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RESEARCH ARTICLE

The present value of human life losses associated with COVID-19 and likely cost savings from vaccination in Kenya [version 1; peer review: awaiting peer review]

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Abstract
Background: The study estimates the total present value (TPV_{KENYA}) of human lives lost due to COVID-19, total indirect costs attributed to COVID-19 mortality, total direct costs of all COVID-19 cases, and projected cost savings due to COVID-19 vaccination as of 25 July 2022.
Methods: We used a human capital approach (HKA) model to estimate TPV_{KENYA}. The indirect cost of COVID-19 $(IC_{i=1,..,6})$ for each of the six productive age groups equals the present value multiplied by the relevant employment-to-population ratio. The direct cost $(DC_{i=1,..,4})$ for each of the four disease severity categories (asymptomatic, mild/moderate, severe, critical) is the product of the number of COVID-19 cases in a severity category and the average total direct cost per patient. The total direct cost saving equals the number of infections averted with vaccination multiplied by the average total direct cost per patient treated. The total indirect cost saving equals the number of COVID-19 deaths prevented with vaccination multiplied by the average total indirect cost per death.
Results: The cumulative 5670 human life losses had a TPV_{KENYA} of Int$268,408,687 and an average total present value of Int$47,338 per human life. A re-run of the HKA model with (a) discount rates of 5% and 10% reduced TPV_{KENYA} by 16% and 39%, respectively; (b) Africa's highest life expectancy of 78.76 years and world's highest life expectancy of 88.17 years increased TPV_{KENYA} by 79% and 129%, respectively; (c) excess mortality of 180,215 increased TPV_{KENYA} by 3,078%. Total indirect and direct costs of COVID-19 were Int$36,833 per death and Int$1,648.2 per patient/case, respectively. The 30% target population's COVID-19 vaccination coverage may have saved Kenya a total cost of Int$ 1,400,945,809.
Conclusions: The pandemic continues to erode Kenya's human health and economic development. However, scaling up COVID-19 vaccination coverage would save Kenya substantial direct and indirect

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costs.

Keywords
COVID-19, value of life, direct cost, indirect cost, cost savings from vaccination

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1. Background

Kenya is on the Eastern side of the African continent. It is one of the East African Community's seven member states (including the Democratic Republic of the Congo, Burundi, Rwanda, South Sudan, Uganda, and the United Republic of Tanzania).[1] In 2022, it had an estimated population of 56,206,851 people,[2] a total gross domestic product (GDP) of International Dollars (Int$) 293.423 billion, and a GDP per capita of Int$ 5762.003.[3] In 2021, the country had a Gini Coefficient of 40.8.[4] The national income shares held by the poorest 40 per cent, richest 10 per cent, and richest one per cent were 16.5%, 31.6%, and 15.2%, respectively.

According to the World Bank, during the global coronavirus disease (COVID-19) pandemic, the real GDP contracted by 0.4% in 2020 compared with 5.4% in 2019.[5] The first case of COVID-19 was confirmed in Kenya on 12 March 2020.[6] As of 25 July 2022, Kenya had reported a cumulative total of 337,339 coronavirus disease (COVID-19) cases, consisting of 330,910 recoveries, 5,670 deaths and 759 active cases.[7] However, the level of testing in the country has been low. For example, by 25 July 2022, Kenya had conducted 67,769 COVID-19 laboratory tests per million population compared with 426,031 and 7,614,872 per million population in South Africa and the United Kingdom (UK), respectively.[8] Therefore, there is a likelihood that the COVID-19 burden in Kenya is substantively underreported.

The morbidity and mortality from COVID-19 in Kenya could be attributed to underperformance in four health-related systems. First, the sub-optimal national health system (NHS). For instance, in 2019, Kenya's average universal health coverage (UHC) service index was 56 on a scale of 0 to 100 (target).[9] It signifies an overall gap in essential health services coverage of 44, which is attributed to deficits in its constituent components of 65 in the UHC coverage sub-index (UHCCSI) on service capacity and access, noncommunicable diseases (NCDs) UHCCSI of 28, infectious diseases (IDs) UHCCSI of 47, and reproductive, maternal, neonatal and child health UHCCSI of 27.

Second, weaknesses in Kenya's integrated disease surveillance system (IDSS) as reflected in gaps in the implementation of International Health Regulations (IHR) capacities.[10] For example, as shown in Table 1, in 2020, Kenya's average 13 IHR core capacity score was 44 on a scale of 0 to 100, denoting an implementation gap of 56%.[11]

None of the 13 IHR capacities listed in Table 1 had an optimal score of 100. The IHR capacities of human resources and radiation emergencies had gaps of 80%; legislation and financing, health service provision, points of entry, chemical events, and coordination/national focal point functions had gaps of 60%; the national health emergency framework had a gap of 53%; surveillance had a gap of 50%; laboratory, risk communication, food safety, zoonotic events and the human-animal interface had a gap of 40%.

Table 1. A comparison of the International Health Regulations (IHR) capacity scores for Kenya with those for the World Health Organization (WHO) African Region (WAR).

IHR capacity	Kenya in 2020	WAR in 2020
Legislation and financing	40	47
IHR coordination and National IHR Focal Point Functions	40	54
Laboratory	60	61
Surveillance	50	64
Human resources	20	52
National health emergency framework	47	48
Health service provision	40	46
Risk communication	60	55
Points of entry	40	42
Chemical events	40	32
Radiation emergencies	20	32
Food safety	60	46
Zoonotic events and the human-animal interface	60	52
Average of 13 IHR core capacity scores	44	49

Source: WHO.[11]

The third is the underperformance of systems tackling social determinants of health (SDH), such as education, food, shelter, sanitation and water. For example, in 2018, the literacy rate was 81.54% among people aged 15 years and above, meaning about 5,746,249 people were illiterate.[12]

In 2022, according to Concern Worldwide and Welthungerhilfe,[13] Kenya had a Global Hunger Index (on a scale of 0 denoting no hunger and 100 being the worst) score of 23.5, which signified a severe level of hunger. In addition, about 32.2% of the population is undernourished, the prevalence of wasting in children under five years is 4.8%, and the prevalence of stunting in children under five years is 23.6%.

Concerning shelter, 46.1% of the urban population lived in slum households in 2018, characterised by a lack of access to improved sanitation and water, plus a lack of sufficient living area and quality/durability of structure.[14] According to the World Health Organization (WHO), in 2020, 19.5% of the population primarily relied on clean fuels and technologies for cooking.[15]

In 2020, 26.76% of the total population had basic handwashing facilities at home, 61.63% used basic drinking water services, and 32.7% used basic sanitation services.[16]

Fourth, in 2019, Kenya had a national health research system (NHRS) barometer score of 85%,[17] denoting the existence of a performance deficit of 15%. An optimally performing NHRS timeously generates pertinent evidence and facilitates its use in policy, planning, innovation, and development of products to combat pandemics.[18]

The sub-optimal performances of the NHS, IDSS, SDH, and NHRS may be attributed to both underinvestment and inefficient allocation and use of systems resources. For example, in 2019, Kenya's current health expenditure per capita of US$83[19] was 43% below the target recommended for lower-middle-income countries by Stenberg *et al.*[20] of US$146 per person to attain the health-related Sustainable Development Goal 3.[21]

Moreover, the Kenya Health Policy 2014–2030[22] and the Health Sector Strategic and Investment Plan[23] underscore the need to increase the cost-effectiveness and cost-efficiency of resource allocation and use.[22] It calls for concerted action by the Ministry of Health to mount evidence-based advocacy within the government (in the context of the 'Health-in-all-Policies' approach), the Ministry of Finance, the Ministry of Labour, and other relevant ministries), the domestic private sector, and stakeholders to augment investments to bridge health-related systemic gaps.[24]

According to Card and Mooney,[25] explicit monetary valuation of human life is a vital component of a decision theory model for allocating scarce health development resources rationally. Rice[26] explains that its essential to translate the magnitude of disease in dollar terms because it is the universal language of decision-makers in the policy arena. Some studies have applied the human capital approach to monetarily value human life losses associated with COVID-19 in Brazil,[27] Canada,[28] China,[29] France,[30] Germany,[31] India,[32] Iran,[33] Italy,[34] Japan,[35] Mauritius,[36] South Africa,[37] Spain,[38] Turkey,[39] UK,[40] and United States of America (USA).[41] There is a dearth of such economic evidence for Kenya, yet it is still needed for advocacy. In addition, although Barasa *et al.*[42] assessed the unit costs for COVID-19 case management in Kenya, no study has estimated the potential total cost savings due to COVID-19 vaccination. The study reported in this paper was a modest attempt to bridge those knowledge gaps.

The specific study objectives were to estimate the following:

a) The total present (discounted) value of reported human lives lost in Kenya due to COVID-19, as of 25 July 2022.

b) The total indirect costs (productivity losses) attributed to reported mortality from COVID-19, as of 25 July 2022.

c) The total direct costs (health system inputs costs) incurred in caring for all the COVID-19 cases reported, as of 25 July 2022.

d) The potential/projected direct and indirect cost savings due to COVID-19 vaccination, as of 25 July 2022.

2. Methods

2.1 Study location and design

The valuation of human life cross-sectional study on Kenya was for the 5,670 deaths the government reported between 12 March 2020 and 25 July 2022.[7] The 47 Kenya's administrative counties' share of COVID-19 deaths were as follows:

- Fewer than two deaths in Baringo, Elgeyo Marakwet, Homa Bay, Kirinyaga, Nyamira, Nyandarua, Samburu, Tana River, Tharaka Nithi, and West Pokot.

- Two to 10 deaths in Bomet, Bungoma, Embu, Isiolo, Kakamega, Lamu, Kisii, Kitui, Mandera, Marsabit, Nandi, Trans Nzoia, Vihiga, and Wajir.

- Ten to 20 deaths in Garissa, Laikipia, Meru, Muranga, Kerichu, Kwale, Siaya, Taita Taveta, and Turkana.

- Twenty-one deaths and above in Busia, Kiambu, Kajiado, Kilifi, Kisumu, Machakos, Makueni, Migori, Mombasa, Nairobi city, Nakuru, Narok, Nyeri, and Uasin Gishu.

The indirect costs calculation was for the 5,586 reported deaths in the economically productive age bracket of 15 years and above.[7,8] Also, the direct cost estimation was for a cumulative total of 337,339 COVID-19 cases reported, as of 25 July 2022.[7,8]

The direct cost savings estimations encompassed the projected 182,423 COVID-19 infections averted, assuming 30% coverage of the target population (15 years and above) of 31,786,253 with the Oxford-AstraZeneca vaccine.[52,53] The indirect cost savings calculations included the projected 29,872.27 deaths prevented, assuming 30% coverage of the target population with the COVID-19 vaccine.[52–54]

2.2 Analytical framework

2.2.1 Model for estimating the present value of reported human lives lost

According to Culyer,[43] there are three main approaches for valuing human life: the human capital approach (HKA), the social decisions approach or implied values approach (IVA), and the contingent valuation approach (CVA) or willingness-to-pay approach. First, the HKA assesses the value of a human life lost from any cause (disease or injury) in terms of the discounted expected money worth of goods and services lost by society due to their premature death. Weisbrod[44] defines the present value of a human being as their discounted expected future income stream net of their consumption.

Second, the IVA (or revealed preference approach as observed in actual choices) infers values from actual past life-saving choices (or decisions) in the public sector.[43]

Third, the CVA seeks to establish through a questionnaire survey the maximum amount of money individuals are willing to pay for small reductions in the risk of death they face concerning any cause, *e.g.,* COVID-19.[43] Unfortunately, according to Robinson *et al.,*[45] there are few or no direct estimates of value per statistical life for most low- and middle-income countries which employ the willingness-to-pay (WTP) approach to assess the willingness of those affected by public health challenges (such as COVID-19) to trade their income for small reductions in risk of death.

Due to the availability of data on GDP per capita and current health expenditure per person, we applied HKA to estimate the total present value (TPV_{KENYA}) of human lives lost in Kenya due to COVID-19 as of 25 July 2022. A similar approach has been used in Brazil,[27] Canada,[28] China,[29] France,[30] Germany,[31] India,[32] Iran,[33] Italy,[34] Japan,[35] Mauritius,[36] South Africa,[37] Spain,[38] Turkey,[37] UK,[40] and USA.[41]

The TPV_{KENYA} is a summation of the present value of human lives lost in age groups $(PV_{i=1,..,7})$ 0–9 years, 10–19 years, 20–29 years, 30–39 years, 40–49 years, 50–59 years, and 60 years and above. Formally[27–41]:

$$TPV_{KENYA} = \sum_{i=1}^{i=7} PV_i \tag{1}$$

where: PV_i is the present value of human lives lost due to COVID-19 in i^{th} age group; i = 1 is group 0–9 years, 2 = 10–19 years, 3 = 20–29 years, 4 = 30–39 years, 5 = 40–49 years, 6 = 50–59 years, 7 = 60 years and above; $\sum_{i=1}^{i=7}$ is the sum of $PV_{i=1,\ldots,7}$ across the seven age groups.

The $PV_{i=1,\ldots,7}$ for each of the seven age groups was a sum of the product of undiscounted years of life lost (UYLL), net GDP per capita, and COVID-19 deaths in a specific age group.[27–41] Formally:

$$PV_i = \sum_{t=1}^{T} \left(\frac{1}{(1+r)^t} \right) \times (GDPPC_{KENYA} - CHEPP_{KENYA}) \times (COVIDD_{KENYA} \times PD_i) \quad (2)$$

Where: $\sum_{t=1}^{T}$ is the summation from the undiscounted year one of life lost [UYLL] (t = 1) to the final UYLL (T) in a specific age group, where the age group's total number of UYLL equals average life expectancy at birth for Kenya (ALE_{KENYA}) minus average age at onset of death ($AAD_{i=1,\ldots,7}$); r is the discount rate of 3%; $\frac{1}{(1+r)^t}$ is the discount factor formula; $COVIDD_{KENYA}$ is the total number of COVID-19 deaths in Kenya between 12 March 2020 and 25 July 2022; PD_i is the i^{th} age group share of COVID-19 deaths.

In Equation 2, all the years lost due to COVID-19, even those below the minimum working age of 15 years, are valued. We did this because Subsection 2.2.1 primarily concerns the monetary valuation of human lives lost at all ages, irrespective of productivity.

2.2.2 Model for estimating productivity losses (indirect costs) attributed to reported mortality from COVID-19

Kenya's total indirect cost or productivity loss (TIC_{KENYA}) is a summation of indirect costs in economically productive age groups ($IC_{i=1,..,6}$), *i.e.* 1 = 15–19 years, 2 = 20–29 years, 3 = 30–39 years, 4 = 40–49 years, 5 = 50–59 years, and 6 = 60 years and above.

Formally[27–41]:

$$TIC_{KENYA} = \sum_{i=1}^{i=6} IC_{i=1,..,6} \quad (3)$$

The $IC_{i=1,..,6}$ for each age group, 1, 2, 3, 4, 5 and 6 equals the present value ($PV_{i=1,..,6}$) multiplied by the relevant employment-to-population ratio ($EPR_{i=2,..,6}$) and i^{th} age group share ($SHARE_{i=1}$). Formally:

$$IC_{i=1,..,6} = PV_{i=1,\ldots,6} \times EPR_{i=1,\ldots,6} \times SHARE_{i=1,\ldots,6} \quad (4)$$

The $PV_{i=1,..,6}$ was computed as explained in Subsection 2.2.1. The $EPR_{i=1,..,6}$, the proportion of a country's working age population employed, was obtained from the Kenya National Bureau of Statistics (KNBS) quarterly labour force report.[46] $SHARE_{i=1,\ldots,6}$ is the proportion of the indirect cost to be apportioned to the age group, which varies from 0 to 1.

According to the International Labour Organization (ILO) Minimum Age Convention No. 138, the minimum working age "… shall not be less than the age of completion of compulsory schooling and, in any case, shall not be less than 15 years (Article 2)".[47] Therefore, since the minimum working age in Kenya is 15 years, we assume that 50% of deaths from COVID-19 in age group 1 (10–19 years) were between 15 and 19 years. Therefore, the IC_1 for age group 1 (15–19 years) equals the present value (PV_1) multiplied by the group employment-to-population ratio (EPR_1) multiplied by 0.5, *i.e.,* age group's share ($SHARE_{i=1}$).

2.2.3 Model for estimating the total direct cost of reported COVID-19 cases care

The total direct costs of COVID-19 (TDC_{KENYA}) encompass the value of quantities of inputs used by the NHS to provide appropriate health interventions to different disease severity categorises. For instance, TDC_{KENYA} is the sum of direct costs across the four disease severity categories ($DC_{s=1,..,4}$), *i.e.* 1 = home-based isolation and care for asymptomatic cases, 2 = hospital/isolation centre care for mild/moderate cases, 3 = hospital high dependency unit care for severe cases, and 4 = hospital intensive unit care for critical cases.

Formally:

$$TDC_{KENYA} = \sum_{s=1}^{s=4} DC_{s=1,..,4} \quad (5)$$

The $DC_{i=1,..,4}$ for each disease severity category 1, 2, 3, and 4 is the product of the number of COVID-19 cases in a severity category ($CASES_{s=1,..,4}$), average total direct cost per patient ($ADC_{s=1,..,4}$), and conversion rate from US$ to Int$ (CR). Formally:

Table 2. Variables and data sources used in estimation of direct cost of asymptomatic, mild/moderate, severe, and critical COVID-19 cases in Kenya.

Management place	Number of cases*	Total direct cost per patient (US$)**	Conversion rate (*CR*) from US$ to Int$ (or PPP)***
Home-based isolation and care for asymptomatic	330,910 cases × 0.7306 = 241,762.8	226.71	2.51560771941256
Hospital/isolation centre care for mild/moderate cases	330,910 cases × 0.2694 × 0.729 = 64,988.3	764.41	2.51560771941256
Hospital high dependency unit care for severe cases	330,910 cases × 0.2694 × 0.121 = 10,786.8	1494.38	2.51560771941256
Hospital intensive care unit for critical cases	330,910 cases × 0.2694 × 0.15 =13,372.1	7194.07	2.51560771941256

*Number of cases from Worldometers[2] and Republic of Kenya.[7]
**Total cost per patient from Barasa *et al.*[42]
***Kenya's GDP in 2022 is US$116.641 billion, which is equivalent to Int$293.423 billion from International Monetary Fund (IMF).[3] Thus, the *CR* from US$ to Int$ equals 2.51560771941256, i.e. Int$293.423 billion divided by US$116.641 billion.

$$DC_{i=1,..,4} = CASES_{i=1,\ldots,4} \times ADC_{i=1,\ldots,4} \times CR \tag{6}$$

The $ADC_{s=1,..,4}$ estimates from Baraza *et al.*[42] were used to estimate the cost of managing the four clinical categories of COVID-19 cases (see Table 2). The health system input costs by Baraza *et al.*[42] included human resources for health, health worker transport, accommodation and overheads, pharmaceuticals (*e.g.* medicines), non-pharmaceuticals (fluids, oxygen, devices), COVID-19 tests, other laboratory tests, radiology, personal protective equipment, oxygen therapy, and capital items (*e.g.* buildings, medical equipment and vehicles).

2.2.4 Model for estimating potential direct and indirect cost savings due to COVID-19 vaccination

The potential savings associated with vaccination equals total direct cost savings $(TDCS_{KENYA})$ plus indirect cost savings $(TICS_{KENYA})$.

2.2.4.1 Direct cost savings model

The $TDCS_{KENYA}$ equals the number of COVID-19 cases averted with vaccination $(AVERTED_{INFECTIONS})$ multiplied by the average total direct cost per patient treated $(ATDC)$. In other words:

$$TDCS_{KENYA} = AVERTED_{INFECTIONS} \times ATDC \tag{7}$$

$$AVERTED_{INFECTIONS} = (PoPI_{WITHOUT} - PoPI_{WITH}) \times VACOV \tag{8}$$

where: $PoPI_{WITHOUT}$ is the number of people in the target population expected to have COVID-19 infection without vaccination; $PoPI_{WITH}$ is the number of people in the target population expected to have COVID-19 infection with vaccination; $VACOV$ is the proportion of the target population fully vaccinated against COVID-19.

$$PoPI_{WITHOUT} = TPoP_{KENYA} \times IR_{CONTROL} \tag{9}$$

where: $TPoP_{KENYA}$ is the total population in Kenya eligible for COVID-19 vaccination; $IR_{CONTROL}$ is the COVID-19 infection risk without vaccination from a vaccine efficacy study.

$$PoPI_{WITH} = TPoP_{KENYA} \times IR_{AZ} \tag{10}$$

where: IR_{AZ} is the COVID-19 infection risk with vaccination from a vaccine efficacy study.

2.2.4.2 Indirect cost savings model

The $TICS_{KENYA}$ equals the number of COVID-19 deaths prevented with vaccination $(COVID19D_{PREVENTED})$ multiplied by the average total indirect cost per death $(ATIC)$. Formally:

$$TICS_{KENYA} = COVID19D_{PREVENTED} \times ATIC \quad (11)$$

$$COVID19D_{PREVENTED} = (PoPD_{WITHOUT} - PoPD_{WITH}) \times VACOV \quad (12)$$

where: $PoPD_{WITHOUT}$ is the number of people in Kenya expected to die from COVID-19 without full vaccination; $PoPD_{WITH}$ is the number of people in Kenya expected to die from COVID-19 even though fully vaccinated; $VACOV$ is the proportion of the target population fully vaccinated against COVID-19.

$$PoPD_{WITHOUT} = PoPI_{WITHOUT} \times DR_{unvaccinated} \quad (13)$$

where: $PoPI_{WITHOUT}$ is the number of people in the target population expected to have COVID-19 infection without vaccination; $DR_{unvaccinated}$ is the risk of COVID-19 death among the unvaccinated target population.

$$PoPD_{WITH} = PoPI_{WITH} \times DR_{PB} \quad (14)$$

where: $PoPI_{WITH}$ is the number of people infected by COVID-19 in Kenya expected to die without vaccination; DR_{PB} is the risk of COVID-19 death among those fully vaccinated with the Pfitzer-Biontech vaccine.

2.3 Data and sources

Table 3 shows the data and sources used in the Kenya analysis.

2.4 Data analysis

2.4.1 The total present value of reported human lives lost in Kenya due to COVID-19, as of 25 July 2022

Excel Software (Microsoft, New York) was employed to estimate Equations 1 and 2. The process involved seven steps.

Step 1: Computation of the undiscounted years of life lost

As depicted in Table 4, the UYLL for each of the seven age groups (1 = 0–9 years, 2 = 10–19 years, 3 = 20–29 years, 4 = 30–39 years, 5 = 40–49 years, 6 = 50–59 years, 7 = 60 years and above) were computed through subtraction of AAD_k per age group from Kenya's ALE_{KENYA}.

Step 2: Computation of the DYLL

Approximation of the DYLL at a 3% rate for each age group as a product of UYLL and the appropriate discount factor.[27–41] For instance:

- First DYLL in age group 20–29 = Discount factor × UYLL = $[1/(1 + 0.03)^1]$ = 0.970873786 × 1 = 0.970873786;
- Thirtieth DYLL in age group 20–29 = Discount factor × UYLL = $[1/(1 + 0.03)^{30}]$ = 0.41198676 × 1 = 0.41198676;
- Forty-third DYLL in age group 20–29 = Discount factor × UYLL = $[1/(1 + 0.03)^{43}]$ = 0.280542936 × 1 = 0.280542936.
- Summation of the DYLL from year 1 to 43 yields 23.98190213 DYLL per human life lost in the age group 20–29.

The total number of DYLL in the age group 20–29 equals DYLL per human life lost (23.98190213) multiplied by the number of deaths (150) in the age group, *i.e.* 23.98190213 × 150 = 3,597.3. Table 5 depicts the DYLL per age group due to COVID-19 in Kenya at 3%, 5%, and 10% discount rates.

Step 3: Assessment of Kenya's net GDP per person in 2022 International Dollars (F_2)

The net GDP per person $(NGDPPP_{KENYA})$ equals GDP per capita $(GDPPC_{KENYA})$ minus current health expenditure per capita $(CHEPC_{KENYA})$.[27–41] The 2022 $GDPPC_{KENYA}$ was Int$ 5762.003. Kenya's most updated data on $CHEPC_{KENYA}$ were for 2019.[19] The $CHEPC_{KENYA}$ for 2022 was forecasted utilising values of Int$185.41142273 in 2018 and Int $207.61849976 in 2019.[19] Applying the annual growth rate of 11.9771892707702%, the forecast for the 2020

Table 3. Data and data sources.

Variable description	Value	Data source
Discount rate (r)	3%, and 5% and 10% for sensitivity analysis	Past studies on valuation of human life[27–41]
Per capita GDP for Kenya in 2022 ($GDPPC_{KENYA}$)	Int$5,762.003	International Monetary Fund World Economic Outlook database[3]
Current health expenditure per capita for Kenya in 2022 Int$ ($CHEPC_{KENYA}$)	Int$291.510857431964	Author projections using information from the WHO Global Health Expenditure database[19]
Non-health GDP per capita for Croatia in 2022 Int$ ($NGDPPC_{KENYA}$)	Int$5,470.49214256804	Authors' estimate using data from IMF[3] and WHO[19]
Average life expectancy at birth (both sexes) in years in 2022 (ALE_{KENYA})	Kenya: 67.47 years; Africa's highest life expectancy (Algeria females): 78.76 years; World's highest life expectancy (Hong Kong females): 88.17 years	Worldometer demographics database[48]
Average age at onset of death in age groups ($AAD_{i=1,...,7}$)	0–9 years = (0+9)/2 = 4.5 years, 10–19 years: 14.5 years, 20–29 years: 24.5 years, 30–39 years: 34.5 years, 40–49 years: 44.5 years, 50–59 years: 54.5 years, 60 years–67.47 years: 63.735 years	Authors' estimates
Undiscounted years of life lost per dead person in age group ($UYLL_{i=1,...,7}$)	UYLL per person: 0–9 years = (67.47 – 4.5) = 62.97 years; 10–19 years: 52.97 years, 20–29 years: 42.97 years, 30–39 years: 32.97 years, 40–49 years: 22.97 years, 50–59 years: 12.97 years, 60–67.47 years: 3.735 years	Authors' estimates
Discounted years of life lost per death person in age group at 3% discount rate ($DYLL_{i=1,...,7}$)	DYLL per person: 0–9 years = 28.2 years; 10–19 years: 26.4 years; 20-29 years: 24.0 years; 30–39 years: 20.8 years; 40–49 years: 16.4 years; 50–59 years: 10.6 years; 60–67.47 years: 3.7 years	Authors' estimates
Reported cumulative COVID-19 deaths as of 25 July 2022 in Kenya ($COVIDD_{KENYA}$)	5,670	Worldometers Covid-19 Coronavirus Pandemic database[2] and Republic of Kenya[7]
Projected excess COVID-19 deaths as of 25 July 2022 in Kenya ($\text{COVIDED}_{\text{KENYA}}$)	180,217.4721	Authors' projection using data from Worldometers[2] and COVID-19 Excess Mortality Collaborators[49]
Proportion of COVID-19 deaths by seven age groups in Kenya ($PD_{i=1,...,7}$)	0–9 years: 0.010934744; 10–19 years: 0.007760141; 20–29 years: 0.026455026; 30–39 years: 0.072486772; 40–49 years: 0.114991182; 50–59 years: 0.181834215; and 60 years and above: 0.585537919	Republic of Kenya[7]
Proportion of COVID-19 deaths by County ($\text{PCD}_{\text{COUNTY}}$)	Elgeyo Marakwet: 0.000055639; Samburu: 0.000055639; West Pokot: 0.000055639; Kirinyaga: 0.000166917; Tharaka Nithi: 0.000166917; Homa Bay: 0.000166917; Tana River: 0.000222556; Baringo: 0.000278195; Nyandarua: 0.000333834; Nyamira: 0.000333834; Embu: 0.000445112; Marsabit: 0.000445112; Nandi: 0.000612029; Vihiga:	Republic of Kenya[50]

Table 3. *Continued*

Variable description	Value	Data source
	0.000667668; Trans Nzoia: 0.000723307; Isiolo: 0.000778946; Bungoma: 0.000834585; Kakamega: 0.001001502; Bomet: 0.001001502; Mandera: 0.001112780; Kitui: 0.001224058; Kisii: 0.001390975; Lamu: 0.001502253; Wajir: 0.001557892; Meru: 0.001780448; Siaya: 0.001891726; Turkana: 0.002058644; Laikipia: 0.002225561; Muranga: 0.002503756; Taita Taveta: 0.002615034; Kerichu: 0.002726312; Kwale: 0.003115785; Garissa: 0.003227063; Kisumu: 0.003672175; Narok: 0.003672175; Nyeri: 0.003950370; Makueni: 0.004562399; Kilifi: 0.005897735; Uasin Gishu: 0.012908251; Migori: 0.014744339; Nakuru: 0.015745841; Busia: 0.038669115; Machakos: 0.039893173; Kajiado: 0.057586380; Kiambu: 0.063873588; Mombasa: 0.109163746; Nairobi city: 0.588382574	
Employment to population ratios (EPR_i)	15–19 years: 0.214; 20–29 years: 0.581; 30–39 years: 0.8455; 40–49 years: 0.853; 50–59 years: 0.839; 60 years and above: 0.797	Kenya National Bureau of Statistics (KNBS)[46]
Conversion rate (*CR*) from US$ to Int$	2.51560771941256	Authors' estimate using data from International Monetary Fund World Economic Outlook database[3]
Total direct cost per patient by COVID-19 clinical category	Asymptomatic: US$226.71; Mild/moderate: US$764.41; Severe: US $1494.38; Critical: US$7194.07	Baraza *et al.*[42]
Share of COVID-19 cases by community health care (for asymptomatic) and hospital care (for mild moderate, severe, and critical)	Community health care: 0.7306; Hospital care: 0.2694	Republic of Kenya[51]
Share of COVID-19 cases treated at hospitals by disease category	Mild/moderate: 0.729; Severe: 0.121; Critical: 0.15	Republic of Kenya[51]
Target population for COVID-19 vaccination	31,786,253	Republic of Kenya[52]
Efficacy of Oxford-AstraZeneca vaccine in reducing COVID-19 infections	66.7%	Voysey *et al.*[53]
COVID-19 infection risk without vaccination ($IR_{Control}$)	0.02890106 or 2.890106048	Voysey *et al.*[53]
COVID-19 infection risk with Oxford-AstraZeneca vaccination (IR_{AZ})	0.00977085 or 0.97708503	Voysey *et al.*[53]
Number infected without vaccination ($PoPI_{WITHOUT}$)	918,656.405	Authors estimate using data from Republic of Kenya[52] and Voysey *et al.*[53]
Number infected without vaccination ($PoPI_{WITH}$)	310,578.71	Authors estimate using data from Republic of Kenya[52] and Voysey *et al.*[53]
Proportion of target population fully vaccinated against COVID-19 (*VACOV*)	30%	Republic of Kenya[52]
Death risk among unvaccinated persons	0.131380546 or 13.13805463%	Bernal *et al.*[54]
Death risk among vaccinated persons	0.068 or 6.8%	Bernal *et al.*[54]

Table 4. **Undiscounted years of life lost (UYLL) per dead person by age group from COVID-19 in Kenya.**

Age bracket in years	(A) Average life expectancy (in years) for Kenya	(B) Average age at death (AAD)	(C) Undiscounted years of life lost [C = A-B]	(D) Number of COVID-19 deaths per age group	E) Sub-total UYLL [E = C × D]
0-9	67.47	4.5	62.97	62	3,904
10-19	67.47	14.5	52.97	44	2,331
20-29	67.47	24.5	42.97	150	6,446
30-39	67.47	34.5	32.97	411	13,551
40-49	67.47	44.5	22.97	652	14,976
50-59	67.47	54.5	12.97	1,031	13,372
60-67.47	67.47	63.735	3.735	3,320	12,400
TOTAL				5,670	66,980

Table 5. **DYLL from COVID-19 in Kenya.**

		3% discount rate	
Age group	**(A). No. of deaths**	**(B). DYLL per death**	**(C). Subtotal DYLL [C = A × B]**
0–9	62	28.156	1,746
10–19	44	26.375	1,160
20–29	150	23.982	3,597
30–39	411	20.766	8,535
40–49	652	16.444	10,721
50–59	1031	10.635	10,965
60–67.47	3320	3.717	12,341
TOTAL	**5670**		**49,065**
		5% discount rate	
Age group	**(A). No. of deaths**	**(B). DYLL per death**	**(C). Subtotal DYLL [C = A × B]**
0–9	62	19.075	1,183
10–19	44	18.493	814
20–29	150	17.546	2,632
30–39	411	16.003	6,577
40–49	652	13.489	8,795
50–59	1031	9.394	9,685
60–67.47	3320	3.546	11,773
TOTAL	**5670**		**41,457**
		10% discount rate	
Age group	**(A). No. of deaths**	**(B). DYLL per death**	**(C). Subtotal DYLL [C = A × B]**
0–9	62	9.975	618
10–19	44	9.936	437
20–29	150	9.834	1,475
30–39	411	9.569	3,933
40–49	652	8.883	5,792
50–59	1031	7.103	7,324
60–67.47	3320	3.170	10,524
TOTAL	**5670**		**30,103**

$CHEPC_{KENYA}$ equals Int$ 232.485360437389; forecast for the 2021 $CHEPC_{KENYA}$ equals Int$ 260.330572083807; and forecast for the 2022 $CHEPC_{KENYA}$ equals Int$ 291.510857431964. Thus, the $NGDPPP_{KENYA} = GDPPC_{KENYA} - CHEPC_{KENYA}$ = Int$5762.003 − Int$291.510857431964 = Int$5,470.49.

Step 4: Distributing the COVID-19 deaths across seven age groups

This was accomplished through multiplication of the 5670 reported cumulative COVID-19 deaths as of 25 July 2022 in Kenya $(COVIDD_{KENYA})$ by the respective age group's proportion (PD_k).[7] Therefore, the number of deaths accrued per age $(COVIDD_{k=1,\ldots,7})$ was:

(a). $COVIDD_{0-9} = COVIDD_{KENYA} \times PD_{0-9} = 5670 \times 0.010934744 = 62$;

(b). 10–19 years = $COVIDD_{KENYA} \times PD_{10-19} = 5670 \times 0.007760141 = 44$;

(c). 20–29 years = $COVIDD_{KENYA} \times PD_{20-29} = 5670 \times 0.026455026 = 150$;

(c). 30–39 years = $COVIDD_{KENYA} \times PD_{30-39} = 5670 \times 0.072486772 = 411$;

(d). 40–49 years = $COVIDD_{KENYA} \times PD_{40-49} = 5670 \times 0.114991182 = 652$;

(d). 50–59 years = $COVIDD_{KENYA} \times PD_{50-59} = 5670 \times 0.181834215 = 1031$;

(e). 60 years and above = $COVIDD_{KENYA} \times PD_{60\ and\ above} = 5670 \times 0.585537919 = 3320$.

Step 5: Computation of total present value of human lives lost per age group (PV_k)

The $PV_{k=1,\ldots,7}$ was computed through the multiplication of DYLL per person in an age group, $NGDPPP_{KENYA}$, and the number of deaths in an age group $(COVIDD_{k=1,\ldots,7})$.[27–41] For instance, the PV_{20-29} for age group 20–29 years was obtained from the multiplication of DYLL per person in the age group of 23.982, $NGDPPP_{KENYA}$ of Int$5,470.49, and $COVIDD_{20-29}$ of 150. Therefore, $PV_{20-29} = 23.982 \times 5470.49 \times 150 = Int19,678,994$.

Step 6: Distribution of Kenya's total present value by administrative counties

The TPV_{KENYA} was shared across 47 administrative counties $(TPV_{\ j=1,\ldots,47})$ through the multiplication of TPV_{KENYA} by each county's proportion of COVID-19 deaths.[27–41] For example, given TPV_{KENYA} is Int$ 268,408,687 and $PD_{NAIROBI}$ is 0.588382574 (Table 3), the share of TPV_{KENYA} for Nairobi County equals Int$157,926,994.

Step 7: Sensitivity analysis

One-way sensitivity analysis was conducted through re-estimation of the economic model five times, assuming (i) a 5% discount rate, (ii) a 10% discount rate, (iii) Africa's highest average life expectancy at birth of 78.76 years (Algeria females),[48] (iv) the world highest life expectancy of 88.17 years (Hong Kong females),[48] and (v) projected excess COVID-19 mortality of 180,217.4721 deaths as of 25 July 2022 in Kenya ($COVIDD_{KENYA}$).[7,8,50] How was the latter forecasted?

The COVID-19 Excess Mortality Collaborators[49] estimated that the actual number of COVID-19-associated deaths may have been far more significant than those reported due to Kenya's weak death registration system. According to COVID-19 Excess Mortality Collaborators,[36] by 31 December 2021, the reported COVID-19 deaths in Kenya were 5380 (5.7 per 100,000), and the estimated excess deaths were 171,000 (181.2 per 100,000). The ratio between excess mortality and the reported COVID-19 mortality rate was 31.78438662. The projected excess number of COVID-19 deaths as of 25 July 2022 was 180,217.4721, *i.e.* 5670 reported deaths as of 25 July 2022 multiplied by 31.784.

2.4.2 The indirect costs (productivity losses) attributed to reported mortality from COVID-19

Equations 3 and 4 were built into an Excel spreadsheet and used to estimate the indirect costs following the seven steps below.

Step 1: Search the ILO website for the minimum working age in Kenya.[47]

Step 2: Delineate the economically productive age groups[46]: 1 = 15–19 years, 2 = 20–29 years, 3 = 30–39 years, 4 = 40–49 years, 5 = 50–59 years, and 6 = 60 years and above.

Step 3: Extract the present values for each of the six economically productive age groups from the results obtained following procedures explained in Subsection 2.2.1.

Step 4: Extract the employment-to-population ratio for each productive age group $(EPR_{i=1,..,6})$ from KNBS quarterly labour force report of 2021.[46]

Step 5: Ascertain the proportion (ranging from 0 to 1) of the indirect costs to be apportioned to the age group. Age groups coded 2 to 6 were allotted a share of 1 because all persons in those age groups were presumed to be potentially economically productive. Given that in the age group 10–19, only persons aged 15 to 19 years (i.e., five years) are potentially productive, we divided five years by 10 years (number of years in the age group) and obtained a value of 0.5, as the age group $SHARE_{i=1}$.

Step 6: Estimate the $IC_{i=1,..,6}$ for each age group 1, 2, 3, 4, 5 and 6 by multiplying the present value $(PV_{i=1,..,6})$, the relevant employment-to-population ratio $(EPR_{i=1,..,6})$, and the share of the indirect cost to be apportioned to the age group $(SHARE_{i=1,..,6})$.

Step 7: Sum up the six age groups' indirect costs to derive Kenya's total indirect cost or productivity loss (TIC_{KENYA}).

2.4.3 The direct cost attributed to reported COVID-19 cases

Equations 5 and 6 were built into an Excel spreadsheet and used to estimate the direct costs following the six steps below.

Step 1: Determine the share of the total COVID-19 cases reported in Kenya by four disease categories: 1 = asymptomatic cases on home-based care, 2 = mild/moderate cases on hospital/isolation centre care, 3 = severe cases on hospital high dependency unit care, and 4 = critical cases on hospital intensive unit care. According to the Kenya Ministry of Health COVID-19 daily report 940,[51] out of the total number of COVID cases, 73.06% were from home-based care, and 26.94% were from various health facilities. Out of the total COVID-19 cases treated at health facilities, 72.9% were mild-to-moderate cases admitted in a general ward, 12.1% were severe cases treated in a high dependency unit, and 15.0% were treated in an intensive care unit.

Step 2: Estimate the number of COVID-19 cases per disease category $(CASES_{s=1,..,4})$ by multiplying the total number of reported cases (330,910) by the share for each clinical category (obtained from Step 1). For instance, category 1 = 330,910 cases × 0.7306 = 241,762.8; category 2 = 330,910 cases × 0.2694 × 0.729 = 64,988.3; category 3 = 330,910 cases × 0.2694 × 0.121 = 10,786.8; category 4 = 330,910 cases × 0.2694 × 0.15 =13,372.1.

Step 3: Search in 'Pubmed.com' for a published Kenyan study documenting the average total direct cost per patient per clinical category $(ADC_{s=1,..,4})$. The search revealed a study by Barasa *et al.*[42] that reported $ADC_{s=1,..,4}$ (see Table 2).

Step 4: Derive a rate for converting (CR) unit costs expressed in US Dollars (US$) into International Dollars (Int$) using GDP data from the IMF World Economic Outlook Database.[3] As shown in Table 2 in 2022, Kenya's GDP in 2022 was US$116.641 billion, equivalent to Int$293.423 billion.[3] Thus, the *CR* from US$ to Int$ equals 2.51560771941256, *i.e.* Int $293.423 billion divided by US$116.641 billion.

Step 5: Estimate the direct cost per disease severity category $(DC_{i=1,..,4})$ by multiplying the number of COVID-19 cases in a severity category $(CASES_{s=1,..,4})$ from Step 2 by the respective average total direct cost per patient $(ADC_{s=1,..,4})$ from Step 3 and *CR* from Step 4.

Step 6: Calculate Kenya's total direct cost (TDC_{KENYA}) through summation of direct cost (obtained in Step 5) across the four disease severity categories $(DC_{s=1,..,4})$.

2.5 The potential projected direct and indirect cost savings due to COVID-19 vaccination

Our study estimates the potential savings from COVID-19 vaccination using actual population coverage of 30%, as of 25 July 2022, and the potential direct and indirect cost savings of the projected COVID-19 cases and deaths averted due to vaccination.

As explained by the COVID-19 Excess Mortality Collaborators[49] (Subsection 2.4.1), the actual number of COVID-19-associated deaths may have been underestimated by a ratio of 31.784. For this reason, we decided to base the estimation of potential direct and indirect cost savings from COVID-19 vaccination on the projected total number of cases and deaths as of 25 July 2022.

2.5.1 Expected savings in total direct costs due to COVID-19 vaccinations

Equations 7, 8, 9 and 10 were built into an Excel spreadsheet and used to estimate the expected total direct cost savings attributable to vaccination with the Oxford-AstraZeneca vaccine following seven steps.

Step 1: Obtain target population (15 years and above) of 31,786,253 for Kenya from the Kenya COVID-19 vaccination programme daily situation report dated 26 July 2022.[52]

Step 2: Search PubMed for an epidemiological study on COVID-19 vaccine efficacy. The research revealed a study by Voysey *et al.*[53] that found "Overall vaccine efficacy more than 14 days after the second dose was 66·7% (95% CI 57·4–74·0), with 84 (1·0%) cases in the 8597 participants in the ChAdOx1 nCoV-19 group and 248 (2·9%) in the 8581 participants in the control group (p. 881)". Their study was a pooled analysis of four randomised trials (Brazil, South Africa, and the UK) with 8597 participants receiving the Oxford-AstraZeneca vaccine and 8581 receiving the control vaccine or saline.

Step 3: Use the evidence in Step 2 to estimate the COVID-19 infection risk without $(IR_{Control})$ and with Oxford-AstraZeneca (IR_{AZ}) in the Voysey *et al.*[53] pooled analysis of randomised trials in Brazil, South Africa, and the UK (Table 6). Infection risk in a group equals the number of infected persons divided by group size.

Step 4: Estimate the number of people in Kenya expected to contract COVID-19 without vaccination $(PoPI_{without})$. The $PoPI_{without}$ was obtained by multiplying the target population $(TPoP_{KENYA})$ of 31,786,253 by the $IR_{Control}$ of 0.02890106.[52,53] Thus, $PoPI_{without}$ equals 918,656.405, *i.e.* $TPoP_{KENYA} \times IR_{Control} = 31,786,253 \times 0.02890106$.

Step 5: Approximate the number of people in Kenya expected to contract COVID-19 even after being fully vaccinated with the Oxford-AstraZeneca vaccine $(PoPI_{with})$. The $PoPI_{with}$ was derived by multiplying respective $TPoP_{KENYA}$ by IR_{AZ} of 0.00977085.[52,53] Therefore, $PoPI_{with}$ equals 310,578.71, *i.e.* $TPoP_{KENYA} \times IR_{AS} = 31,786,253 \times 0.00977085$.

Step 6: The number of infections averted, assuming 30% population coverage, equals the difference between $PoPI_{without}$ and $PoPI_{with}$, multiplied by 0.30 (30% coverage).[52] Since $PoPI_{without}$ = 918,656.41 (from Step 4) and $PoPI_{with}$= 310,578.71 (from Step 5), infections averted through 30% vaccination coverage with Oxford-AstraZeneca equals 182,423.31, *i.e.* (918,656.41 − 310,578.71) × 0.30.

Step 7: The total direct cost savings expected from vaccination equals the number of infections averted (from Step 6) multiplied by the average total direct cost per patient. For instance, the expected savings in Kenya equals Int $300,668,273, *i.e.* 182,423.31 infections averted (from Step 6) multiplied by the average total direct cost per patient of Int$1,648.19.

2.5.2 Expected savings in projected total indirect costs due to COVID-19 vaccination

Equations 11, 12, 13 and 14 were built into an Excel spreadsheet and used to estimate the expected savings in total indirect costs due to COVID-19 vaccination following the six steps below.

Table 6. COVID-19 infection risk without and with Oxford-AstraZeneca vaccination.

Group	(A). Group size	(B). No. infected	(c). Infection risk [C = (B/A)]	(D). Infection risk (%) [D = C × 100]
Control	8581	248	0.02890106	2.890106048
ChAdOx1 nCov-19 (Oxford-AstraZeneca)	8597	84	0.00977085	0.97708503

Source: Voysey *et al.*[53]

Table 7. Risk of COVID-19 resulting in death among the unvaccinated and those vaccinated with the Pfizer-BioNTech BNT162b2.

Group	(A). Total no. of cases*	(B). No. of deaths*	(c). Death risk [C=(B/A)]**	(D). Death risk (%) [D=C × 100]**
Unvaccinated	8091	1063	0.131380546	13.13805463
≥14 days after vaccination	750	51	0.068	6.8
Vaccine efficacy (VE)			48.24195673	

*Bernal *et al.*[54]
**Authors' calculation.

Step 1: A search in the PubMed.com database for COVID-19 vaccine effectiveness in reducing the risk of death revealed an article by Bernal *et al.*,[54] which attempted "to estimate the real-world effectiveness of the Pfizer-BioNTech BNT162b2 and Oxford-AstraZeneca ChAdOx1-S vaccines against confirmed covid-19 symptoms, admissions to hospital, and deaths" (p.1).

Step 2: Utilise the evidence in Step 1 to calculate the risk of COVID-19 resulting in death among the unvaccinated$(DR_{unvaccinated})$ and those vaccinated with the Pfizer-BioNTech BNT162b2(DR_{PB}) (Table 7). The risk of death in a group equals the number of deaths from COVID-19 in an age group divided by the total number of cases in the group.

Step 3: Estimate the number of people infected in Kenya expected to die from COVID-19 without vaccination $(PoPD_{without})$ as a product of $PoPI_{without}$ (918,656.41) and $DR_{unvaccinated}$ (0.131380546). Thus, $PoPD_{without} = PoPI_{without} \times DR_{unvaccinated} = 918,656.41 \times 0.131380546 = 120,693.58$.

Step 4: Estimate the number of people in Kenya expected to die from COVID-19 even though vaccinated with Pfizer-BioNTech BNT162b2$(PoPD_{with})$ through the multiplication of the number of people expected to contract COVID-19 though vaccinated $(PoPI_{with})$ (from Step 5 of Subsection 2.5.1) by the probability of death in a vaccinated group (DR_{PB}) of 0.068. In Kenya, for instance, the $PoPI_{with}$ equals 310,578.71 persons multiplied by $DR_{PB}$of 0.068, *i.e.* $PoPD_{with} = PoPI_{with} \times DR_{PB} = 310,578.71 \times 0.068 = 21,119.35$.

Step 5: The number of COVID-19-associated deaths prevented $(COVID - 19D_{Prevented})$, assuming 30% population vaccine coverage, equals the difference between the number of people expected to die of COVID-19 without $(PoPD_{without})$ and with $(PoPD_{with})$ vaccination, multiplied by 30%. In other words, $COVID - 19D_{Prevented} = (PoPD_{without} - PoPD_{with}) \times (30/100)$. The number of deaths averted through 30% vaccination coverage equals 29,872.27, which is 120,693.58 (from Step 3 in Subsection 2.5.2) minus 21,119.35 (from Step 5 in Subsection 2.5.2) multiplied by 0.30.

Step 6: The indirect cost savings expected from vaccination equals the number of deaths prevented $(COVID - 19D_{Prevented})$ (Step 5 in Subsection 2.5.2) multiplied by the average indirect cost per COVID-19 death in Kenya $(ATIC_{KENYA})$ (Subsection 2.4.1 Equation 9). For example, the expected savings from COVID-19-associated deaths prevented in Kenya equals Int$1,100,277,535.56, *i.e.* 29,872.27 deaths prevented (among 15 years and older) multiplied by the indirect cost per death from COVID-19 of Int$36,832.74.

3. Results

3.1 The total present value of reported human lives lost in Kenya due to COVID-19

3.1.1 Findings from the present value of life analysis assuming Kenya's average both sexes life expectancy of 67.47 years and a discount rate of 3%

As of 25 July 2022, Kenya had lost 5,670 human lives from COVID-19, translating to 66,980 UYLL, equivalent to 49,065 DYLL. As depicted in Table 8, the cumulative number of human life losses had a TPV_{KENYA} of Int$268,408,687 and an average total present value of Int$47,338 per human life (*i.e.,* about eight times the GDP per capita for Kenya).

Approximately 3.6% of the TPV_{KENYA} was borne by 0–9-year-olds, 2.4% by 10–19-year-olds, 7.3% by 20–29-year-olds, 17.4% by 30–39-year-olds, 21.9% by 40–49-year-olds, 22.3% by 50–59-year-olds, and 25.2% by 60–year-olds and above. The persons between 20 and 59 years—the most economically productive bracket—incurred 68.9%

Table 8. The total and average present value of human lives lost from COVID-19 in Kenya (in 2022 Int$).

Age group in years	Value of human lives lost at 3% discount rate (Int$)	Number of COVID-19 deaths	Average value per human life lost in an age group (Int$)
0–9	9,549,574	62	154,025
10–19	6,348,504	44	144,284
20–29	19,678,921	150	131,193
30–39	46,689,230	411	113,599
40–49	58,650,419	652	89,955
50–59	59,981,971	1,031	58,178
60 and above	67,510,067	3,320	20,334
TOTAL	**268,408,687**	**5,670**	**47,338**

(Int$185,000,542) of the TPV_{KENYA}. The TPV_{KENYA} decreases as the age of the person advances. For instance, the 0–9-year-olds average TPV of Int$154,025 was eight-fold higher than Int$47,338 among the 60-year-olds and above.

3.1.2 Share of the TPV by administrative counties in Kenya

Figure 1 depicts the share of the TPV_{KENYA} across the 47 administrative counties in Kenya.

The average TPV_{KENYA} was Int$5,710,823 per county, with a standard deviation of Int$23,349,696. The size of TPV_{KENYA} varied widely between counties, i.e., from a minimum of Int$14,934 (in Elgeyo Marakwet, Samburu, and West Pokot Counties) to a maximum of Int$157,926,994 in Nairobi County. Thirty-five (74.5%) counties had a TPV_{KENYA} of less than Int$1,000,000; six counties (12.8%) had between Int1,000,000 and Int$10,000,000; four counties (8.5%) had between Int$10,000,001 and Int$20,000,000; two (4.3%) counties had over Int$20,000,000. Five counties (Kajiado, Kiambu, Machakos, Mombasa, and Nairobi City) bore 86% of the TPV_{KENYA}. Nairobi city alone bore 58.8% (Int $157,926,994) of the TPV_{KENYA}. The size of TPV_{KENYA} borne by a county hinge on the number of COVID-19 life losses sustained.

3.1.3 Sensitivity analysis

3.1.3.1 Impact of changes in the discount rate

Table 9 shows that the re-run of the HKA model with a discount rate of 5% led to a decrease in the TPV_{KENYA} from Int$ 268,408,687 to Int$226,791,171, which is a 16% (Int$41,617,516) decrease. The $ATPV_{KENYA}$ decreased from Int$47,338 to Int$39,998 per COVID-19-associated death.

Re-estimation of the HCA model with a 10% discount rate, all other factors held constant, reduced the TPV_{KENYA} from Int $268,408,687 to Int$164,679,113, which was a 39% reduction (Int$103,729,574). The $ATPV_{KENYA}$ decreased from Int $47,338 to Int$29,044 per COVID-19-associated death.

3.1.3.2 Effect of changes in life expectancy at birth

As portrayed in Table 10, a re-estimation of the economic model with Africa's highest life expectancy at birth of 78.76 years (Algeria's females) grew the TPV_{KENYA} from Int$268,408,687 to Int$480,899,177, which is 79% (Int $212,490,490) growth. Likewise, the mean $ATPV_{KENYA}$ grew from Int$47,338 per human life (obtained assuming a national life expectancy of 67.47 years) to Int$84,815.

Re-estimation of the economic model with the World's highest life expectancy at birth of 88.17 years (Hong Kong females) increased the TPV_{KENYA} from Int$268,408,687 to Int$613,747,054, which is 129% (Int$345,338,367) growth. The $ATPV_{KENYA}$ grew from Int$47,338 per human life (obtained assuming a national life expectancy of 67.47 years) to Int $108,245.

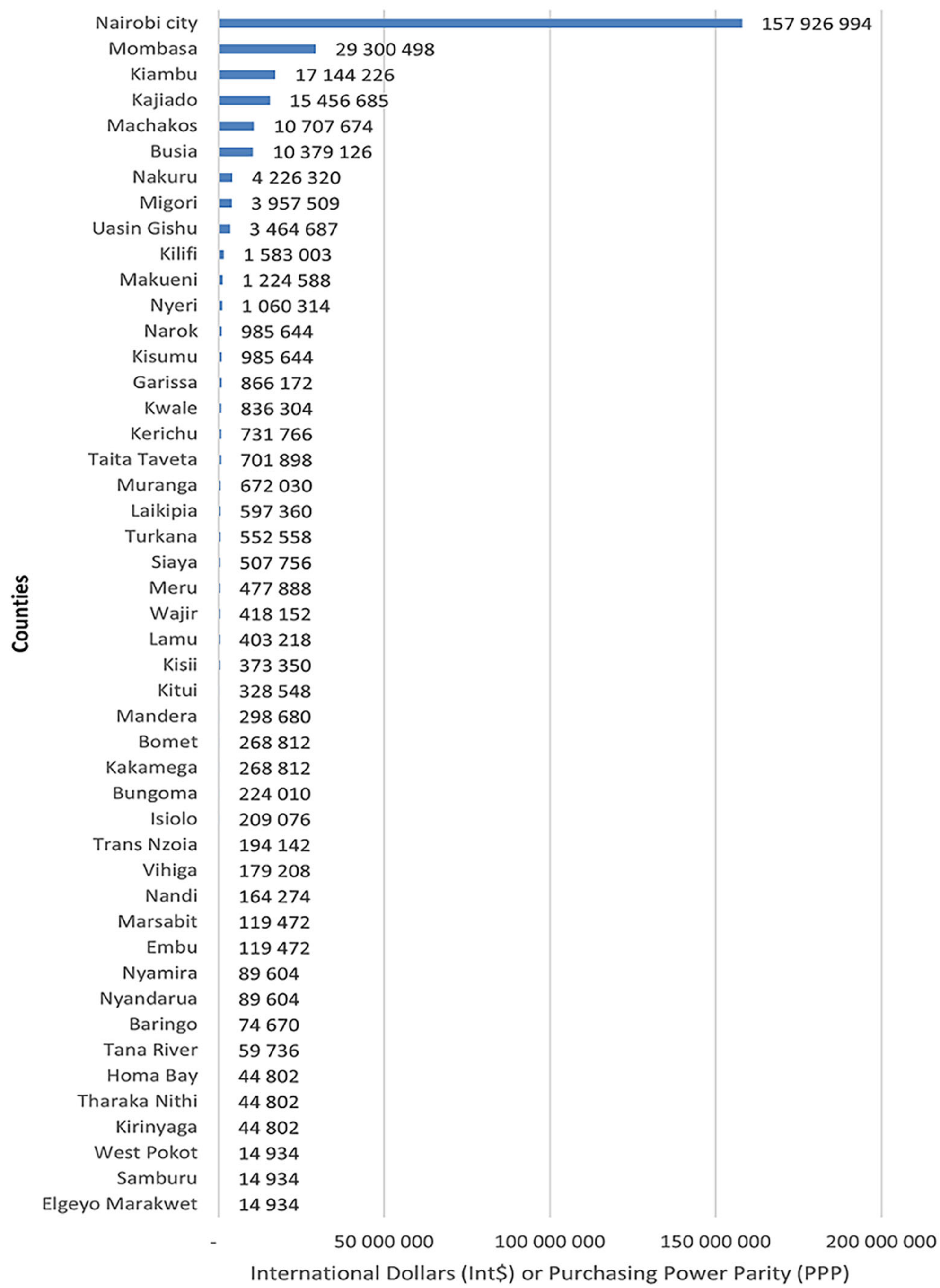

Figure 1. Distribution by county of discounted monetary value of human life losses associated with COVID-19 in Kenya as of 25 July 2022 in international Dollars (Int$).

3.1.3.3 Effect of changes in the number of deaths due to COVID-19

As portrayed in Table 11, a re-run of the economic model with the excess mortality of 180,215, instead of the reported 5670 COVID-19 deaths, increased the TPV_{KENYA} by 3,078% (Int$8,262,796,784), *i.e.,* from Int$268,408,687 to Int $8,531,205,470.

Table 9. Impact of application of 5% and 10% discount rates on the total and average present value of human lives lost from COVID-19 in Kenya (in 2022 Int$).

Age group in years	Value of human lives lost at 5% discount rate (Int$)	Value of human lives lost at 10% discount rate (Int$)
0–9	6,469,705	3,383,336
10–19	4,451,393	2,391,611
20–29	14,397,716	8,069,521
30–39	35,979,688	21,515,646
40–49	48,110,518	31,684,316
50–59	52,980,479	40,063,479
60 and above	64,401,673	57,571,204
TOTAL	**226,791,171**	**164,679,113**

Table 10. Effect of changes in average life expectancy on the total present value of human lives lost from COVID-19 in Kenya (in 2022 Int$).

Age group in years	Value of human lives lost using Africa's highest mean life expectancy of 78.76 years (Int$)	Value of human lives lost using World's highest mean life expectancy of 88.17 years (Int$)
0–9	10,037,033	10,361,688
10–19	6,813,416	7,123,055
20–29	21,808,932	23,227,555
30–39	54,532,637	59,756,475
40–49	75,372,208	86,509,195
50–59	95,517,768	119,185,194
60 and above	216,817,182	307,583,890
TOTAL	**480,899,177**	**613,747,054**

Table 11. Effect of changes of re-estimation of economic model with projected excess mortality from COVID-19 in Kenya (in 2022 Int$).

Age group in years	Excess mortality as of 25 July 2022	Value of human lives lost at 3% discount rate (Int$)
0–9	1,971	303,527,349
10–19	1399	201,783,299
20–29	4768	625,482,436
30–39	13063	1,483,988,550
40–49	20723	1,864,167,595
50–59	32,770	1,906,490,163
60 and above	105,524	2,145,766,078
TOTAL	**180,217**	**8,531,205,470**

3.2 The indirect and direct costs of reported cases

3.2.1 The indirect costs (or productivity losses) of reported deaths

As shown in Table 12, the 5586 COVID-19-reported deaths among those within the economically productive age bracket of 15 years and above resulted in a total indirect cost of Int$ 205,747,692; and an average total indirect cost per death of Int $ 36,833.

Table 12. Indirect cost of COVID-19 by age group (in Int$2022).

Age group	Indirect cost (Int$2022)
0–9	0
10–19	679,290
20–29	11,433,453
30–39	39,475,744
40–49	50,028,807
50–59	50,324,874
60 and above	53,805,524
TOTAL	**205,747,692**
Average total indirect cost	**36,833**

All the 84 deaths that occurred below the age of 15 years, which were not within the working age bracket, were valued at zero. Out of the total productivity losses, 0.3% were borne by 15–19-year-olds; 5.6% by 20–29-year-olds; 19.2% by 30–39-year-olds; 24.3% by 40–49-year-olds; 24.5% by 50–59-year-olds; and 26.1% by 60-year-olds and above.

3.2.2 The direct cost of caring for reported COVID-19 cases

As depicted in Table 13, the estimated total direct cost of caring for the reported 330,910 cases was Int$545,401,259.29; and the average total direct cost was Int$1,648.2 per patient.

Of these, 25% was for home-based isolation and care for asymptomatic cases, 22.9% for hospital/isolation centre care for mild/moderate cases, 7.4% for hospital high dependency unit care for severe cases, and 44.4% for hospital intensive care unit care for critical cases. As expected, due to the resource-intensive nature of hospital intensive unit care, the care of critically sick COVID-19 patients accounted for almost half of the total direct cost.

3.4 The potential projected direct and indirect cost savings due to COVID-19 vaccination

We estimate that the 30% target population's COVID-19 vaccination coverage may have saved Kenya a total cost of Int$ 1,400,945,809. It consists of Int$300,668,273 direct cost savings associated with the prevention of 182,423 COVID-19 projected infections and indirect cost savings of Int$1,100,277,536 from 29,872 deaths averted among 15-year-olds and above.

4. Discussion

4.1 Key findings

This study has seven key findings. First, the 5,670 human lives Kenya reported to have lost from COVID-19 had a TPV_{KENYA} of Int$268,408,687, equivalent to 0.1% of Kenya's total GDP in 2022. Second, the $ATPV_{KENYA}$ of Int$47,338 per human life was eight times the per capita GDP of Kenya. Third, about 59% of TPV_{KENYA} accrued only in Nairobi City County. Fourth, sensitivity analysis revealed that an increase in discount rate reduces TPV_{KENYA}, increases in life expectancy at birth augment TPV_{KENYA}, and increases in the number of deaths associated with COVID-19 grow the estimated TPV_{KENYA}. Fifth, the 5586 COVID-19-reported deaths in the economically productive age bracket of 15 years

Table 13. Direct cost of caring for asymptomatic, mild/moderate, severe, and critical COVID-19 cases in Kenya.

Management place by severity	Number of cases	Total cost per patient (Int$)	Subtotal cost (Int$)
Home based isolation and care for asymptomatic	241,763	570.3	137,880,597.0
Hospital/isolation centre care for mild/moderate cases	64,988	1,923.0	124,969,574.1
Hospital high dependency unit care for severe cases	10,787	3,759.3	40,550,556.5
Hospital intensive care unit for critical cases	13,372	18,097.5	242,000,531.6
Total (Ksh)	**330,910**		**545,401,259.3**
Average direct cost per patient			**1,648.2**

Table 14. A comparison of Kenya's average total present value per human life lost to COVID-19 with those of 15 other countries.

Countries	The average discounted money value per human life	Number of times higher than Kenya's average TPV per human life
Spain[38]	470,798	10
Italy[34]	369,088	8
China[29]	356,203	8
France[30]	339,381	7
Mauritius[36]	312,069	7
USA[41]	292,889	6
Japan[35]	286,973	6
Canada[28]	231,217	5
Turkey[39]	228,514	5
UK[40]	225,104	5
Germany	167,619	4
Iran[33]	165,187	3
Brazil[27]	99,629	2
India[32]	80,928	2
South Africa[37]	74,809	2

Sources: Sources are referenced within the Table.

and above resulted in a total indirect cost of Int$ 205,747,692 and an average total indirect cost per death of Int$ 36,833. Sixth, the estimated total direct cost of caring for the reported 330,910 cases was Int$545,401,259.29, and the average total direct cost was Int$1,648.2 per patient. Seventh, the 30% target population COVID-19 vaccination coverage may have saved Kenya a total cost of Int$ 1,400,945,809.

4.2 Comparison with COVID-19 related value-of-life studies

As depicted in Table 14, Kenya's $ATPV_{KENYA}$ was lower than all the 15 countries that also applied a similar human capital model.

For instance, the $ATPV_{KENYA}$ for Kenya of Int$47,338 is less than those of Spain by approximately 10-fold, Italy by 8-fold, China by 8-fold, France by 7-fold, Mauritius by 7-fold, USA by 6-fold, Japan by 6-fold, Canada by 5-fold, Turkey by 5-fold, UK by 5-fold, Germany by 4-fold, Iran by 3-fold, Brazil by 2-fold, India by 2-fold, and South Africa by 2-fold. Kenya's lower $ATPV_{KENYA}$ might be related to the lower GDP per capita[3] and the lower average life expectancy at birth.[48]

4.3 Limitations of the study

First, the discounted monetary values of life reported in our paper hinge on the number of COVID-19-associated deaths reported by the Government of Kenya (GoK). COVID-19 Excess Mortality Collaborators estimated that the GoK may have underestimated excess mortality due to the pandemic by 31.784-fold.[49] Consequently, our TPV_{KENYA} estimate of Int $268,408,687 might be underestimated by 31.784-fold.

Second, due to the unavailability of research resources, we could not compare our estimates using the HKA with those of alternative human life valuation methods (IVA and CVA) highlighted in the Methods section.[37]

Third, our study uses the GDP per capita as a proxy indicator of the value the Kenyan society attaches to human statistical life. As discussed by Giannetti *et al.*,[55] Stiglitz *et al.*,[56] Fleurbaey[57] and Kahneman and Deaton,[58] the indicator is not an indicator of overall well-being (quality of life, happiness, wellness) of society as it ignores social-economic-political-ecological inequities, omits environmental costs (*e.g.* depletion of natural resources, global warming due to pollution), and excludes most non-monetary production (*e.g.* child and elderly care at home, household chores by full-time homemakers).

Fourth, the HKA omits a person's non-monetary value to the bereaved family,[44] the psychological pain of the loss of a loved one, takes account only of society's loss in national income and ignores the person's desire to live.[56]

Fifth, our study captures only one of the adverse effects of the global COVID-19 pandemic, *i.e.* the associated mortality. It does not value non-fatal short-term and long-term effects on victims' health, which could be significant.[59]

Sixth, our study suffers the limitations explained by Baraza *et al.*[42] because it used their direct unit cost estimates. Furthermore, in calculating direct cost, Baraza *et al.*[42] did not consider the out-of-pocket expenses incurred by COVID-19 patients and their families and friends during diagnosis, isolation, management, and rehabilitation. Thus, in that respect, the total direct cost savings due to the COVID-19 vaccination reported in our paper might be underestimated.

5. Conclusions

The study estimated the total present value of human lives lost in Kenya as of 25 July 2022 to be 0.1% of the national GDP. The average total present value per human life loss of Int$47,338 due to COVID-19 was eight times the per capita GDP of Kenya.

The reported COVID-19 cases cost the country an estimated total of Int$751,148,951, of which 27.4% was indirect costs (productivity losses), and 72.6% was direct costs. However, by 25 July 2022, Kenya had vaccinated 30% of the projected target population with COVID-19 vaccines, which may have saved the country a total cost of Int$ 1,400,945,809.

The pandemic continues to erode human health (quality of life and life expectancy) and economic development. However, scaling COVID-19 vaccination coverage would save Kenya substantial direct and indirect costs.

To mitigate the health and economic effects of the current and future public health emergencies, Kenya ought to augment health development investments to bridge the extant gaps in diseases surveillance system (IHR capacities),[10] NHS (national and devolved),[9] systems that address other basic needs,[12] and national health research system.[17] Furthermore, the economic evidence adduced in this paper complements arguments of human rights to life, medical care, education, clothing, food, housing, and social security when health sector policymakers are making a case for bolstering investments in health-related systems.[60,61]

Author contributions

JMK, GMM, and RNDKM contributed to the literature review, data extraction from various databases, conceptualisation, development of the economic models on Microsoft Excel Software, formal analysis, findings interpretation, and manuscript writing. All authors approved the final version of the paper.

Ethical approval and consent to participate

The study did not require ethical approval because it relied wholly on the secondary data published in international databases of the International Monetary Fund (IMF), Republic of Kenya COVID-19 statistics, Worldometers, and the World Health Organization (WHO).

Data availability

Source data

- Worldometers. https://www.worldometers.info/coronavirus/country/kenya/.[8]
  - Covid-19 case data
- International Monetary Fund (IMF) World Economic Outlook Database. https://www.imf.org/en/Publications/WEO/weo-database/2021/October 3.
  - GDP data
- Worldometers. https://www.worldometers.info/demographics/life-expectancy/#countries-ranked-by-life-expectancy.[48]
  - Average life expectancy data
- World Health Organization (WHO) Global Health Expenditure Database. https://apps.who.int/nha/database/Select/Indicators/en.[19]
  - Per capita current health expenditure data

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