Modeling the Transmission Dynamics of COVID-19 Among Five High Burden African Countries

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**Background:** Today, coronavirus disease-19 has left a permanent dark mark on the history of human beings. The ongoing global pandemic outbreak of COVID-19 has spread to 58 African countries, with over 6.07 million confirmed cases and over 151,412 deaths. The five high burden African countries are South Africa, Morocco, Tunisia, Ethiopia, and Libya, with case fatality rates (CFR) of nearly 0.15%, 0.042%, 0.22%, 0.006%, and 0.086%, respectively. This is why the research aims to adequately understand the transmission dynamics of the virus and its variants in five high-burden African countries.

**Methods:** Our study is a deterministic model, where the population is partitioned into five components on the epidemiological state of the individuals. We presented a year-structured susceptible, infected, mild sever, critical severe, and recover (SIMCR) compartmental model of COVID-19 disease transmission with incidence rate during the pandemic period.

**Results:** The number of susceptible individuals increased by 30,711,930 in South Africa, 5,919,837 in Morocco, 3,485,020 in Tunisia, 7,833,642 in Ethiopia, and 2,145,404 in Libya in the next 3 decades with compare to the unvaccinated population and the number of infected individuals decreased by 30,479,271 in South Africa, 19,809,751 in Morocco, 3,456,406 in Tunisia, 7,761,993 in Ethiopia, and 2,125,038 in Libya.

**Conclusion:** SIMCR model is used to describe the transmission of COVID-19 among five high-burden African countries. For the next 30 years, we will have around 86 million infected individuals and millions of death only in those five African countries. To reduce those problems, vaccination is the best and most effective mechanism. So vaccinating half of the populations in those countries helps to control and reduce the transmission rate of COVID-19 in Africa for the next 30 years. This leads to preventing 17,212,405 people from becoming infected and millions of deaths being reduced in those five high-burden African countries.

**Keywords:** COVID-19, case fatality rate, Africa, mathematical modeling, compartment model, stochastic, infectious diseases

**Introduction**

The disease, now caused by a novel coronavirus called severe Acute Respiratory Syndrome Coronavirus 2, was first identified in the outbreak of the respiratory disease in Wuhan, China. 

Coronavirus disease (COVID-19) raises ongoing and serious public health concerns around the world. As of 07th February 2022, the ongoing global pandemic outbreak of COVID-19 has spread to at least 225 countries and territories causing 410,837,662 cases and 5,829,542 deaths (case fatality rate (CFR) = 1.42%) globally. 

The United States of America (USA) reported the highest number of cases (79,293,924) (3, 4) and 942,944 deaths 

with a CFR of 1.18%, followed by India (42,631,421) cases and 508,665 deaths with a CFR of 1.19%.

As of 07th February 2022, the ongoing global pandemic outbreak of COVID-19 has spread to at least 58 African countries, including South Africa, Morocco, Tunisia, Ethiopia, and, Libya, and resulted in approximately 6,632,037 cases of COVID-19 and 151,537 deaths only on these five Africa countries. 

In South Africa, Morocco, Tunisia, Ethiopia and, Libya, COVID-19 infections 3,623,962, 1,147,243, 944,175, 466,539, and 450,118 and deaths reached 95,835, 15,593, 26,679, 7363, and 6067, with case fatality rate (CFR) of nearly 0.15%, 0.042%, ...
The reproduction number for Omicron COVID-19 variant was first reported in South Africa on November 24, 2021 (26). It is quickly spreading across the world. The severity associated with Omicron is still unknown, but early reports suggest a mild illness, at least in the younger population. Individuals infected with the Omicron variant may show symptoms similar to those of previous variants. The presence and severity of symptoms can be affected by COVID-19 vaccination status, the presence of other conditions, age, and previous history of infection.

The biggest burden of COVID-19 depends on the medical system and on the prompt and timely response to the pandemic. But the problem is that almost all African countries respond slightly too slowly, and some of them cannot use their vaccines effectively. A series of critical factors can lead to the outbreak of the COVID-19 pandemic. However, some of these factors do not seem to be well understood. Infectious disease modeling is a powerful tool for infectious disease control that helps to accurately predict characteristics and understand infectious disease dynamics. In infectious disease models, the incidence rate plays a vital role in the transmission of infectious diseases. Here we consider the incidence of non-linearity, as the number of effective contacts between infectious and susceptible individuals can be saturated by the accumulation of high levels of infectious individuals. This model is also used to calibrate and predict the number of COVID-19 case data in five high-burden African countries, including South Africa, Morocco, Tunisia, Ethiopia, and Libya, to estimate the model parameters. We assessed the impact of year structure on the dynamics of COVID-19 cases in all five high-burden African countries. The study performed an intervention analysis to identify the essential intervention that could support policymakers in controlling the COVID-19 outbreak in the five high-burden African countries. The model findings can be also helpful to many other countries which are dealing with the critical outbreak of COVID-19 and predict what will happen in the future. The COVID-19 pandemic continues to spread in uncertain ways around the world, despite vaccines being available. Due to the uncertainty of the pandemic, it is necessary to properly understand the development of the disease in the community. More research is needed to adequately understand the transmission dynamics of the virus and its variants in Africa. In this study, researchers used a SIMCR model to estimate the basic reproduction number of COVID-19 among five high-burden African countries based on the number of susceptible, infected, mild severe, and series critical severe. The prediction results and the incidence rate estimation could be used by public health officers to plan, and map out strategies to prevent COVID-19 adequately in Africa.

**Methods**

**Study Setting**

The study was conducted among five COVID-19 high burdened African countries. These are South Africa, Morocco, Tunisia, Ethiopia, and Libya.
Our study is deterministic modeling where the population is partitioned into five components based on the epidemiological state of the individuals. The model structure that we selected is based on the nature of COVID-19 and general model assumptions to make it simple. In this model, the population is partitioned into five compartments or classes namely: Susceptible \( S(t) \), infected \( I(t) \), mildly infected population \( M(t) \), critical infected population \( C(t) \), and recovered \( R(t) \) compartments (Figure 1).\(^{41}\) According to this model, a susceptible individual in contact with an infected person is prone to get infected.\(^{41-44}\)

The flow chart of the SLMCR mathematical model shows the five states and the transitions in and out of each state. S: susceptible population; I: Infected population; M: mildly infected population (moderate symptom); C: critical infected population (critical case); R: recovered population; \( \Lambda \): recovered rate; \( \lambda \): infected rate; \( \mu \): death rate; \( \beta \): Recovery rate from M to R; \( \omega \): progression rate from latent to a mild compartment; \( \omega_2 \): progression rate from the latent critical compartment; \( \alpha \): the force of saturation infection; \( \gamma \): recovery rate from mild compartment to recover compartment; \( \beta \): recovery rate from critical compartment to recovery compartment; \( \phi \): the rate of progression from mild to critical compartment due to comorbidities with other diseases (Table 1).\(^{41}\)

**Ordinary Differential Equations (ODE)**

ODEs describe the rate of change in the number of the susceptible, latent, acute, carrier, and recovered compartments at time \( t \).\(^{41}\)

These equations are written as follows:

\[
\frac{ds(t)}{dt} = -\lambda(t) \times s(t)
\]

\[
\frac{dI(t)}{dt} = \lambda(t) \times s(t) - \tau(t) \times I(t) - \delta(t) \times I(t)
\]

\[
\frac{dM(t)}{dt} = \tau(t) \times I(t) - f(t) \times M(t) - \gamma(t) \times M(t)
\]

\[
\frac{dM(t)}{dt} = \delta(t) \times I(t) + \phi(t) \times M(t) - \beta(t) \times C(t)
\]

\[
\frac{dR(t)}{dt} = \gamma(t) \times M(t) + \beta(t) \times C(t)
\]

**Figure 1** Flow chart of the SLMCR mathematical model showing the five states and the transitions in and out of each state.
Table 1 The Assumed and Fitted Values of Model Parameters for Five High-Burden African Countries

| Countries     | Parameters | Descriptive                  | Estimated Values | Reference |
|---------------|------------|-------------------------------|------------------|-----------|
| South Africa  | N          | Population in 2020            | 60,501,086       | Assumed   |
|               | Λ          | Recovery rate                 | 0.0001           |           |
|               | μ          | The death rate per 1000       | 0.00994          | Fitted    |
|               | λ          | Transmission rate             | 0.06             | Fitted    |
|               | τ          | Progression rate from L to M  | 0.00021          | Fitted    |
|               | φ          | Comorbidity rate              | 0.001            | Assumed   |
|               | γ          | The recovery rate from M to C | 0.001            | Assumed   |
|               | δ          | The recovery rate from M to R | 0.00016          | Fitted    |
|               | β          | The recovery rate from M to R |                  |           |
| Morocco       | N          | Population in 2020            | 37,608,226       | Assumed   |
|               | Λ          | Recovery rate                 | 0.0001           |           |
|               | μ          | The death rate per 1000       | 0.0063           | Fitted    |
|               | λ          | Transmission rate             | 0.0305           | Fitted    |
|               | τ          | Progression rate from L to M  | 0.0002           | Fitted    |
|               | φ          | Comorbidity rate              | 0.001            | Assumed   |
|               | γ          | The recovery rate from M to C | 0.0001           | Assumed   |
|               | δ          | The recovery rate from M to R | 0.00027          | Fitted    |
|               | β          | The recovery rate from M to R |                  |           |
| Tunisia       | N          | Population in 2020            | 12,015,844       | Assumed   |
|               | Λ          | Recovery rate                 | 0.0001           |           |
|               | μ          | The death rate per 1000       | 0.0063           | Fitted    |
|               | λ          | Transmission rate             | 0.078            | Fitted    |
|               | τ          | Progression rate from L to M  | 0.00026          | Fitted    |
|               | φ          | Comorbidity rate              | 0.00001          | Assumed   |
|               | γ          | The recovery rate from M to C | 0.001            | Assumed   |
|               | δ          | The recovery rate from M to R | 0.00024          | Fitted    |
|               | β          | The recovery rate from M to R |                  |           |
| Ethiopia      | N          | Population in 2020            | 119,500,320      | Assumed   |
|               | Λ          | Recovery rate                 | 0.0001           |           |
|               | μ          | The death rate per 1000       | 0.0063           | Fitted    |
|               | λ          | Transmission rate             | 0.0039           | Fitted    |
|               | τ          | Progression rate from L to M  | 0.0005           | Fitted    |
|               | φ          | Comorbidity rate              | 0.0001           | Assumed   |
|               | γ          | The recovery rate from M to C | 0.001            | Assumed   |
|               | δ          | The recovery rate from M to R | 0.000497         | Fitted    |
|               | β          | The recovery rate from M to R | 0.00058          | Fitted    |
| Libya         | N          | Population in 2020            | 7,020,278        | Assumed   |
|               | Λ          | Recovery rate                 | 0.0001           |           |
|               | μ          | The death rate per 1000       | 0.0051           | Fitted    |
|               | λ          | Transmission rate             | 0.064            | Fitted    |
|               | τ          | Progression rate from L to M  | 0.0003           | Fitted    |
|               | φ          | Comorbidity rate              | 0.0001           | Assumed   |
|               | γ          | The recovery rate from M to C | 0.001            | Assumed   |
|               | δ          | The recovery rate from M to R | 0.0003           | Fitted    |
|               | β          | The recovery rate from M to R | 0.00034          | Fitted    |

The SICMR model is a compartmental model describing how a COVID-19 disease spreads among the population. The subjects of the SICMR model are susceptible, infected, mild, critical series serious critical, and recovered cases.41
In the model, natural birth rate and natural death rates are considered equal. We use the following symbols to mark the number of individuals in each compartment:

(I) $S(t)$: susceptible, representing the number of individuals who do not have COVID-19 diseases at time $t$ but are likely to have COVID-19 disease in the future

(II) $I(t)$: infected, representing the number of individuals who get COVID-19 disease at time $t$

(III) $R(t)$: recovered, representing the cumulative or total number of the recovered groups at time $t$

(IV) $C(t)$: serious critical infected population, representing the cumulative or total number of patient who has critical symptoms at the time of $t$

(V) $M(t)$: mild severe, representing the cumulative or total number of patient who has mild symptoms at the time of $t$

Results and Discussion

The output below shows the number of people in each compartment. It was modeled for 30 years. As it is shown, the total populations for every five compartments are estimated for each year (Table 2).

This section estimated the model parameters based on the available five African countries’ COVID-19 reported case data from http://worldometers.info. The figures (Figures 2–6) present the pattern of infected individuals, susceptible, mild severe, critical mild severe, and recovered individuals for the next 30 years if the number of infected individuals follows this trend in South Africa, Morocco, Tunisia, Ethiopia, and Libya.

Table 2 The Number of Populations in Each Compartment of the COVID-19 Model Structure Modeled for 30 Years, South Africa, February 2022

| Countries  | Year | Susceptible | Infected | Mild Symptom | Critical Series Symptom | Recovered  |
|------------|------|-------------|----------|--------------|-------------------------|------------|
| South Africa | 2022 | 56,878,876  | 3,622,210 | 3,520,626    | 546                     | 3,477,336  |
|            | 2023 | 53,566,508  | 6,932,672 | 6,825,484    | 1656                    | 6,754,385  |
|            | 2027 | 42,136,908  | 18,343,742| 18,181,292   | 12,440                  | 17,744,899 |
|            | 2032 | 31,215,789  | 29,221,559| 28,929,789   | 37,580                  | 27,661,188 |
|            | 2037 | 23,125,225  | 37,251,931| 36,780,953   | 72,420                  | 34,354,556 |
|            | 2042 | 17,131,588  | 43,172,914| 42,486,587   | 114,337                 | 38,660,915 |
|            | 2047 | 12,691,393  | 47,531,275| 46,603,636   | 161,386                 | 41,199,525 |
|            | 2052 | 9,402,015   | 50,732,068| 49,544,685   | 212,129                 | 42,429,151 |
| Morocco    | 2022 | 36,462,185  | 1,147,243 | 920,626      | 293                     | 1,099,675  |
|            | 2023 | 35,5170,259 | 1,568,144 | 1,341,647    | 564                     | 1,512,400  |
|            | 2027 | 48,833,865  | 2,977,733 | 2,977,733    | 6,623                   | 3,090,457  |
|            | 2032 | 41,926,749  | 4,918,921 | 4,918,921    | 12,624                  | 4,905,423  |
|            | 2037 | 35,996,583  | 6,750,710 | 6,750,710    | 25,177                  | 6,554,635  |
|            | 2042 | 30,905,187  | 8,479,255 | 8,479,255    | 20,355                  | 8,047,588  |
|            | 2047 | 33,730,097  | 10,110,361| 10,110,361   | 29,703                  | 9,393,243  |
|            | 2052 | 32,870,935  | 11,649,509| 11,649,509   | 40,561                  | 10,600,055 |
| Tunisia    | 2022 | 11,075,621  | 940,223   | 92,454       | 200                     | 828,324    |
|            | 2023 | 10,244,556  | 1,770,862 | 923,647      | 335                     | 1,651,113  |
|            | 2027 | 7,498,826   | 4,512,569 | 3,060,218    | 1617                    | 4,321,365  |
|            | 2032 | 5,077,131   | 5,925,190 | 6,084,306    | 4,499                   | 6,574,817  |
|            | 2037 | 3,437,507   | 8,552,620 | 7,715,961    | 8,360                   | 7,989,185  |
|            | 2042 | 2,327,388   | 9,648,440 | 8,816,302    | 12,871                  | 8,835,634  |
|            | 2047 | 1,575,774   | 10,384,340| 9,556,918    | 17,807                  | 9,297,757  |
|            | 2052 | 1,066,888   | 10,876,563| 10,053,982   | 23,018                  | 9,499,858  |
To parameterize the model, we obtained some of the parameter values from the literature (Table 2). Others were fitted or estimated from the data. The model was fitted using R version 4.0.5 using starting points from the data (South Africa, Morocco, Tunisia, Ethiopia, and Libya, COVID-19 infections 3,623,962, 1,146,041, 940,223, 466,455, and 445,876 and deaths reached 95,817, 15,593, 26,679, 7363, and 6067 respectively).  

The prediction results from the model are also shown in the figure below to show direction and to understand the importance of intervention in the evidence-based decision-making process. The predicted result shows that if the number of infected individuals, number of recovered, and critical series severe follow this trend for the next year, there will be around 6,932,672 in South Africa, 1,568,144 in Morocco, 1,770,862 in Tunisia, 929,366 in Ethiopia, and 853,195 in Libya patients infected. In addition to this, if this trend continues in the next 10 years, there will be around 29,221,559 in South Africa, 5,144,339 in Morocco, 5,925,190 in Tunisia, 5,002,988 in Ethiopia, and 3,545,001 in Libya recovered from

### Table 2 (Continued)

| Countries | Year | Susceptible | Infected | Mild Symptom | Critical Series Symptom | Recovered |
|-----------|------|-------------|----------|--------------|-------------------------|-----------|
| Ethiopia  | 2022 | 119,033,865 | 466,455  | 44,225       | 232                     | 400,734   |
|           | 2023 | 118,570,537 | 929,366  | 507,809      | 301                     | 859,824   |
|           | 2027 | 116,735,190 | 2,760,302| 2,344,255    | 1040                    | 2,651,927 |
|           | 2032 | 114,480,904 | 5,002,988| 4,600,060    | 2981                    | 4,793,889 |
|           | 2037 | 112,270,151 | 7,195,521| 6,812,473    | 6028                    | 6,828,948 |
|           | 2042 | 110,102,091 | 9,338,893| 8,982,311    | 10,156                  | 8,759,385 |
|           | 2047 | 107,975,898 | 11,434,070| 11,110,375  | 15,339                  | 10,587,436|
|           | 2052 | 105,890,764 | 13,462,005| 13,197,431  | 21,531                  | 12,315,293|
| Libya     | 2022 | 6,574,402   | 445,876  | 43,645       | 133                     | 6,052     |
|           | 2023 | 6,166,822   | 853,195  | 451,400      | 198                     | 410,393   |
|           | 2027 | 4,773,996   | 2,243,496| 1,845,150    | 829                     | 1,772,626 |
|           | 2032 | 3,466,632   | 3,545,001| 3,154,063    | 2,292                   | 3,009,603 |
|           | 2037 | 2,517,292   | 4,486,259| 4,105,273    | 4,309                   | 3,862,113 |
|           | 2042 | 1,827,929   | 5,165,933| 4,796,727    | 6,726                   | 4,435,543 |
|           | 2047 | 1,327,349   | 5,655,665| 5,299,551    | 9,430                   | 4,806,418 |
|           | 2052 | 963,853     | 6,007,478| 5,665,393    | 12,340                  | 5,030,308 |

Figure 2 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, South Africa, February 2022.
COVID-19 by April 30th, 2032, as shown in tables and figures below. This is consistent with the report of WHO, which stated that the number of newly confirmed cases was higher among African countries. The pattern of increasing cases is driven by South Africa and Ethiopia, which continue to report the highest numbers of new cases.

If this trend continues for the next 3 decades, the number of susceptible individuals will decrease, but the number of infected, mild severe patients and recovered individuals will increase. The number of susceptible individuals decreased by 50,732,068 in South Africa, 11,782,920 in Morocco, 10,876,563 in Tunisia, 13,482,005 in Ethiopia, and 6,007,478 in Libya in the next 3 decades.

The following are the ggplots of the above table (Table 2). As those graphs clearly show, the number of susceptible individuals decreased among five high-burden African countries. But the number of infected, mild severe, critical severe, and recovered populations will increase at the end of the studying years. The population in the three compartments will increase over the next 30 years. The population in the critical severe compartment will remain almost constant throughout the study period (Figures 2–6).
Intervention Implementation

Providing COVID-19 vaccine to the population of five high-burden African countries is 70–95% effective to prevent COVID-19 transmission from individual to individual.

Now we can think of the COVID-19 vaccine as an intervention to reduce coronavirus transmission from person to person. Currently, the distribution of vaccines is being offered in all African countries. We want to plan the intervention, by assuming that it is possible to offer the COVID-19 vaccine to half of the population in five high-burden African countries. The model formulation considering the intervention is done as follows.

Let the intervention to be offered is labeled as: “CD_COVID-19”

Coverage of COVID-19 vaccine (C_CD_COVID-19) = 0.5(50%),

Efficacy of COVID-19 vaccine (E_CD_COVID-19) = 0.76(76%)

Lambda intervention for South Africa = lambda*(1- (C_CD_COVID-19 * E_CD_COVID-19))

The value of the force of infection (lambda) after intervention will be:

Lambda intervention = lambda*(1- (C_CD_COVID-19 * E_CD_COVID-19))

Figure 5 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Ethiopia, February 2022.

Figure 6 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Libya, February 2022.
Lambda intervention = 0.64 * (1 - (0.5 * 0.76))
Lambda intervention = 0.64 * (1 – 0.38)
= 0.64 * 0.62
= 0.3968

Therefore, the intervention will reduce the force of infection by 62%.

Lambda intervention for Morocco =\( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))

The value of the force of infection (\( \lambda \)) after intervention will be:
Lambda intervention = \( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))
Lambda intervention = 0.03 * (1 - (0.5 * 0.76))
Lambda intervention = 0.05 * (1 – 0.38)
= 0.03 * 0.62
= 0.0186

Therefore, the intervention will reduce the force of infection by 62%.

Lambda intervention for Tunisia =\( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))

The value of the force of infection (\( \lambda \)) after intervention will be:
Lambda intervention = \( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))
Lambda intervention = 0.85 * (1 - (0.5 * 0.76))
Lambda intervention = 0.85 * (1 – 0.38)
= 0.85 * 0.62
= 0.527

Therefore, the intervention will reduce the force of infection by 62%.

Lambda intervention for Ethiopia =\( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))

The value of the force of infection (\( \lambda \)) after intervention will be:
Lambda intervention = \( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))
Lambda intervention = 0.004 * (1 - (0.5 * 0.76))
Lambda intervention = 0.05 * (1 – 0.38)
= 0.004 * 0.62
= 0.00248

Therefore, the intervention will reduce the force of infection by 62%.

Lambda intervention for Libya =\( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))

The value of the force of infection (\( \lambda \)) after intervention will be:
Lambda intervention = \( \lambda \) * (1 - (C_{CD\_COVID-19} * E_{CD\_COVID-19}))
Lambda intervention = 0.068 * (1 - (0.5 * 0.76))
Lambda intervention = 0.068 * (1 – 0.38)
= 0.068 * 0.62
= 0.04216

Therefore, the intervention will reduce the force of infection by 62%.

The prediction results after intervention are shown in Table 3. If 50% of the population is vaccinated and if the number of infected individuals, recovers, and critical severe follow the same trend for the next 10 years, it is possible to reduce the number of infected individuals in Africa. There will be around 9,847,641 in South Africa, 15,183,777 in Morocco, 3,773,632 in Tunisia, 2,255,118 in Ethiopia, and 1,893,279 in Libya infected. In addition to this, if this trend continues in the next 10 years, there will be around 9,158,288 in South Africa, 14,268,506 in Morocco, 3,525,578 in Tunisia, 2,117,100 in Ethiopia, and 1,399,768 in Libya recovered from COVID-19 by April 30th, 2032 as shown in figures and tables below. A similar study reported that COV2.S given two months after the initial immunization increased vaccine effectiveness in the short term to 100% against severe disease.\(^{45}\) The previous study has also found that vaccination is an important protective factor against COVID-19.\(^{46–55}\)

If this trend continues for the next 3 decades the number of susceptible individuals will increase but the number of infected, mild severe patients, and recovered individuals will decrease. The number of the susceptible individual
increased by 30,711,930 in South Africa, 5,919,837 in Morocco, 3,485,020 in Tunisia, 7,833,642 in Ethiopia, and 2,145,404 in Libya in the next 3 decades with compare to the unvaccinated population and the number of infected individuals decreases by 30,479,271 in South Africa, 19,809,751 in Morocco, 3,456,406 in Tunisia, 7,761,993 in Ethiopia and 2,125,038 in Libya.

Table 3 The Number of Populations After Intervention in Each Compartment of the COVID-19 Model Structure Modeled for 30 Years, February 2022

| Countries       | Year | Susceptible | Infected      | Mild Symptom | Critical Series Symptom | Recovered |
|-----------------|------|-------------|---------------|--------------|-------------------------|-----------|
| South Africa    | 2022 | 56,878,876  | 3,622,210     | 3,520,626    | 546                     | 3,477,336 |
|                 | 2023 | 56,220,644  | 4,279,019     | 4,173,295    | 1374                    | 4,102,449 |
|                 | 2027 | 53,663,015  | 6,828,637     | 6,699,401    | 6034                    | 6,473,730 |
|                 | 2032 | 50,628,974  | 9,847,641     | 9,674,085    | 14,754                  | 9,158,288 |
|                 | 2037 | 47,766,475  | 12,689,831    | 12,456,406   | 26,500                  | 11,548,769|
|                 | 2042 | 45,065,817  | 15,365,215    | 15,057,428   | 41,075                  | 13,661,928|
|                 | 2047 | 42,517,852  | 17,883,234    | 17,487,589   | 58,296                  | 15,513,574|
|                 | 2052 | 40,113,945  | 20,252,797    | 19,756,734   | 77,991                  | 17,118,625|
| Morocco         | 2022 | 36,532,983  | 1,146,041     | 920,626      | 293                     | 1,099,675 |
|                 | 2023 | 35,709,455  | 1,969,008     | 1,742,255    | 619                     | 1,909,839 |
|                 | 2027 | 50,750,630  | 9,738,326     | 9,600,949    | 7604                    | 9,323,634 |
|                 | 2032 | 45,282,653  | 15,183,777    | 14,979,554   | 20,675                  | 14,268,506|
|                 | 2037 | 40,403,807  | 20,030,845    | 19,732,407   | 39,065                  | 18,409,318|
|                 | 2042 | 36,050,619  | 24,344,021    | 23,927,290   | 62,155                  | 21,832,945|
|                 | 2047 | 32,166,451  | 28,180,848    | 27,624,674   | 89,392                  | 24,616,906|
| Tunisia         | 2022 | 11,075,621  | 3,622,210     | 940,223      | 200                     | 828,324   |
|                 | 2023 | 10,752,157  | 4,902,841     | 4,161,15     | 309                     | 4,723,767 |
|                 | 2027 | 9,550,050   | 2,463,101     | 1,618,182    | 1057                    | 2,302,232 |
|                 | 2032 | 8,234,613   | 3,773,632     | 2,931,880    | 2614                    | 3,525,578 |
|                 | 2037 | 7,100,366   | 4,901,069     | 4,062,753    | 4770                    | 4,532,956 |
|                 | 2042 | 6,122,352   | 5,870,635     | 5,035,987    | 7436                    | 5,354,193 |
|                 | 2047 | 5,279,051   | 6,704,080     | 5,873,295    | 10,535                  | 6,015,009 |
|                 | 2052 | 4,551,908   | 7,420,157     | 6,593,402    | 14,004                  | 6,537,581 |
| Ethiopia        | 2022 | 119,033,865 | 466,455       | 44,225       | 232                     | 400,734   |
|                 | 2023 | 118,852,952 | 647,035       | 225,392      | 287                     | 578,217   |
|                 | 2027 | 118,132,046 | 1,365,537     | 947,341      | 689                     | 1,275,113 |
|                 | 2032 | 117,237,059 | 2,255,118     | 1,843,685    | 1594                    | 2,117,100 |
|                 | 2037 | 116,348,853 | 3,135,277     | 2,733,301    | 2940                    | 2,927,023 |
|                 | 2042 | 115,467,376 | 4,006,093     | 3,616,230    | 4722                    | 3,705,211 |
|                 | 2047 | 114,592,577 | 4,867,645     | 4,492,516    | 6935                    | 4,451,989 |
|                 | 2052 | 113,724,406 | 5,720,012     | 5,362,201    | 9574                    | 5,167,680 |
| Libya           | 2022 | 6,574,402   | 445,876       | 43,645       | 133                     | 6052      |
|                 | 2023 | 6,412,336   | 607,731       | 205,879      | 186                     | 165,472   |
|                 | 2027 | 5,803,050   | 1,215,550     | 815,930      | 552                     | 756,757   |
|                 | 2032 | 5,122,198   | 1,893,279     | 1,497,927    | 1332                    | 1,399,768 |
|                 | 2037 | 4,521,228   | 2,489,853     | 2,100,223    | 2429                    | 1,947,762 |
|                 | 2042 | 3,990,768   | 3,014,798     | 2,632,168    | 3805                    | 2,411,930 |
|                 | 2047 | 3,522,545   | 3,476,520     | 3,102,010    | 5426                    | 2,802,150 |
|                 | 2052 | 3,109,257   | 3,882,440     | 3,517,032    | 7261                    | 3,127,140 |
The following are the ggplots of the above table result after intervention (Table 3). As those graphs (Figures 7–11) clearly show, the number of susceptible individuals decreased among five high-burden African countries. But compared to the previous result (before intervention) the number of susceptible increased and the intervention reduced the number of infected individuals throughout the study period. From the figure, the number of Infected, Mild severe, critical severe, and recovered populations will increase at the end of the studying years. But compared to the previous results (before intervention) there is a dramatic decrease in the number of infected individuals.

The incidence rates of symptoms and diseases in the general population are important indicators of a population’s health status. The incidence of the COVID-19 pandemic is shown below for the next 30 years among five high-burden African countries. The incidence in the first year will be 55 cases per 1000 in South Africa, 984 cases per 10,000 population in Morocco, 1216 cases per 1000 population, 769 cases per 100,000 population in Ethiopia, and 1097 cases per 1000 population.

![Figure 7](Image) The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, South Africa, February 2022.

![Figure 8](Image) The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Morocco, February 2022.
per 10,000 population during one year at risk before intervention. The incidence rate of the COVID-19 pandemic will then decrease till the end of the next 30 years in all countries. But if 50% of the population is vaccinated, the incidence rate in those countries decreases dramatically compared to the unvaccinated population. The Incidence rate after the intervention is 3652 cases per 100,000 in South Africa, 2076 cases per 1,000,000 population in Morocco, 4915 cases per 100,000 population, 3 cases per 1000 population in Ethiopia, and 4385 cases per 100,000 population during one year at risk (Table 4).
Conclusion

SIRD and SIRS models are classical and effective stochastic models of infectious diseases. In this research, the SIMCR model is used to describe the transmission of COVID-19 among five high-burden African countries. South Africa, Morocco, Tunisia, Ethiopia, and Libya are the top 5 COVID-19 high-burden African countries. Through the analysis of

![Figure 11](https://doi.org/10.2147/CLEP.S366142) The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Libya, February 2022.

| Countries     | Year | Incidence Rate Per 1000 Population Before Intervention | Incidence Rate Per 1000 Population After Intervention |
|---------------|------|-------------------------------------------------------|-------------------------------------------------------|
| South Africa  | 2022 | NA                                                    | NA                                                    |
|               | 2023 | 98.39                                                 | 36.52                                                 |
|               | 2027 | 66.26                                                 | 29.29                                                 |
|               | 2032 | 43.29                                                 | 23.01                                                 |
|               | 2037 | 29.56                                                 | 18.57                                                 |
|               | 2042 | 20.70                                                 | 15.29                                                 |
|               | 2047 | 14.72                                                 | 12.77                                                 |
|               | 2052 | 10.54                                                 | 10.79                                                 |
| Morocco       | 2022 | NA                                                    | NA                                                    |
|               | 2023 | 55                                                    | 20.76                                                 |
|               | 2027 | 44                                                    | 18.35                                                 |
|               | 2032 | 34                                                    | 15.94                                                 |
|               | 2037 | 28                                                    | 14.002                                                |
|               | 2042 | 23                                                    | 12.42                                                 |
|               | 2047 | 19                                                    | 11.10                                                 |
|               | 2052 | 16                                                    | 9.99                                                  |

(Continued)
the recent data, the number of infected individuals has increased today. If this trend is continuous for the next 30 years we will have around 86 million infected individuals and millions of deaths only in those five African countries. Also, the incidence rates of those countries are high before intervention compared to after intervention. To reduce those problems, vaccination is the best and most effective mechanism. So, vaccinating half of the population in those countries helps to control and reduce the transmission rate of COVID-19 in Africa for the next 30 years. This will lead to preventing 17,212,405 people from becoming infected and millions of deaths being reduced in those five high-burden African countries for the next 30 years. Finally, we hope that the governments will impose the strictest, most scientifically effective containment measures to quickly conquer COVID-19.

Many research works have been done for short terms forecasting periods like 25, 30, and 60 days. Where in this study, the authors took data for the last year and predicted the scenario for the next 30 years. Moreover, the SIRD model showed excellent accuracy in the prediction force of infection and the best intervention method which previous models could not achieve.

So, this model should be applied for forecasting future analysis and identifying the force of infection for any dataset. The limitation that was observed during prediction was that SIRD models upturn the number of susceptible, infected, recovered, and deaths. But SIRD model is the greatest and most effective model to identify the best intervention method and force of infection. In the future, investigators can explore some predictive models such as the ARIMA model and Bayesian networks in COVID-19. This model is also recommended to be applicable for future pandemics and to identify the most effective intervention method.
**Ethics Approval**

The study was based on aggregated COVID-19 surveillance data in South Africa, Morocco, Tunisia, Ethiopia, and Libya taken from the worldometer. No confidential information was included because analyses were performed at the aggregate level. Therefore, no ethical approval is required.

**Data Sharing Statement**

The datasets generated and/or analyzed during the current study are available on the following website: [https://www.worldometers.info/coronavirus/](https://www.worldometers.info/coronavirus/).

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**Disclosure**

The authors declare that there are no conflicts of interest.

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