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ORIGINAL RESEARCH

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

Sebwedin Surur Jemal, Bizuwork Derebew Alemu

Department of Statistics, College of Natural and Computational Sciences, Mizan-Tepi University, Tepi, Ethiopia

Correspondence: Sebwedin Surur Jemal, Department of Statistics, College of Natural and Computational Sciences, Mizan-Tepi University, Tepi, Ethiopia, Tel +251977237466, Email sebwedinsurur@gmail.com

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 severs, 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.[1] 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.[2] The United States of America (USA) reported the highest number of cases (79,293,924) (3, 4) and 942,944 deaths[3–7] with a CFR of 1.18%, followed by India (42,631,421) cases and 508,665 deaths with a CFR of 1.19%.[3,4,7–10] The first case of coronavirus in Africa was reported in Egypt on February 14, 2020.[11,12] By the end of October 2021, 47 African countries were affected, with over 150,000 deaths and over 6.07 million confirmed cases.[13] Africa is considered one of the most vulnerable continents due to its strong trade relations with China and poor health care system.[4,14,15] As of 07th February 2022, the ongoing global pandemic outbreak of COVID-19 has spread to at least 58 African countries,[14,16] 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.[2] 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%,

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0.22%, 0.006%, and 0.086%, respectively.[2] This disease has left a permanently dark mark on the history of the human race.[12] The coronavirus disease-19 (COVID-19) pandemic will be infamously recorded in history forever.[12]

In the case of the Southern African countries, the basic reproduction number (R0) for South Africa was estimated to be 7.02.[17] This was followed by Zambia with R0 = 2.59 and Namibia with R0 = 2.37.[17] The reproduction number for Malawi was 2.16.[17] Among the Central African countries considered, Cameroon had an R0 of 3.74, Chad (2.03),[17] Gabon (2.37),[17] and the Republic of the Congo (2.54).[17] Of these countries, Cameroon was the first to be infected with COVID-19, followed by the Republic of the Congo, Gabon, and Chad. Among the African island nations,[18] Madagascar (4.97) and Mauritius (9.66) showed the highest breeding numbers.[17] In North Africa, Morocco (3.92) is estimated to have the highest basic reproduction number, followed by Tunisia (3.87), Algeria (3.31), and Egypt (2.72).[13,17] Similar results were obtained in East African countries. Sudan has the lowest reproduction number (1.98), followed by Ethiopia (2.55), Kenya (3.77), and Rwanda (4.04).[17] In addition to this, a new type of COVID-19 emerged in the world.[19–21] The virus is constantly changing, which can lead to the emergence of new variants or strains of the virus.[19,22] Variants usually do not affect the behavior of the virus. But sometimes they make it work differently.[23–25] Omicron variants spread more easily than the original virus that causes COVID-19 and delta variants.[17,19,20] The Omicron COVID19 variant was first reported in South Africa on November 24, 2021 (26). It is quickly spreading across the world.[20,21,26] The severity associated with Omicron is still unknown, but early reports suggest a mild illness, at least in the younger population.[19–21] 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 COVID19 vaccination status, the presence of other conditions, age, and previous history of infection.[20,22,27]

The biggest burden of COVID19 depends on the medical system and on the prompt and timely response to the pandemic.[27–33] But the problem is that almost all African countries respond slightly too slowly, and some of them cannot use their vaccines effectively.[34–36] 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.[17,37] Infectious disease modeling is a powerful tool for infectious disease control that helps to accurately predict characteristics and understand infectious disease dynamics.[38–40] In infectious disease models, the incidence rate plays a vital role in the transmission of infectious diseases.[38–40] From an epidemiological point of view, the number of people infected per unit time is called the incidence.[38–40] 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.[38–40] 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 COVID19 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; Λ: recovered rate, λ: infected rate; μ: death rate; β: Recovery rate from M to R; ω: progression rate from latent to a mild compartment; ω2: progression rate from the latent critical compartment; α: the force of saturation infection; γ: recovery rate from mild compartment to recover compartment; β: recovery rate from critical compartment to recovery compartment; ϕ: 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:

$$\frac{ds(t)}{d(t)} = -\lambda(t)\times s(t)$$

$$\frac{dI(t)}{d(t)} = \lambda(t)\times s(t) - \tau(t)\times I(t) - \delta(t)\times I(t)$$

$$\frac{dM(t)}{d(t)} = \tau(t)\times I(t) - f(t)\times M(t) - \gamma(t)\times M(t)$$

$$\frac{dM(t)}{d(t)} = \delta(t)\times I(t) + \phi(t)\times M(t) - \beta(t)\times c(t)$$

$$\frac{dR(t)}{d(t)} = \gamma(t)\times M(t) + \beta(t)\times C(t)$$

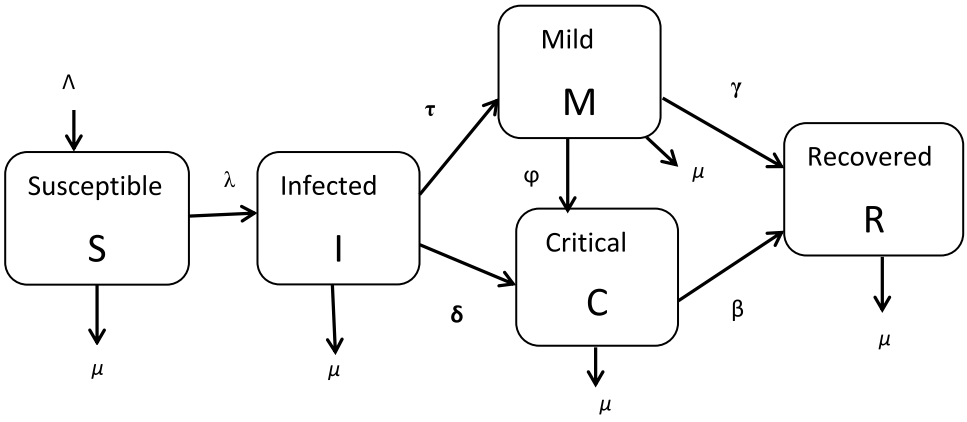

Figure 1 Flow chart of the SLMCR mathematical model showing the five states and the transitions in and out of each state.

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	
	Λ	Recovery rate	0.0001	Assumed
	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	0.001	Assumed
	δ	R Progression rate from L to C	0.00015	Fitted
	β	The recovery rate from M to R	0.00016	Fitted
Morocco	**N**	Population in 2020	37, 608, 226	
	Λ	Recovery rate	0.0001	Assumed
	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	0.0001	Assumed
	δ	R Progression rate from L to C	0.00026	Fitted
	β	The recovery rate from M to R	0.00027	Fitted
Tunisia	**N**	Population in 2020	12, 015, 844	
	Λ	Recovery rate	0.0001	Assumed
	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	0.001	Assumed
	δ	R Progression rate from L to C	0.000213	Fitted
	β	The recovery rate from M to R	0.00024	Fitted
Ethiopia	**N**	Population in 2020	119, 500, 320	
	Λ	Recovery rate	0.0001	Assumed
	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	0.001	Assumed
	δ	R Progression rate from L to C	0.000497	Fitted
	β	The recovery rate from M to R	0.00058	Fitted
Libya	**N**	Population in 2020	7, 020, 278	
	Λ	Recovery rate	0.0001	Assumed
	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	0.001	Assumed
	δ	R Progression rate from L to C	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]

$$N = S(t)+I(t)+R(t)+D(t)$$

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:[41]

(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.[2] 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	6,745,385
	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	3,203,750	2,977,733	6,623	3,090,457
	2032	41,926,749	5,144,339	4,918,921	12,624	4,905,423
	2037	35,996,583	6,975,532	6,750,710	25,177	6,554,635
	2042	30,905,187	8,659,240	8,479,255	20,355	8,047,588
	2047	33,730,097	10,268,800	10,110,361	29,703	9,393,243
	2052	22,780,935	11,782,920	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

(*Continued*)

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	13,482,005	13,197,451	21,551	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

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).[2]

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

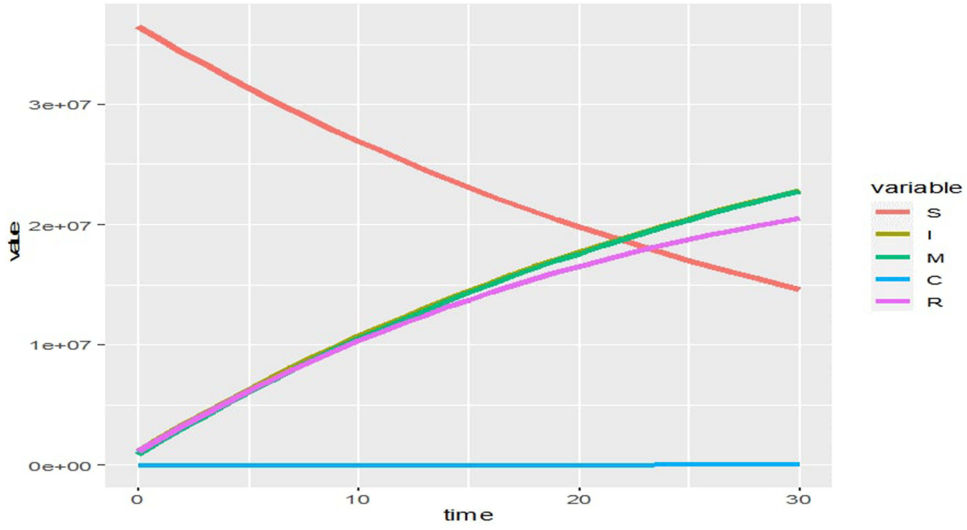

Figure 2 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, South Africa, February 2022.

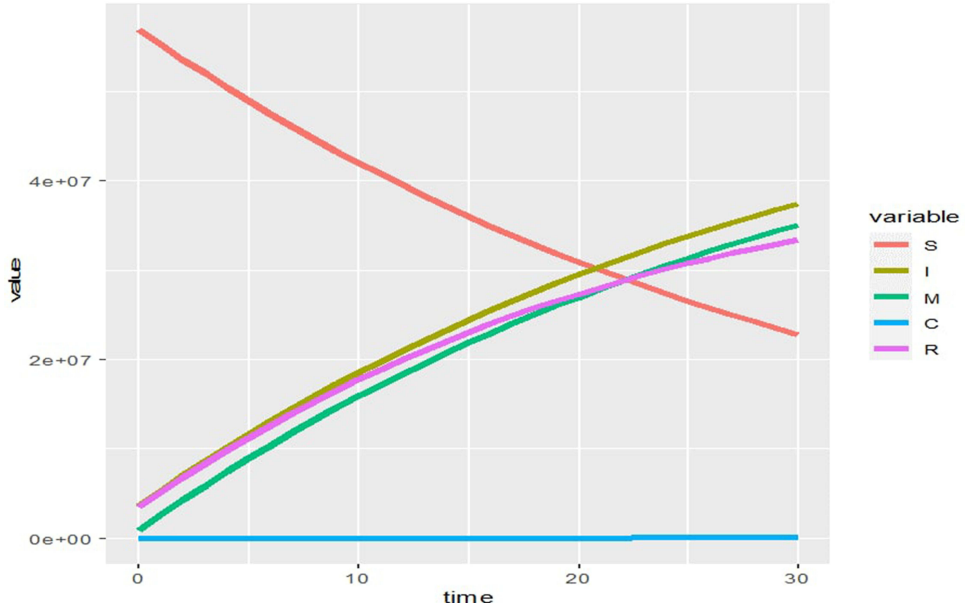

Figure 3 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Morocco, February 2022.

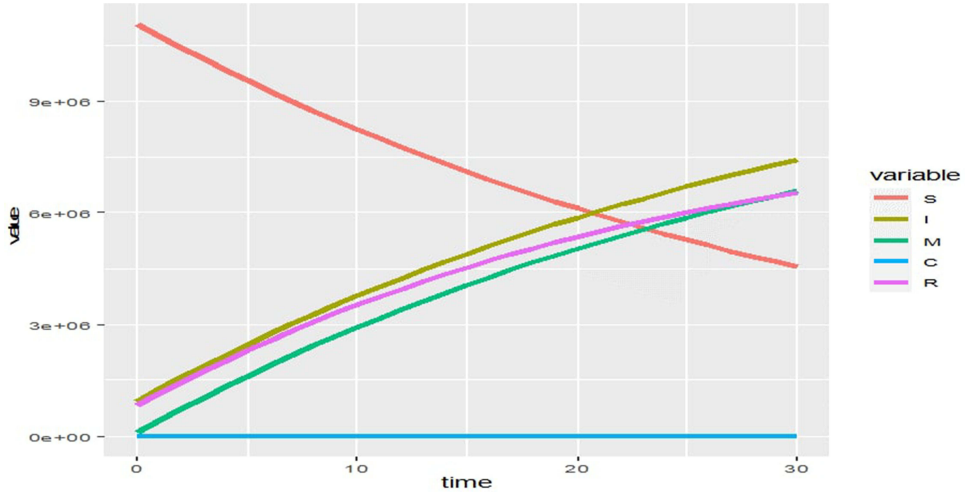

Figure 4 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Tunisia, February 2022.

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.[42] The pattern of increasing cases is driven by South Africa and Ethiopia, which continue to report the highest numbers of new cases.[42]

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).

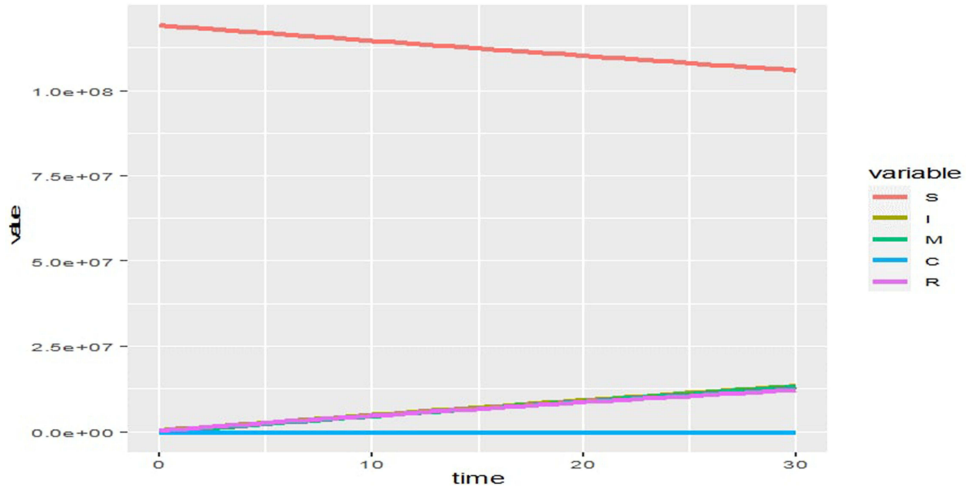

Figure 5 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Ethiopia, February 2022.

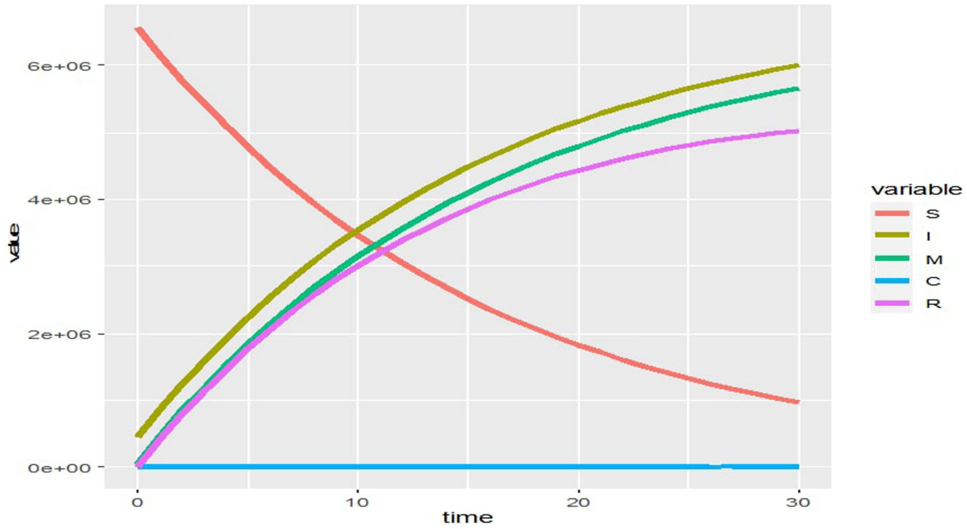

Figure 6 The number of populations in each compartment of the COVID-19 model structure modeled for 30 years, Libya, February 2022.

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))

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

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
	2052	28,700,772	31,592,671	30,878,517	120,286	26,830,366
Tunisia	2022	11,075,621	3,622,210	940,223	200	828,324
	2023	10,752,157	4,902,841	416,115	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

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.

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

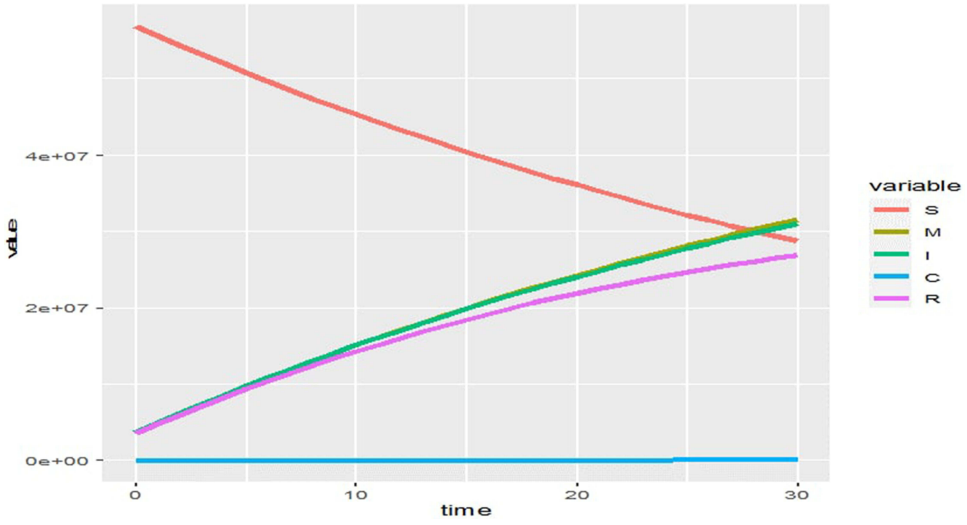

Figure 7 The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, South Africa, February 2022.

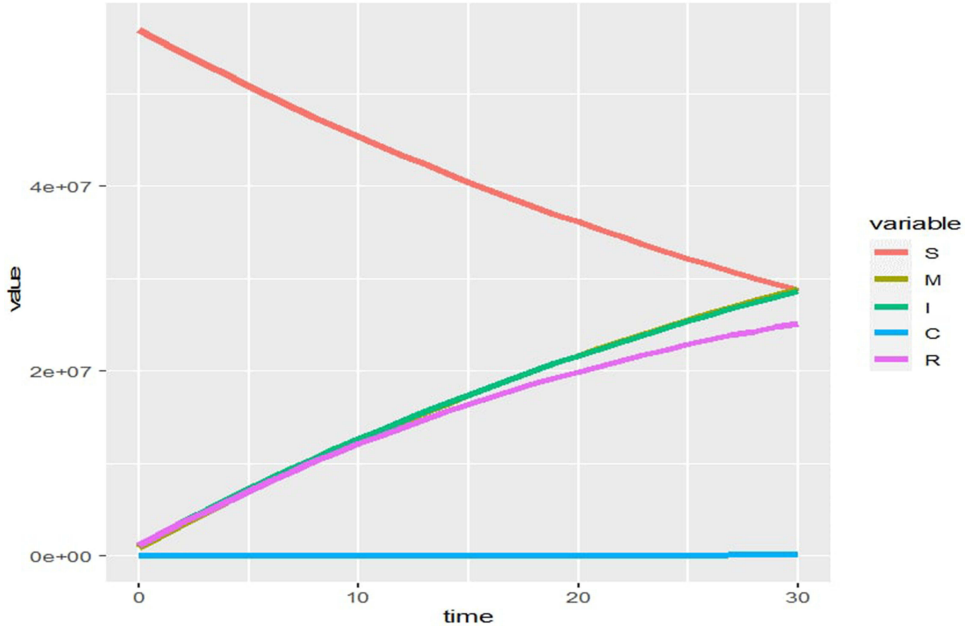

Figure 8 The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Morocco, February 2022.

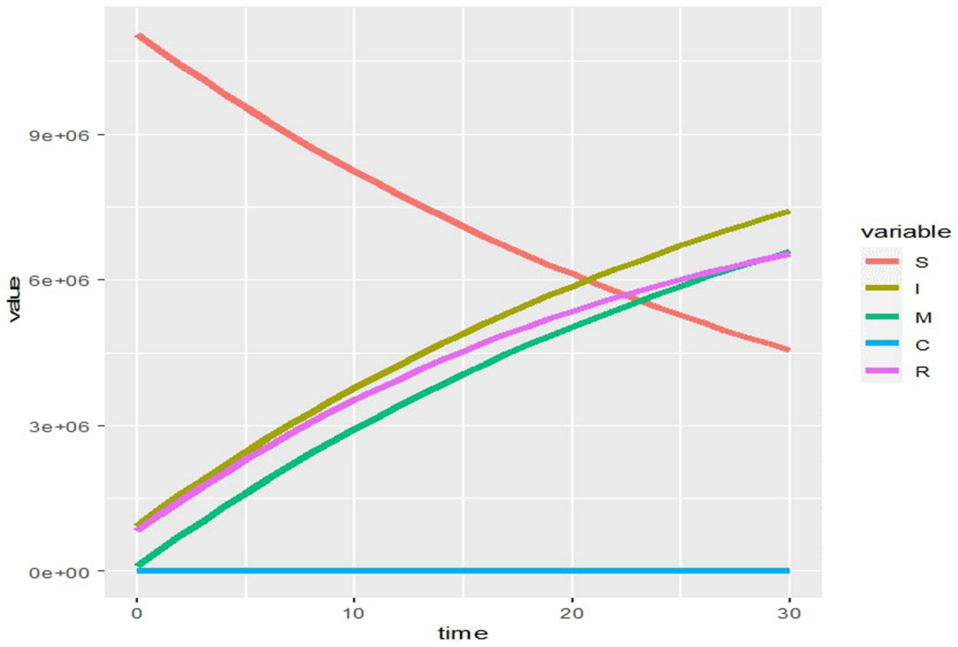

Figure 9 The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Tunisia, February 2022.

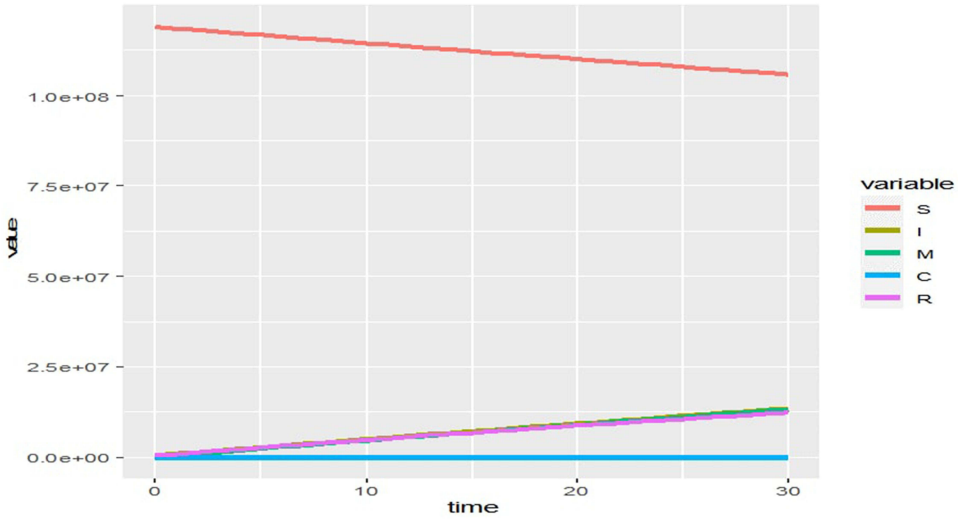

Figure 10 The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Ethiopia, February 2022.

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).

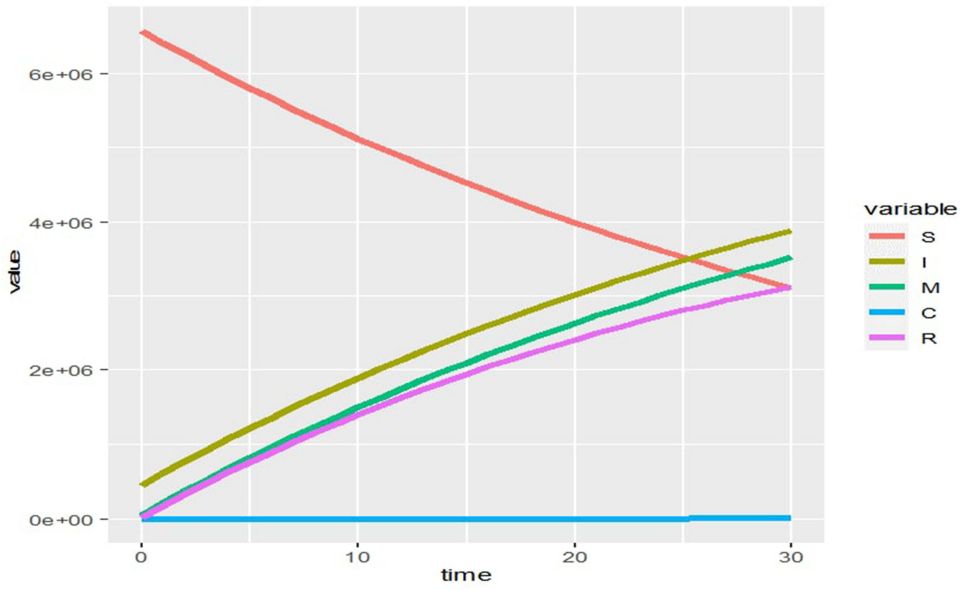

Figure 11 The number of populations in each compartment of the COVID-19 modeled for 30 years after the intervention, Libya, February 2022.

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

Table 4 Incidence Rate per 1000 Population Before Intervention and After the Intervention, 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*)

Table 4 (Continued).

Countries	Year	Incidence Rate Per 1000 Population Before Intervention	Incidence Rate Per 1000 Population After Intervention
Tunisia	2022	NA	NA
	2023	121.6	49.15
	2027	73.39	40.09
	2032	44.18	31.81
	2037	27.72	25.72
	2042	17.94	21.09
	2047	11.81	17.49
	2052	7.84	14.62
Ethiopia	2022	NA	NA
	2023	7.69	2.93
	2027	7.46	2.877
	2032	7.18	2.813
	2037	6.92	2.753
	2042	6.68	2.694
	2047	6.45	2.54
	2052	6.24	2.35
Libya	2022	0	0
	2023	109.7	43.85
	2027	71.74	34.12
	2032	45.64	26.08
	2037	30.53	20.62
	2042	21.03	16.69
	2047	14.77	13.74
	2052	10.49	11.46

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/.

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Disclosure

The authors declare that there are no conflicts of interest.

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