaccinated patients' impact on the number of deceased patients in Germany and the United Kingdom. The results for linear regression signposted the association for vaccinated and fully vaccinated in the United Kingdom to be 0.666699 and 0.72753 for deceased patients respectively. The results in Germany indicated a correlation of 0.58710 and 0.64492 for vaccinated and fully vaccinated patients respectively.[1] Multivariable logistic regression was used to measure the odds of in-hospital mortality by vaccination eminence among admitted patients in Zambia. The results exposed that patients who had received more than one vaccine dose, 22 (9.3 percent) died compared with 343 (24.2 percent) among unvaccinated patients ($p<0.01$).[2]

Expressive statistics show that vaccination strategy can reduce the integer of patients with COVID-19 in all age groups with lower hospitalization and death rates in adult populations in the United States.[23] Unsupervised clustering algorithm indicated that as full vaccination proportion surges the number of death cases decreased in Azerbaijan.[10] Age-specific dynamic transmission model was fitted to describe COVID-19 deaths in 27 African countries to anticipate health outcomes for different programmes. The results display that vaccination programmes with early start dates produced the most health benefits and lowest incremental cost-effectiveness ratios (ICERs) likened to those with late starts.[15]

An agent-based model was developed to evaluate the impact of vaccination on COVID-19 outbursts in the United States. The result shows that vaccination reduced deaths lessening by 69.3 percent.[17] Literature review gauged how mathematical models were used to study COVID-19 vaccination to potentially enlighten pandemic planning and reaction in Africa. The literature search yielded 462 articles, of which 32 were encompassed based on the suitability criteria. Nineteen studies had a first author allied with an African country. Of the 32 included studies 30 were compartmental models.

By country, most studies were about or involved South Africa consisting of (37 percent), followed by Morocco (19 percent) and Ethiopia (16 percent).[21] The fitted linear curve showed the association between the growth rate of total cases and at least 1 dose of vaccination to be -0.006 and the coefficient of determination was 35.3 percent in the United States.[3] Cox regression discovered that vaccine effectiveness against COVID-19 mortality was more than 90 percent for all age groups two months after accomplishment of the primary series.[4] ANOVA test was used to assess variances in means for confirmed cases, doses administered, fully vaccinated and deaths in 30 African countries. The linear regression indicated a relationship between the total number of deaths in relation to the confirmed cases, doses administered and fully vaccinated.[5] The impacts of vaccination, testing and government policies on COVID-19 mortality and incidence rates were examined across the globe. Results indicated that the number of vaccinated people did not consistently decrease the mortality across all global burden of disease regions.22 Zimbabwe was one among the first countries to run a national COVID-19 vaccination programme in Africa. By the end of May 2021, Zimbabwe had rolled out one of the largest COVID-19 immunization programmes in sub-Saharan Africa.[19]

Despite efforts to roll out vaccines in several Sub-Saharan African nations by free of charge distribution of vaccines, the level of acceptance of vaccines in most cases remained low. During mass vaccination campaigns, activities aiming at generating vaccines demand are usually intensified to counter vaccine hesitancy, which is considered the leading cause of low vaccine uptake in Africa due to little trust on vaccines on whether they reduce COVID-19 deaths or not since the invention took place in short period of time.[16] The majority of COVID-19 deaths reported in Africa appeared in Sub-Saharan Africa despite the vaccination intervention to start in January 2021. Therefore, the objective of this study was confined to examining the impact of COVID-19 vaccines on whether they reduce COVID-19 deaths or not. The fundamental driving force behind this study was the realization to establish a link between COVID-19 vaccines and COVID-19 deaths. This study offers responses to the following questions: Is there a link between COVID-19 vaccines and COVID-19 deaths? What implications does the relationship between COVID-19 vaccines and COVID-19 deaths have for the wellbeing of people in Sub-Saharan African countries? There are limited studies exploring vaccination impacts for COVID-19 in Sub-Saharan Africa. The findings could provide insight for policymakers to focus on intervention based on the impact of vaccine provided by the study in order to increase vaccine acceptance and hence increase vaccine uptake and vaccination levels and combat the spread of infection.

METHODS

Data

This study adopted a panel research design as it is concerned with the transient changes in risk of acute outcomes with time-varying exposures as well as intervention over time. The study used panel data extracted from the World Health Organization Dataset from January 2020 to December 2023 focusing on the Sub-Saharan African countries. These data show trends, patterns, correlations and dynamics of change over time. Number of COVID-19 deaths is the dependent variable used for the study. The number of cases, number of people vaccinated, cardiovascular death rate, GDP per capita and population density were employed as independent variables for the models. The sample was obtained through stratified sampling technique. The number of Sub-Saharan African countries was listed. The ten most affected sub-Saharan African countries were selected from the listed countries. These countries were selected due to the fact that they took early measure of vaccinating their people at least to a large extent which gives the insight on the trend of COVID-19 deaths on the basis of vaccination initiatives. Finally, the units of measurement which are the people being vaccinated were selected purposively from the earliest date of vaccination.

Model description

The panel data models permit to study the dynamics of change of a variable over time. The models enhance the quality and quantity of data in ways that would be otherwise impossible using other models.

Pre and post diagnosis of the variables

Before running the actual model there must be a pre diagnosis of the variables in order to test whether they conform to the predetermined criteria. Pre diagnosis involves testing for unit root and zero mean residue. Post diagnosis involves verifying whether the models were correctly applied. This involves stationarity testing, autocorrelation testing, heteroscedasticity and multicollinearity testing. The unit root test must be stationary at (0) or (1) for panel models. The panel model is given by

$$Y_{\text{it}} = \rho_i Y_{it-1} + \mu_{\text{it}}$$

$i = 1,...,N$ denoting individual cross-sectional units and denoting time series observations.

μ_{it} is assumed to be independently distributed across individuals and follow a stationary invertible ARMA process for each individual and is denoted by

$$\mu_{it} = \sum_{j=1}^{\infty} \theta_{ij} \mu_{it-j} + \varepsilon_{it}$$

Therefore, the model can be written

$$Y_{\text{it}} = \rho_i Y_{it-1} + \sum_{j=1}^{\infty} \theta_{ij} \mu_{it-j} + \varepsilon_{it}$$

and since $\Delta Y_{it} = \mu_{it}$ under the unit root null hypothesis, the above regression becomes

$$Y_{\text{it}} = \rho_i Y_{it-1} + \sum_{j=1}^{\infty} \theta_{ij} \Delta Y_{it-j} + \varepsilon_{it}$$

The null hypothesis of interest is:

$$H_o : \rho_i = 1 \, for \, all \, Y_{it}$$

Against alternative hypothesis

$$H_a : |\rho_i| < 1 \, for\ some\, Y_{it}$$

The advanced panel data models have been selected because they enable to construct and test more complicated behaviour than other models would permit. Advanced panel data model can rely on the inter-individual discrepancies to reduce the collinearity between current and lag variables to estimate unrestricted time-adjustment patterns while the estimation of time-adjustment pattern using time series data often has to rely on arbitrary prior constraints such as Koyck or Almon distributed lag models because time series observations of current and lagged variables are likely to be extremely collinear.

Stationarity testing

Non-stationarity is an econometric problem that happens in most macro-economic variables. Regressing such kind of non-stationary variables can falsely infer the presence of a significant relationship. Therefore, this study employed Zivot-Andrews test (1992) due to the fact that the traditional unit root tests by Dickey and Fuller (1979) and the P-P by Phillips and Perron (1988) are not able to account for structural breaks in the data because of assuming a steady relationship over time, but structural breaks interrupt this assumption. A structural break is an impulsive change in the underlying procedure generating the time series, which can lead to improper conclusions about the presence of a unit root.

The Zivot-Andrews test is predominantly useful in this situation as it allows for the uncovering of a single structural break in the existence of a unit root, which is a common characteristic in time series data. It tests the null hypothesis that the series has a unit root with a structural break against the alternative hypothesis of stationarity with a break. Zivot-Andrews' approach suggests three models to test the stationarity as follows. One-time change in the constant is permitted by the first model as presented below.

$$\Delta X_t = \hat{\mu}^1 + \hat{\theta}^1 DU_t + \hat{\beta}^1 t + \hat{\alpha}^1 X_{t-1} + \sum_{i=1}^{k} \hat{\gamma}_i^1 \Delta X_{t-i} + \hat{e}_t$$

The non-stationary is examined around a broken trend by the second model as given by

$$\Delta X_t = \hat{\mu}^2 + \hat{\beta}^2 t + \hat{\rho}^2 DT_t^* + \hat{\alpha}^2 X_{t-1} + \sum_{i=1}^{k} \hat{\gamma}_i^1 \Delta X_{t-i} + \hat{e}_t$$

Then the chance of adjustment in the constant or in a broken drift is evaluated by the third model as given below

$$\Delta X_t = \hat{\mu}^3 + \hat{\theta}^3 DU_t + \hat{\beta}^3 t + \hat{\rho}^3 DT_t^* + \hat{\alpha}^3 X_{t-1} + \sum_{i=1}^{k} \hat{\gamma}_i^1 \Delta X_{t-i} + \hat{e}_t$$

The Zivot-Andrews stationarity testing approach undertakes that the null hypothesis for the three equations is equals to zero. This implies that has a structural break that is non-stationary.

The null hypothesis of interest is.

$$H_o : \hat{\alpha} = 0 \, for\ all\, X_{it}$$

Against alternative hypothesis

$$H_a : |\hat{\alpha}| < 0 \, for\ some\, X_{it}$$

Thus, the null hypothesis infers that the variables have unit roots and is rejected if any one of the variables is stationary with $H_a : |\hat{\alpha}| < 0$. The refutation of the null hypothesis does not imply that the whole panel is stationary. The null hypothesis indicate that all the time series are unit root nonstationary and the alternative hypothesis denotes that some time series are nonstationary while others are not.

Pooled ordinary least squares regression model

The pooled ordinary least squares (POLS) model is a model that serves as an introductory analytical tool for panel data which combines cross-sectional and time-series data. This model commences that, despite the potential assortment across entities and over time, a mutual effect exists that can be captured through a single regression line. The model is specified as follows.

$$Y_{it} = \alpha_i + \beta_k X_{k,it} + \mu_{it} + \varepsilon_{it}$$

where:

Y_{it} =The number of deaths

i = Individual cross-sectional units

t = time series observations.

β_1 =Coefficients for respective and control variables.

$X_{k,it}$ =Independent and control variables (COVID-19 cases, number of people vaccinated, cardiovascular death rate, population density, GDP per capita).

α_i =The time-invariant unobserved heterogeneity that differs across countries.

μ_{it} =The individual impact which is not a measurable variable.

ε_{it} = Error term

Fixed effect model

The fixed effects model is a statistical regression model in which the intercept of the regression model is permissible to vary spontaneously across entities or groups. This type of model permits for heterogeneity or individuality among diverse cross-sections tolerating each cross-section to have its intercept.

$$Y_{it} = \beta_0 + \lambda_i + \beta_1 X_{1it} + \ldots + \beta_k X_{kit} + \varepsilon_{it}$$

Where:

Y_{it} = The number of deaths

$\beta_1,\ldots,\beta_k$ = Coefficients for respective and control variables.

$X_{k,it}$ = Independent and control variables (COVID-19 cases, number of people vaccinated, cardiovascular death rate, population density, GDP per capita).

ε_{it} =Error term

λ_{i} = Individual effect which is constant over time

Random effect model

Random effects model is a statistical model that undertakes that the data are drawn from a hierarchy of dissimilar populations, each of which has its characteristics. These physiognomies can influence the outcome variable but are not directly detected. The random effects are normally distributed across these groups, with a mean of zero and there is independence between the random effects and the error terms within the model.

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \ldots + \beta_k X_{kit} + \mu_i + \varepsilon_{it}$$

Where,

Y_{it} = The number of deaths.

$\beta_1 \ldots \beta_k$ = Coefficients for respective and control variables.

$X_{k,it}$ = Independent and control variables (COVID-19 cases, number of people vaccinated, cardiovascular death rate, population density, GDP per capita)

μ_{it} =The individual impact which is not a measurable variable.

ε_{it} = Error term.

RESULTS

The study used inferential statistical approaches to analyse the data. The analysis of the impact of COVID-19 vaccines on the number of deaths was performed using the R4.4.1 statistical package. The trend of the data concerning COVID-19 was reported by WHO on daily basis.

The data findings from the Zivot-Andrews unit root tests show that all the variables are stationary at (I) as given by the Table 1.

Zero residual mean testing

$$H_o : MR = 0$$

$$H_a : MR \neq 0$$

During the model fitting, the regression line minimizes the sum of squared residuals. This ensures that the residuals are centred around zero, making their mean approximately zero. Thus, the null hypothesis implies that the residual values have a mean of zero while the alternative hypothesis shows that the residual values do not have a mean of zero. The computation of the mean residual is given by

$$\text{Mean of residuals} = \frac{1}{n}\sum_{i=1}^{n} e_i \approx 0$$

where $e_i = y_i - \hat{y}$

y_i = Observed values

$\hat{y}$ = Predicted values

Autocorrelation testing

H_o : There is no autocorrelation

H_a : There is autocorrelation

The findings revealed that there is no autocorrelation in the data. The Durbin's test gave a value of 2.0061 with p value= 0.6322 for pooled regression, 2.3458 with p-value= 1 for fixed effect model and 2.3399 with p value= 1 for random effect model. The null hypothesis is not rejected implying that autocorrelation problem does not exist in the data.

Multicollinearity testing

H_o : There is no perfect collinearity

H_a : There is perfect collinearity

The findings from Table 2 shows that the variance inflation factor for all the variables is less

than 5 which indicate that there is no Multicollinearity between independent variables.

Pooled regression model on the number of COVID-19 deaths

The data findings from Table 3 for the pooled regression model report R Squared and adjusted R squared of 0.99229 and 0.99221 respectively confirming that the model has good fittings, with the variations in the values of the explanatory variables of the equation being responsible for 99.23 percent of the variations in the number of COVID-19 deaths in Sub-Saharan Africa.

To corroborate this assertion, the pooled results of the model, with an F value of 12206.7, estimated at 5 and 474 degrees of freedom gave a ρ value of 0.000. This implies that the independent variables are responsible for explaining the number of COVID-19 deaths in Sub-Saharan African countries. This means that at a significance level of 5 percent, the null hypothesis is rejected and the alternative hypothesis of the model, that the exogenous variables influence the variations in a number of COVID-19 deaths significantly is upheld.

The coefficient of 0.025993 recorded for a number of COVID-19 cases implies that for every increase in the number of COVID-19 case, the number of COVID-19 deaths increases by 2.6 percent in Sub-Saharan Africa. The coefficient of -0.000063754 recorded for the number of people vaccinated implies that for every increase in the number of vaccinated persons the number of COVID-19 deaths decreases by 0.00637 percent.

The coefficient of 15.609 recorded for population density implies that for every increase in population density, the number of COVID-19 deaths increases by 15.6 deaths in Sub-Saharan Africa. The coefficient of 20.059 recorded for cardiovascular death rate implies that for every increase in cardiovascular death rate, the number of COVID-19 deaths increases by 20 deaths in Sub-Saharan Africa. The coefficient of 0.46109 recorded GDP per capita implies that for every increase in GDP per capita of people, the number of COVID-19 deaths increases by 46.1 percent.

Fixed effect model on the number of COVID-19 deaths

The results from Table 4 for the fixed effect model give R Squared and adjusted R squared of 0.97607 and 0.9755 respectively confirming that the model has good fittings, with the variations in the values of the explanatory variables of the equation being responsible for 97.6 percent of the variations in the number of COVID-19 deaths in Sub-Saharan Africa. The value of the R squared demonstrates the high explanatory power of the dependent variable relative to the independent variables.

To corroborate this assertion, the fixed results of the model, with an F value of 9542.67, estimated at 2 and 468 degrees of freedom gave a p value of 0.000. This implies that the independent variables included in a model have influence on the dependent variable. The independent variables are responsible for explaining the number of COVID-19 deaths in Sub-Saharan African countries.

In evaluating the theoretical validity of the model, it was observed that all the exogenous variables of the equation conformed to the a priori expectations. The coefficient of 0.024904 recorded for a number of COVID-19 cases implies that for every increase in the number of COVID-19 case, the number of COVID-19 deaths increases by 2.49 percent in Sub-Saharan Africa. The coefficient of --0.000048099 recorded for the number of people vaccinated implies that for every increase in the number of vaccinated persons, the number of COVID-19 deaths decreases by 0.0048 percent being statistically significant at 5 per cent level with p value 0.000. The results reveal the prominence of being vaccinate.

Random effect model on the number of COVID-19 deaths

The data findings from the random effect model report R Squared and adjusted R squared of 0.98307 and 0.98289 respectively approving that the model has good fittings, with the variations in the values of the explanatory variables of the equation being accountable for 98.3 percent of the variations in the number of COVID-19 deaths in Sub-Saharan Africa. The figure considers the relationship strength between the model and the dependent variable which is very high.

To substantiate this allegation, the random effect outcomes of the model, with chi-square value of 27527.1, estimated at 5 degrees of freedom gave a p value of 0.000. This implies that the independent variables are responsible for explaining the number of COVID-19 deaths in Sub-Saharan African countries. This means that at a significance level of 5 percent, the null assumption explaining no substantial effect of the exogenous variables on the number of COVID-19 deaths in Sub-Saharan Africa is rejected and the alternative hypothesis of the model is maintained.

The coefficient of 0.025253 recorded for a number of COVID-19 cases implies that for every increase in the number of COVID-19 case, the number of COVID-19 deaths increases by 2.5 percent in Sub-Saharan Africa.

The coefficient of -0.000052665 recorded for the number of people vaccinated implies that for every increase in the number of vaccinated person, the number of COVID-19 deaths decreases by 0.0052 percent.

The coefficient of 14.296 recorded for population density implies that for every increase in population density, the number of COVID-19 deaths increases by 14.29 deaths in Sub-Saharan Africa. The coefficient of 18.822 recorded for cardiovascular death rate implies that for every increase in cardiovascular death rate, the number of COVID-19 deaths increases by 18.82 deaths in Sub-Saharan Africa. The coefficient of 0.56151 recorded GDP per capita implies that for every increase in GDP per capita of people, the number of COVID-19 deaths increases by 56.15 percent.

Table 1: Zivot-Andrews unit root test.

Coefficients	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	-416.12277	104.53924	-3.981	<0.001***
y.l1	0.69956	0.04816	14.526	<0.001***
trend	97.53047	15.53219	6.279	<0.001***
y.dl1	0.31286	0.11063	2.828	<0.01**
du	644.37270	121.64020	5.297	<0.001***
dt	-90.31243	14.00326	-6.449	<0.001***

significant codes 0'***' 0.001 '**' 0.01 '*'.

Table 2: Multicollinearity testing.

Variable	Variance inflation factor
Total number of cases	1.705285
Number of people vaccinated	1.255913
Population density	1.929397
GDP per capita	1.821486
Cardiovascular death rate	1.739200

Table 3: Pooled regression estimates for covid deaths.

Coefficients	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	-8783	610.51	-14.3862	<0.001***
Total number of cases	0.025993	0.00013951	186.3115	<0.001***
Number of people vaccinated	0.000063754	0.0000061328	-10.3956	<0.001***
Population density	15.609	1.8497	8.4387	<0.001***
Cardiovascular death rate	20.059	1.6790	11.9469	<0.001***
GDP per capita	0.46109	0.036961	12.4749	<0.001***

Diagnostics: Balanced Panel: n=10 T=48 N=480 Test for Autocorrelation: Durbin's test=2.0061, p value=0.6322 Variance Inflation Factor (VIF) <5; Mean residual=1.383417e-13 RMSE=2088.69
Residuals: Min. -3870.077, 1st Qu. -1069.619, Median -15.062, 3rd Qu. 825.967, Max. 12557.218; Signif. Codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1.

Table 4: Fixed effect model estimates for covid deaths.

Coeffients	Estimate	Std. Error	t-value	Pr(>|t|)
Total number of cases	0.024904	0.00018795	132.5015	<0.001***
Number of people vaccinated	-0.000048099	0.0000062937	-7.6424	<0.001***
Total Sum of Squares: 7.3633e+10	Residual Sum of Squares: 1762400000		R-Squared: 0.97607	
Adj. R-Squared: 0.9755	F-statistic: 9542.67 on 2 and 468 DF,		P value: <0.001	

Diagnostics: Balanced Panel: n=10 T=48 N=480; Test for Autocorrelation: Durbin's test=2.3458, p-value=1 Variance Inflation Factor(VIF) <5; Mean Residual=-1.802229e-12 RMSE=22637.08
Residuals: Min. -6938.895 1st Qu. -827.024 Median -64.545 3rd Qu. 733.040 Max. 11905.084

Table 5: Random effect model estimates for covid deaths.

Coefficients:	Estimate	Std. Error	z-value	Pr(>|z|)
(Intercept)	-8624.4	1345	-6.4123	<0.001***
Total number of cases	0.025253	0.00017457	144.6585	<0.001***
Number of people vaccinated	-0.000052665	0.0000062695	-8.4003	<0.001***
Population density	14.296	3.9419	3.6266	<0.001***
Cardiovascular death rate	18.822	3.6778	5.1176	<0.001***
GDP per capita	0.56151	0.073715	7.6173	<0.001***
Total Sum of Squares: 1.0964e+11	Residual Sum of Squares: 1.856e+09		R-Squared: 0.98307	
Adj. R-Squared: 0.98289	Chisq: 27527.1 on 5 DF,		P value: < 0.001	

Diagnostics: Balanced Panel: n=10 T=1459 N=14590; Test for Autocorrelation: Durbin's test=2.3399, p-value=1; Variance Inflation Factor(VIF) <5; Mean residual=4.653532e-13, RMSE=13301.06
Residuals: Min. -5539.94, 1st Qu. -964.80, Median -191.97, 3rd Qu. 630.73, Max. 12391.
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

DISCUSSION

This section involves a discussion of findings on the impact of COVID-19 vaccines on the number of deaths in Sub-Saharan Africa compared to findings from other researchers. The descriptive results indicate that there is variation on the effect of vaccines country-wise in Sub-Saharan Africa. The discrepancy is due to population density and the number of people vaccinated in the country as well as factors that are not taken into consideration in the study. The study used pooled regression, fixed effect and random effect models to determine the relationship between the number of COVID-19 deaths and people vaccinated. The result from the analysis gave R Squared of 0.99229, 0.97607 and 0.98307 for pooled regression, fixed effect and random effect model respectively.

Based on the coefficients of determination the pooled regression model explains better than the fixed and random effect models with 99.2 percent followed by the random effect model with 98.3 percent and the fixed effect model with 97.6 percent. Also, the results gave the root mean square error of 2088.69, 22637.08, 13301.06 for pooled regression, fixed effect and random effect model respectively. Therefore, random effect model is the most precise model for assessing prediction due to the fact that it is more accurate giving a smaller root mean square error compared with other models.

The study is in line with the study which employed regression algorithms such as LSTM, Prophet and SVR considering the number of cases and the number of vaccinated people. The prophet algorithm indicated a correlation of −0.521 in the United Kingdom and−0.774 in the United States between the numbers of vaccinated individuals and deaths.[7] Also, the study coincides with the study which used a mathematical compartmental model to assess the impact of vaccination programs on curbing the burden of COVID-19 in DR Congo, Kenya and Rwanda.

The findings indicated that vaccination had a greater impact in falling COVID-19 deaths from confirmed cases compared to those from symptomatic cases.[18] The effect of vaccination on COVID-19 cases and deaths was analysed in Asian countries using a Polynomial regression model. The results publicized COVID-19 death rate was reduced to 75.31 percent after getting the second dose of vaccination.[24] Also the result resembles with the study which employed a generalized additive model to analyse the association between daily vaccinated people and daily new cases and deaths of COVID-19. The findings displayed that daily increasing cases of COVID-19 would be reduced by 24.4 per cent with 10,000 fully vaccinated people per day.[15]

However, the study is conflicting with the study which revealed that some countries have recently practiced high mortality rates despite the continuing vaccination drive which is partly due to the inefficacy of vaccines on new COVID-19 variants.[12] The study is also associated with the study which investigated the Global impact of the first year of COVID-19 vaccination exhausting mathematical modelling. The result revealed that vaccinations had a global reduction of 63 per cent in overall deaths during the first year of COVID-19 vaccination.[28]

The advanced panel data model employed in the study indicated a high correlation of COVID-19 vaccine and deaths in evaluating the impact of vaccines compared to other models employed by other researchers.

CONCLUSION

The study found vaccine to be the most scientific strategy to combat the COVID-19 pandemic. The result indicates that the more people are vaccinated the less the number of deaths in Sub-Saharan Africa. The problem is that many Sub-Saharan African countries failed to vaccinate at least half of their population except for Mozambique and Zambia. Many African countries, capacity to engage in large-scale roll-outs of COVID-19 vaccinations is limited by supply challenges and weak health system infrastructure. The distribution of COVID-19 vaccines to sub-Saharan Africa is a great challenge in the contemporary world.

Basing on the importance of vaccines derived from this study, the government of the sub-Saharan African countries should invest more and continue to prioritize vaccinations instead of looking on the number of infections and deaths. Sub-Saharan African countries should make sure that all the people are being vaccinated so as to protect them from being exposed to future eruption of the pandemic with different variant. Also, there is a need to analyse the impact of different vaccines on the number of deaths in Sub-Saharan Africa in order to identify the most effective vaccine within the region so as to clarify results and improve the preparedness of countries to face next pandemic crisis and control negative impact on public health, economy and society.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

REFERENCES

1. Baressi Šegota S, Lorencin I, Anđelić N, Musulin J, Štifanić D, Glučina M, et al. Applying Regressive Machine Learning Techniques in Determination of COVID-19Vaccinated Patients' Influence on the Number of Confirmed and Deceased Patients. Mathematics 2022;10(16):2925.
2. Chanda D, Hines JZ, Itoh M, Fwoloshi S, Minchella PA, Zyambo KD, et al. COVID-19Vaccine Effectiveness Against Progression to In-Hospital Mortality in Zambia, 2021–2022. Open Forum Infect Dis. 2022;9(9):469.
3. Chen YT. The Effect of Vaccination Rates on the Infection of COVID-19 under the Vaccination Rate below the Herd Immunity Threshold. Int J Env Res Publ Health. 2021;18(14):7491.
4. De Gier B, Van Asten L, Boere TM, Van Roon A, Van Roekel C, Pijpers J, et al. Effect of COVID-19vaccination on mortality by COVID-19 and on mortality by other causes, the Netherlands, January 2021–January 2022. Vaccine. 2023;41(31):4488–96.
5. Setubi AF, Nakoya E, Tchougene AF, Fopokam XG. El impacto de la cobertura de la vacuna COVID-19 en el resultado de muertes en África, las diferencias subregionales y la necesidad de un esfuerzo renovado de varios niveles. Iberoamerican J Med. 2022;4(2):83-91.
6. Di Gennaro F, Pizzol D, Marotta C, Antunes M, Racalbuto V, Veronese N, et al. Coronavirus Diseases (COVID-19-19) Current Status and Future Perspectives: A Narrative Review. Int J Env Res Publ Health. 2020;17(8):2690.
7. Didi Y, Walha A, Ben Halima M, Wali A. COVID-19Outbreak Forecasting Based on Vaccine Rates and Tweets Classification. Computational Int Neurosci. 2022;1:16.
8. Govender K, Nyamaruze P, McKerrow N, Meyer-Weitz A, Cowden RG. COVID-19 vaccines for children and adolescents in Africa: Aligning our priorities to situational realities. BMJ Global Health. 2022;7(2):7839.
9. Haider N, Hasan MN, Guitian J, Khan RA, McCoy D, Ntoumi F, et al. The disproportionate case–fatality ratio of COVID-19 between countries with the highest vaccination rates and the rest of the world. IJID Regions. 2023;6:159–66.
10. Hajirahimova MS, Aliyeva AS. Analyzing the impact of vaccination on COVID-19 confirmed cases and deaths in Azerbaijan using machine learning algorithm. Int J Educ Manag Eng. 2022;12:1-10.
11. Jabłońska K, Aballéa S, Toumi M. The real-life impact of vaccination on COVID-19mortality in Europe and Israel. Public Health. 2021;198:230–7.
12. Jassat W, Mudara C, Ozougwu L, Tempia S, Blumberg L, Davies MA, et al. Difference in mortality among individuals admitted to hospital with COVID-19during the first and second waves in South Africa: A cohort study. Lancet Global Health. 2021;9(9):1216–25.
13. Kissling E, Hooiveld M, Sandonis Martín V, Martínez-Baz I, William N, Vilcu AM, et al. I-MOVE-COVID-19primary care study team. Vaccine effectiveness against symptomatic SARS-CoV-2 infection in adults aged 65 years and older in primary care: I-MOVE-COVID-19 project, Europe, December 2020 to May 2021. Eurosurveillance. 2021; 26(29).
14. Kubheka BZ, Kabala T. COVID-19 Vaccine donations: Blessings and curses for Africa. J Global Health Econ Pol. 2022;2:67.
15. Liu Y, Procter SR, Pearson CAB, Montero AM, Torres-Rueda S, Asfaw E, et al. Assessing the impacts of COVID-19 vaccination programme's timing and speed on health benefits, cost-effectiveness and relative affordability in 27 African countries. BMC Med. 2023;21(1):85.
16. Mboussou F, Farham B, Nsasiirwe S, Atagbaza A, Oyaole D, Atuhebwe PL, et al. COVID-19Vaccination in the WHO African Region: Progress Made in 2022 and Factors Associated. Vaccines. 2023;11(5):1010.
17. Moghadas SM, Vilches TN, Zhang K, Wells CR, Shoukat A, Singer BH, et al. The Impact of Vaccination on Coronavirus Disease 2019 (COVID-19-19) Outbreaks in the United States. Clin Infect Dis. 2021;73(12):2257–64.
18. Montcho Y, Nalwanga R, Azokpota P, Doumatè JT, Lokonon BE, Salako VK, et al. Assessing the Impact of Vaccination on the Dynamics of COVID-19 in Africa: A Mathematical Modeling Study. Vaccines. 2023;11(4):857.
19. Murewanhema G, Burukai TV, Chireka B, Kunonga E. Implementing national COVID-19vaccination programmes in sub-Saharan Africa- early lessons from Zimbabwe: A descriptive cross-sectional study. Pan African Medical J. 2021;40:4346.
20. Nie R, Abdelrahman Z, Liu Z, Wang X. Evaluation of the role of vaccination in the COVID-

19pandemic based on the data from the 50 U.S. States. Comput Struc Biotechnol J. 2022;20:4138–45.
21. Ofori SK, Dankwa EA, Estrada EH, Hua X, Kimani TN, Wade CG, et al. COVID-19 vaccination strategies in Africa: A scoping review of the use of mathematical models to inform policy. Tropical Med Int Health. 2024;29(6):466–76.
22. Park MB, Lee J. The Role of Vaccination, Testing and Public Restriction Policies in COVID-19 Mortality and Incidence: Insights from Global Burden of Disease Regions. Arch Med Sci. 2024;2:587.
23. Roghani A. The Influence of COVID-19 Vaccination on Daily Cases, Hospitalization and Death Rate in Tennessee, United States: Case Study. JMIRx Med. 2021;2(3):29324.
24. Rustagi V, Bajaj M, Tanvi, Singh P, Aggarwal R, AlAjmi MF, et al. Analyzing the Effect of Vaccination Over COVID-19 Cases and Deaths in Asian Countries Using Machine Learning Models. Front Cell Infect Microbiol. 2022;11:806265.
25. Selvaraj P, Wagner BG, Chao DL, Jackson ML, Breugelmans JG, Jackson N, et al. Rural prioritization may increase the impact of COVID-19vaccines in a representative COVAX AMC country setting due to ongoing internal migration: A modeling study. PLOS Global Publ Health. 2022;2(1):53.
26. Sinumvayo JP, Munezero PC, Tope AT, Adeyemo RO, Bale MI, Mutsaka-Makuvaza MJ, et al. Vaccination and vaccine-preventable diseases in Africa. Scientific African. 2024;24:2199.
27. Takasu N, Yamagata T. Distribution of COVID-19 Vaccines to 49 Sub-Saharan African Countries. 2022;40(1):83-111.
28. Watson OJ, Barnsley G, Toor J, Hogan AB, Winskill P, Ghani AC. Global impact of the first year of COVID-19 vaccination: A mathematical modelling study. Lancet Infect Dis. 2022;22(9):1293–302.
29. WHO Coronavirus disease 2019 (COVID-19) situation report. 2020.

Cite this article as: Malakasuka PN, Kitumi DL, Mbago MCY. Advanced panel data models in examining the impact of COVID-19 vaccines on the number of deaths in Sub-Saharan Africa. Int J Community Med Public Health 2025;12:5487-96.