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Model-based estimation of burden of COVID-19 with disability-adjusted life years and value of statistical life in West Bengal, India

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ABSTRACT

Objectives The COVID-19 pandemic has posed unprecedented challenges to health systems and populations, particularly in India. Comprehensive, population-level studies of the burden of disease could inform planning, preparedness and policy, but are lacking in India. In West Bengal, India, we conducted a detailed analysis of the burden caused by COVID-19 from its onset to 7 January 2022.

Setting Open-access, population-level and administrative data sets for West Bengal were used.

Primary and secondary outcome measures Disability-adjusted life years (DALYs), years of potential productive life lost (YPPLL), cost of productivity lost (CPL: premature mortality and absenteeism), years of potential life lost (YPLL), premature years of potential life lost, working years of potential life lost (WYPLL) and value of statistical life (VSL) were estimated across scenarios (21 for DALY and 3 each for YPLL and VSL) to evaluate the effects of different factors.

Results COVID-19 had a higher impact on the elderly population with 90.2% of deaths arising from people aged above 45. In males and females, respectively, DALYs were 190 568.1 and 117 310.0 years, YPPLL of the productive population was 28 714.7 and 16 355.4 years, CPL due to premature mortality was INR3 198 259 615.6 and INR583 397 335.1 and CPL due to morbidity was INR2 505 568 048.4 and INR763 720 886.1. For males and females, YPLL ranged from 189 103.2 to 272 787.5 years and 117 925.5 to 169 712.0 years for lower to higher age limits, and WYPLL was 54 333.9 and 30 942.2 years. VSL (INR million) for the lower, midpoint and upper life expectancies was 883 330.8; 882 936.4; and 880 631.3, respectively. Vaccination was associated with reduced mortality.

Conclusions The losses incurred due to COVID-19 in terms of the computed estimates in West Bengal revealed a disproportionately higher impact on the elderly and males. Analysis of various age-gender subgroups enhances localised and targeted policymaking to minimise the losses for future pandemics.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ The study estimates the burden of disease using disability-adjusted life years, productivity losses and value of statistical life in West Bengal, India.
- ⇒ Open-source data of various age-gender cohorts were used for the analyses.
- ⇒ Sensitivity analyses were performed to explain the impact of contributory factors on the burden of disease.
- ⇒ Losses associated with psychological effects and social determinants of health were not investigated.
- ⇒ Postrecovery disability and long-term illness were not included.

INTRODUCTION

Ever since the first case of COVID-19 was detected in December 2019, it has laid its mark across 228 countries and territories causing 620 154 009 infections with 600 193 720 recoveries and 6 540 178 deaths as of 25 September 2022.[1] The rapid and substantial spread of infection in its earlier phase resulted in the pandemic being declared a 'Public Health Emergency of International Concern' by WHO in January 2020.[2] This is of serious concern to low and middle-income countries (LMIC) that have limited healthcare infrastructure, denser populations, malnutrition-related problems, etc.[3 4] Apart from the direct effects, postrecovery syndromes and the social determinants of health (SDH) such as food insecurity, damages caused to the caregivers, loss of employment, disproportionate impact on front-line workers, etc have worsened the consequences.[4 5] India ranks second in terms of the total infections (44 568 114) with 528 510 deaths and 43 995 610 recoveries as of 25 September 2022.[1]

Observing the trend of infections and mortalities provides more clarity on the dynamics of infection. Analysis on subcategories to understand the differential risk with gender, age and geography might be useful for better policymaking.[6] Governments have been taking measures like prohibiting non-essential gatherings, restricting workforce in industries, offering work from home, imposing lockdowns, etc to curtail the spread.[3 7–9] As these measures are not viable in the long run, the introduction of vaccines was a major breakthrough to reduce infections and mortality.[10 11] India started administering vaccines on 16 January 2021 and has reached over 1.8 billion doses as of 16 March 2022.[12] Vaccines have proven effective in curtailing infectious diseases in the past.[13]

West Bengal is the sixth largest state of India which is located in the eastern part of India. Being the second most densely populated state, it contributes 8% of the total population of India. The state is one of the most affected ones and has witnessed a significant COVID-19 surge in all the three waves in India.[14 15] All these factors make West Bengal an important study area to examine the impact of COVID-19.[16 17] This study quantifies the losses from COVID-19 in terms of various measures like disability-adjusted life years (DALY), years of potential productive life lost (YPPLL), cost of productivity lost (CPL), years of potential life lost (YPLL), premature years of potential life lost (PYPLL), working years of potential life lost (WYPLL) and value of statistical life (VSL). Our paper aims to present the various findings and the effects of altering the variables across all possible platforms after publication to assist policymaking for the present and future events in West Bengal and other locations. Additionally, vaccination data have been used to observe its effects on various COVID-19 estimates in West Bengal over time.

METHODOLOGY

Data collection

An age-gender cohort-based observational study has been conducted for West Bengal to compute economic and health impacts using various measures. The burden of disease (BoD) has been computed including multimorbidity and productivity losses have been estimated using a human capital approach.[18] The approach considers the discounted future income and defines the present value of human life.[19 20] Data such as COVID-19 statistics, vaccination data, per-capita gross domestic product, etc were acquired from open sources as presented in table 1.[17 21 22] The age-wise recovery period and the proportion of hospitalised and home-quarantined cases were used as presented by John *et al*[18] based on the data of 1012 admitted patients in Kerala.[23] The data collected were all standardised to represent 15-year age-gender cohorts. The population estimates for 2022 were used for calculating the YPLL, PYPLL, WYPLL and VSL to give a better representation.[22]

Cohort description

The population data of the state were used from the openly available sources.[17 22] No patients were involved in the study. The COVID-19-related population information on incidence, admissions, recovery and deaths was collected from various sources as mentioned in table 1.

Disability-adjusted life year

The DALY is the most widely used public health measure that explains losses in terms of life years lost. It is estimated as the sum of years of life lost (YLL) and years lived with disability (YLD).[20 24 25] The former indicates the losses due to premature mortality while the latter indicates the losses incurred due to the disability due to the infection.[20] DALY estimates are computed using the incidence-based approach that does not include the severity of infections. Yet, considering the lopsided impact of COVID-19, the study categorised the infections based on severity. Infections isolated at home were considered to be mild and the ones that required hospitalisation were divided into moderate and severe. Also, to pull in the effect of multimorbidity to improve accuracy, the disability weight (DW) of various symptoms was used with their weights per the proportion of patients who experienced each symptom (online supplemental table S1).[25] YLLs often contribute the major share of DALYs compared with that of YLDs.[20 24 26] YLLs elevate because of the mortality of youngsters and/or higher mortality rate.[6] Both undiscounted and discounted DALY estimates are presented in table 2.[27]

$$YLD = \frac{I \times DW \times D\left(1 - e^{-rD}\right)}{r} \quad (1)$$

where r=discount rate; D=disability duration (years); I=number of incident cases.

$$YLL = \frac{N}{r}\left(1 - e^{-rL}\right) \quad (2)$$

where L=life expectancy at age of death (years); N=number of deaths.

$$DALY = YLL + YLD \quad (3)$$

Combined disability weights (CDW) were computed using additive, multiplicative and maximum limit approaches as reported by Hilderink *et al*.[25]

$$Dw_{ij} = DW_i + DW_j \quad (4)$$

$$DW_{ij} = 1 - \left(1 - DW_i\right) \times \left(1 - Dw_j\right) \quad (5)$$

$$DW_{ij} = \max\left(DW_i,\ DW_j\right) \quad (6)$$

where 'i' and 'j' indicate the DWs of 'i'th and 'j'th disabilities.

Productivity losses (YPPLL and CPL)

YPPLL refers to the productive years an individual would have lived in the absence of an event. Henceforth, only the working population in each age-gender subgroup was considered (online supplemental table S2). The human capital approach was employed to compute permanent and temporary losses that are due to premature mortality and absenteeism, respectively.[19 20] Three age groups from 15 to 60 were chosen based on the employment and retirement age in India.[28 29]

$$YPPLL = \sum_{i=1}^{n} D_i \times w_i \times d \;\mid\; i = 1, 2, \ldots, n \quad (7)$$

Table 1 Input parameters for the study

Parameters	Values: Value	Values: Sensitivity analysis (SA)*	Reference	End date
Number of cases: 1 711 957		10% (S12), 20% (S13) and 30% (S14) increase in infected cases	21	7 January 2022
Number of deaths: 19 864		10% (S18), 20% (S19) and 30% (S20) increase in deaths	21	7 January 2022
Quarantine		10% (S15), 20% (S16) and 30% (S17) increase in mild cases	23 59	29 August 2020
Home isolation	158 543			
Hospitalised	14 646	–		
Severity			38	NA
Moderate	80%			
Severe/critical	20%			
Disability weights (DW) (average: S3, S4, S5); (lower: S6, S7, S8; upper: S9, S10, S11)—three methods of DW calculation in each case				
Whopping cough	0.051	(0.032, 0.074)	24 39–41	NA
Severe paratyphoid fever	0.133	(0.088, 0.19)		
Asthma	0.043	(0.036, 0.05)		
Moderate iron-deficiency anaemia	0.052	(0.034, 0.076)		
Mild diarrhoeal diseases	0.074	(0.049, 0.104)		
Mild symptomatic peptic ulcer disease without anaemia	0.011	(0.005, 0.021)		
Pharyngitis	0.07	(0.07, 0.07)		
Symptomatic tension-type headache	0.037	(0.022, 0.057)		
Moderate angina due to ischaemic heart disease	0.08	(0.052, 0.113)		
Moderate symptomatic peptic ulcer disease with mild anaemia	0.118	(0.081, 0.163)		
Other moderate mental disorders	0.133	(0.091, 0.186)		
Life expectancy		25% (S1) and 50% (S2) decrease	17 24	NA
Burden of isolation after recovery	0	2 weeks' isolation (S21)	24	NA
Recovery time for age-gender cohort (duration of disability)				
Age group	*Recovery period (days)*		23	Available for 1012 patients
0–15	15.1			
16–30	13.6			
31–45	14.3			
46–60	14.2			
61–75	15.9			
75+	14.6			
Life expectancy at age of death (L)				
Age	*Male*	*Female*	17	NA
0–15	70.7	72.6		
16–30	58.0	60.1		
31–45	43.7	45.9		
46–60	30.0	31.7		
61–75	17.9	19.2		
75+	8.6	9.3		
Discount rate for the value of life	2.9%	–	45	NA

Continued

Table 1 Continued

Parameters	Values: Value	Values: Sensitivity analysis (SA)*	Reference	End date
Age-gender population		–	17	NA
Age-gender working population				
Discount rate (financial benchmark)	4.25%	–	30	6 November 2020
Stay in intensive care unit (ICU)	8 days	–	32 33	NA
Retirement age (years)	60	–	28	NA
Number of working days in a week	6	–	28	NA
Per-capita gross domestic product (GDP) in Kerala	INR121 267/year	–	70	

*S1–S21 indicate the scenarios enacted for sensitivity analysis.
INR, Indian rupee.

where 'i' represents 'n' age-gender cohorts; D_i=deaths at age; w_i=productive years remaining at age of death (years); d=discount rate for the value of life, as proposed by the Reserve Bank of India (RBI), were selected.[30] These are applicable for every year excluding the first year.[31] CPL for premature mortality and absenteeism was computed as shown in equations (8) and (9).

$$CPL = \sum_{j=1}^{J} YPPLL_j \times \ per\ capita\ GDP \times P \tag{8}$$

$$CPL_{absenteeism} = \sum_{j=1}^{J} S \times L_j \times N \times P \tag{9}$$

where S=average salary per day considering the number of paid working days per week as 6; L_j=average recovery time; N=Number of incident cases; P=proportion of the working population in cohort 'j'. For the computation of productivity losses, the proportion of the working population was considered along with an extended disability period for severe cases to account for the intensive care unit stay.[32 33]

Table 2 DALY estimates (base scenario)

Age	DALYs until 7 January 2022 (years): Discounted M	Discounted F	Undiscounted M	Undiscounted F
0–15	1161.3	674.6	2703.1	1591.6
16–30	5505.7	4163.4	11 310.0	8714.0
31–45	25 935.3	12 949.8	45 666.8	23 354.9
46–60	64 536.7	40 050.9	96 588.4	61 198.8
61–75	73 671.6	44 157.8	94 412.4	57 564.7
75+	19 929.9	15 461.5	22 514.4	17 637.8
Total	190 740.6	117 458.1	273 195.0	170 061.9

DALY, disability-adjusted life year.

Years of potential life lost

YPLL, which presents the duration of life in the absence of the event, is computed based on life expectancy by assigning higher weights to deaths at a younger age and vice versa.

$$YPLL = \sum_{i=0}^{\infty} d_i \times L_i \tag{10}$$

where L_i is the life expectancy at age 'i' and d_i is the number of deaths at age 'i'. The deaths are weighted by the life expectancy at each age.

$$Standardised\ YPLL = YPLL \times \frac{P_{i,r}}{N_r} \times \frac{N}{P_i} \tag{11}$$

where $P_{i,r}$ is the population in the ith age group in West Bengal and N_r is the total population in West Bengal. P_i is the population affected by COVID-19 in the ith age group in West Bengal and N is the total population affected by COVID-19 in West Bengal.

Premature years of potential life lost

PYPLL projects the economic and social impacts of an event due to premature death that are public health priorities for policymaking. The upper slab for age depends on the preferences and objectives of studies.[34] The present study considered the life expectancies of the male and female populations to compute the PYPLL of respective cohorts.

$$PYPLL = \sum_{i=0}^{U} d_i \times (U - i) \tag{12}$$

where d_i is the number of deaths at age i, and U is the upper age limit. The upper age limit is decided by taking the average life expectancy of the state.

$$Standardised\ PYPLL = PYPLL \times \frac{P_{i,r}}{N_r} \times \frac{N}{P_i} \tag{13}$$

$P_{i,r}$ is the population in the ith age group in West Bengal and N_r is the total population in the (0–71) age group for males and (0–73) females in West Bengal. P_i is the population affected by COVID-19 in the ith age group in West Bengal and N is the total population in the (0–71) age group for males and (0–73) and females affected by COVID-19 in West Bengal.

Working years of potential life lost

WYPLL indicates the years lost in the working age group. For the death of people below 15 years, a fixed weight 'W' is used, whereas it is varied as the difference between the upper slab of age and midpoint of the age group is considered.[34]

$$WYPLL = \sum_{i=0}^{U} d_i \times (R - W) + \sum_{i=0}^{U} d_i \times (R - i) \quad (14)$$

where d_i is the number of deaths at an age 'i' and R is the upper limit for working age which is taken as the retirement age of 60 years in West Bengal while W is the lower bound of working age which is taken as 15 years.

$$Standardised\ WYPLL = WYPLL \times \frac{P_{i,r}}{N_r} \times \frac{N}{P_i} \quad (15)$$

where $P_{i,r}$ is the population in the ith age group in West Bengal and N_r is the total population in the (0–60) age group in West Bengal. P_i is the population affected by COVID-19 in the ith age group in West Bengal and N is the total population in the (0–60) age group affected by COVID-19 in West Bengal.

Value of statistical life

VSL is the rate of substituting the possibility of survival and income/money, that is, a trade-off between survival and money. This health risk at workplaces based on job characteristics and personal parameters is an important measure used by governments for cost-benefit analysis and risk monetisation.[35] In the present study, VSL was computed for various 15-year age-gender cohorts. Since no specific VSL_p value was available for West Bengal state, the value calculated by Majumder and Madheswaran[36] for all of India (INR44.7 million) was used.[36] This was used to compute the value of statistical year and thereby VSL.

$$VSLY_i = \frac{VSL_p}{L_i} \quad (16)$$

$$VSL = \sum_{i=1}^{U} YPLL_i \times VSLY_i \quad (17)$$

where VSL_p is the VSL of population, $VSLY_i$ is the value of statistical year of group 'i'.

Sensitivity analysis

A total of 21 scenarios (online supplemental table S3) were enacted to compare if the variations in DALY COVID-19 estimates are altered. The main intention of this sensitivity analysis (SA) is to explain the variations in losses that could be produced by each parameter. Scenarios 1 and 2 were developed considering that majority of the deceased had some form of comorbidity that could shorten the life expectancy.[6 37] Other scenarios deal with altering the deaths, and infections provide useful estimates to anticipate any future events and make policies.[24]

Validation

All the data gathered on COVID-19 were from published research, official bulletins, reports and internet articles.[17 23 24 32–34 36 38–42] The DALY, productivity losses, estimates of premature mortality and VSL were computed based on the works by Wyper *et al*,[43] Rumisha *et al*,[44] Dubey and Mohanty[34] and Etheridge and Spantig.[42–44] The approaches used for computing CDW were as per the approach suggested by Hilderink *et al*.[25] The financial benchmark and value of life were discounted based on RBI and Shanmugam,[45] respectively.

Patient and public involvement

The model-based analysis employed in the study used secondary data and did not involve the public and/or patients directly in any of the phases including plan, design or reporting. The DALY estimates, productivity losses and measures of premature mortality (YPLL, PYPLL, WYPLL), as well as VSL for West Bengal until 7 January 2022 were computed in the study. Apart from the losses quantified in the study, other indirect losses involving SDH are not within the scope of the study.

RESULTS

Baseline characteristics

Based on the data on infections and deaths gathered, it was evident that the youngsters were affected minimally compared with the elderly people which is in line with the trend observed in Kerala (online supplemental figure S1, online supplemental table S4). Though the prevalence of infection among the males and females in the 31–45 years age group was 28.0% and 25.8%, respectively, deaths in this group contributed only 8.4% and 6.8% of the total deaths. In males and females, the incidence in the 61–75 years age group was 20.3% and 16.9%, respectively, with their proportions of mortalities being 42.6% and 40.0%. In males and females of the above 75 years age group, the incidence was 7.4% and 4.7% with their proportionate mortalities being 21.1% and 25.3% showing an increased level of impact on elderly cohorts.

Disability-adjusted life year

The DALY estimates (table 2) showed that, despite the larger incidence and life expectancies of younger cohorts, the elderly people contributed a larger share which is due to the higher mortality proportion. The 61–75 years age group contributed 38.6% and 37.6% to the overall DALY of males and females, respectively, followed by the cohorts of 46–60 years age group contributing 33.8% and 34.1%, respectively. DALYs of male and female groups less than 30 years cumulate to only 3.5% and 4.1%, respectively. The undiscounted DALYs of males and females are 43.2% and 44.8% higher than the discounted estimates. The discount rate employed for the study was 2.9% as presented by Shanmugam.[45] The DALYs per million were 368.6 and 239.0 years for the male and female cohorts based on the projected population of the state for 2022.[22]

Table 3 Productivity losses: YPPLL and CPL (premature mortality and morbidity)

Age group	YPPLL (years)		CPL–death (INR)		CPL–morbidity (INR)	
	Male	Female	Male	Female	Male	Female
16–30	1603.6	1188.9	121 109 476.3	30 631 364.6	456 220 319.0	182 870 088.1
31–45	9569.7	4653.2	1 105 253 710.1	178 014 946.5	1 168 893 217.4	310 833 606.6
46–60	17 541.4	10 513.4	1 971 896 429.2	374 751 024.0	880 454 512.1	270 017 191.3
Total	28 715.7	16 355.4	3 198 259 615.6	583 397 335.1	2 505 568 048.4	763 720 886.1

CPL, cost of productivity lost; INR, Indian rupee; YPPLL, years of potential productive life lost.

Observing the gender-wise estimates in online supplemental figure S2A–I reveals that the DALY of male cohorts is greater than those of the corresponding female cohorts. The male population contributes 61.9% of the overall DALY which could be attributed to risk factors at work, widespread contact networks, etc. The overall DALY share of the 61–75 years age group population is 38.2% while the number of cases in this group is only 18.7%. This indicates the disproportionate impact of the disease on the elderly.

Productivity losses (YPPLL and CPL)

To quantify the productivity losses, YPPLL and CPL were determined for the three age groups from 16 to 60 that are productive. The male and female age groups of 46–60 contribute 61.1% and 64.3%, respectively, of the YPPLL (table 3). Despite the higher incidence of the disease in the 31–45 years age group, its lesser impact has fortunately helped reduce the losses that could have occurred otherwise.

The CPL values in table 3 indicate that the male and female cohorts of the 46–60 years age group contributed 61.7% and 64.2% of CPL due to premature mortality and 35.1% and 35.4% of the CPL–morbidity, respectively. Also, the males and females of the 31–45 years age group contributed the maximum concerning CPL due to morbidity, that is, 46.7% and 40.7%, respectively.

Years of potential life lost

The population estimates for 2022 were used to compute the various premature mortality measures. The YPLL and standardised YPLL were computed for all the age groups (table 4). The estimates were calculated for the lower, midpoint and upper age limits to know the variations that the consideration of cohorts could account for. For the lower age limit, the age groups of 46–60 and 61–75 years

Table 4 YPLL and standardised YPLL

Age	Life expectancy					
	Lower age limit		Midpoint		Upper age limit	
	Male	Female	Male	Female	Male	Female
YPLL (years)						
0–15	2681.1	1573.2	2567.3	1512.6	2381.5	1408.5
16–30	11 247.3	8640.5	10 316.5	7964.8	9385.7	7274.7
31–45	45 556.9	23 266.7	40 761.4	20 833.6	35 966.0	18 400.5
46–60	96 503.8	61 117	82 993.3	52 441.1	69 804.5	44 536.4
61–75	94 314.4	57 493.7	76 400.0	46 414.2	59 539.3	36 831.9
75+	22 483.9	17 620.9	16 470.8	12 884.1	12 026.3	9473.6
Total	272 787.5	169 712	229 509.3	142 050.2	189 103.2	117 925.5
Standardised YPLL (years)						
0–15	12 172.2	7374.5	11 655.7	7090.1	10 812.1	6602.6
16–30	19 345.4	11 386.4	17 744.4	10 495.9	16 143.4	9586.6
31–45	37 747.2	21 282.7	33 773.8	19 057.1	29 800.4	16 831.4
46–60	67 729.8	36 114.6	58 247.6	30 987.9	48 991.2	26 316.9
61–75	32 986.8	23 133.5	26 721.2	18 675.5	20 824.1	14 819.9
75+	4861.4	6373.5	3561.2	4660.2	2600.3	3426.6
Total	174 842.7	105 665.3	151 703.9	90 966.7	129 171.4	77 584.0

YPLL, years of potential life lost.

Table 5 PYPLL, WYPLL and standardised estimates

Age group	PYPLL (years)		Standardised PYPLL (years)		WYPLL (years)		Standardised WYPLL (years)	
	Male	Female	Male	Female	Male	Female	Male	Female
0–15	2396.7	1410.7	10 239.6	6410.9	1706.5	975.1	6135.2	3916.6
16–30	9250.0	7130.9	14 972.2	9110.3	7175.0	5319.4	9772.8	6006.3
31–45	34 089.5	17 538.7	26 580.7	15 553.6	22 934.8	11 151.8	15 048.5	8740.4
46–60	56 937.3	37 788.4	37 605.2	21 648.1	22 517.6	13 495.9	12 514.8	6833.1
61–72	16 092.7	14 295.1	5296.7	5576.4				
Total	118 766.1	78 163.9	94 694.3	58 299.1	54 333.9	30 942.2	43 471.3	25 496.4

PYPLL, premature years of potential life lost ; WYPLL, working years of potential life lost.

contribute a major share of 35.6% and 34.3%, respectively, for YPLL and 37.0% and 20.0% for standardised YPLL. The corresponding estimates for the upper age limit were 37.2% and 31.4% for the 46–60 years age group and 36.4% and 17.2% for the 61–75 years age group.

Premature years of potential life lost

The PYPLL estimates (table 5) for the age groups were computed and the results were found to complement those of the other productivity losses as the elderly population showed higher losses. The 46–60 years age group contributed the maximum share of 48.1% and 38.7% of PYPLL and standardised PYPLL, respectively. The age groups of 0–15 and 16–30 years contributed only 1.9% and 8.3% of the total PYPLL. Concerning the WYPLL, the cohorts of the 46–60 years age group shared 42.23% of the total value with the 31–45 years age group contributing 40.0% of WYPLL.

Value of statistical life

The VSL values, as anticipated, followed the same trend being proportional to age (table 6). The 61–75 years age group had the maximum share of 41.5% and 41.4% for the lower and upper age limits of life expectancy, respectively. The elderly cohorts greater than 75 years contributed 22.8% and 22.7%, respectively, for the lower and upper age limits. The younger population aged 0–15 and 16–30 years contributed only 0.3% and 1.7%, respectively, for the lower age limit and 0.3% and 1.7% for the upper age limit.

Sensitivity analysis

The SAs and variation of the DALY across scenarios are explained through figure 1A–E and figure 1F, respectively. Shortening the life expectancy by 25% (S1) and 50% (S2) lowered the DALY by 18.5% and 40.7% for males and 18.3% and 40.4% for females, respectively. Concerning figure 1B,C,E, only YLD estimates were compared as the variations were only in the number of cases. Since YLDs relatively contribute lesser to the overall DALYs, comparing the latter might explain the variations less effectively. The changes reflected the similar variations in DALY estimates as observed by John *et al.*[18] There was a proportionate increase in YLDs with an increase in the overall cases. Increasing the mild cases by 10%, 20% and 30% raised the YLDs by 9.2%, 18.3% and 27.5% for cohorts of both genders. An increase in DALY by 10%, 20% and 30% was observed when the deaths were increased by 10%, 20% and 30%, respectively. The burden of isolation for 2 weeks after recovery raised the YLDs from 407.5 to 1995.9 years for males and from 349.9 to 1726.1 years for females, respectively.

A total of nine scenarios have been enacted using the three approaches to compute CDW with one of the lower, average and upper limit values of DW. An increase in deaths seemed to elevate the DALY drastically. This estimate might have further spiked if the disease had created higher mortality among the younger population.

Table 6 VSL range based on life expectancy

Age	Life expectancy		
	Lower age limit	Midpoint	Upper age limit
VSL (INR million)			
0–15	2655.4	2654.0	2654.8
16–30	15 064.2	15 073.6	15 041.5
31–45	68 808.2	68 817.0	68 633.8
46–60	228 703.8	229 263.8	229 143.1
61–75	366 719.1	368 359.9	364 985.3
75+	201 380.2	198 768.0	200 172.8
Total	883 330.8	882 936.4	880 631.3
VSL ($ million)			
0–15	38.0	38.0	38.0
16–30	215.7	215.9	215.4
31–45	985.4	985.5	982.9
46–60	3275.2	3283.3	3281.5
61–75	5251.7	5275.2	5226.9
75+	2883.9	2846.5	2866.7
Total	12 650.1	12 644.4	12 611.4

INR, Indian rupee; VSL, value of statistical life.

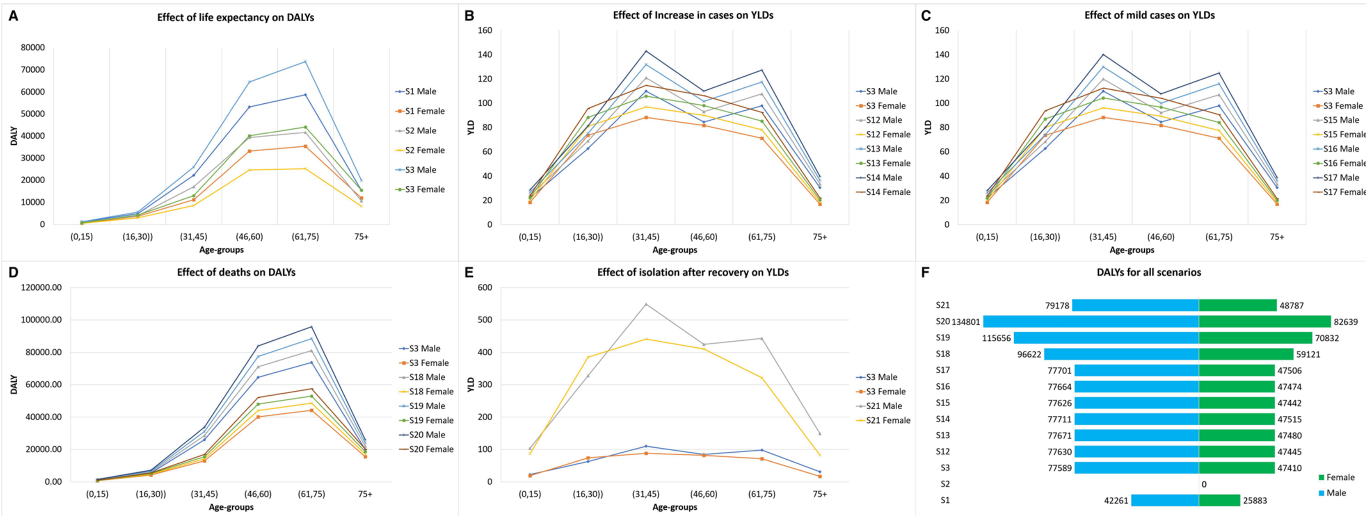

Figure 1 (A) Effect of life expectancy on disability-adjusted life years (DALYs); (B) effect of increase in cases on years lived with disability (YLDs); (C) effect of mild cases on YLDs; (D) effect of deaths on DALYs; (E) effect of isolation after recovery on YLDs; (F) change in DALYs for all scenarios.

DISCUSSION

Key findings of this study

This study comprehensively presented several measures such as DALYs, YPPLL, CPL, YPLL, PYPLL, WYPLL and VSL in West Bengal, India. SAs were performed to explain the impact of the contributory variables for the estimates. The YLL values determined in this scenario were 407.5 and 349.4 years for males and females with their corresponding YLLs being 190 333.1 and 117 108.2 years (online supplemental table S5). The undiscounted YLL computed for the baseline scenario was 272 787.5 and 169 712 years for males and females, respectively. The corresponding DALYs per million were 368.6 and 239.0 years based on the projected population for 2022.[22] The accuracy of these estimates depends on the quality of referred sources and the model employed. Taking into account the effect of asymptomatic spreaders might increase the losses concerning presenteeism.[46] Other concerns such as under-reporting as reported by Biswas[47] and Yadav[48] might show reduced measures.[47 48]

The productivity losses showed a similar trend where the elderly population contributed a major share. The YPPLL of males and females was 28 714.7 and 16 355.4 years, respectively, with the 46–60 years age group contributing to 61.1% and 64.3%, respectively. The overall CPL due to premature mortality and morbidity was INR3 198 259 615.6 and INR583 397 335.1 for males and INR2 505 568 048.4 and INR763 720 886.1 for females, respectively. The YPLL and standardised YPLL were determined for the lower, midpoint and upper age limits of life expectancies. The YPLL values for the lower age limit were 272 787.5 and 169 712.0 years for males and females while those for the upper age limit were 189 103.2 and 117 925.5 years, respectively. The PYPLL of the productive population was 118 766.1 and 78 163.9 years for the males and females, respectively, with the standardised estimates being 94 694.3 and 58 299.1 years. The WYPLL estimates of males and females were computed to be 54 334 and 30 942 years, respectively, with the standardised values being 43 471 and 25 496 years. The VSL was computed for three values of life expectancies, viz lower, mid and upper limits. The corresponding VSL (INR million) is 883 330.8; 882 936.4; and 880 631.3, respectively, with the standardised VSL being 12 650.1; 12 644.4; and 12 611.4, respectively. Despite the relatively lower incidence among the elderly, across all these estimates, the cohorts above 45 years were the ones that shared a major proportion of the losses. This is a clear indication of the disproportionate impact of the disease. Also, the male cohorts of all age groups have incurred greater losses compared with the corresponding female cohorts.

The effect of vaccination

The curves in figure 2 indicate that the slopes of the curves of VSL and CPL–premature mortality that depend on mortality have reduced after June 2021. Despite the increase in the slope of CPL–morbidity from December 2021 to January 2022, the slopes of VSL and CPL–premature mortality have remained to be constant indicating the effectiveness of the vaccines in preventing mortality despite incidence. A similar trend is observed in YLL and YLD. This highlights the importance of administering the vaccination campaigns effectively to overcome the hesitancy among the people.[49 50]

What is already known on this topic

Owing to the vast impact created by COVID-19, there have been studies on the estimation of the BoD measures, productivity losses, quality-adjusted life year (QALY) and VSL. Some of the research conducted in the context of COVID-19 includes the determination of YLL in Italy,[20] Swiss,[7] India[26] and the USA.[6] Some works estimated DALY in Italy[20] and Korea.[24] YPPLL has been studied in the past for the top five causes of mortalities in Iran,[51] cancer in

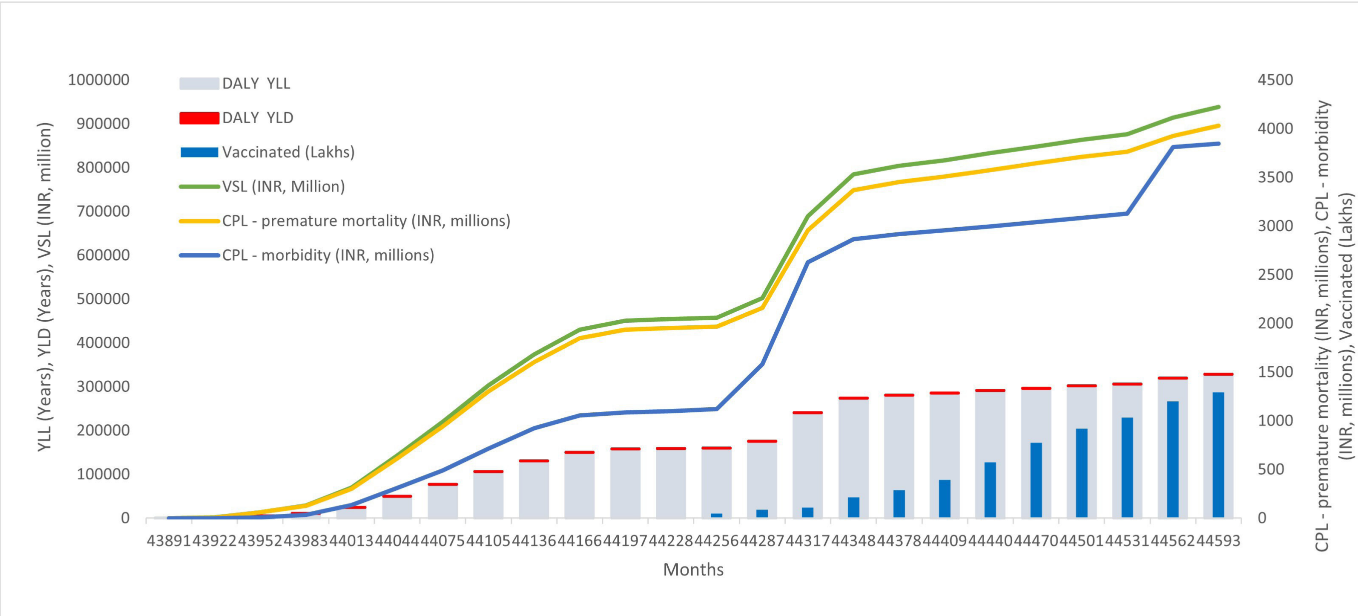

Figure 2 Time trend of estimates and total number vaccinated. CPL, cost of productivity lost; DALY, disability-adjusted life year; VSL, value of statistical life; YLL, years of life lost.

Brazil, Russia, India, China and South Africa[52] and due to psychological illness and cardiovascular diseases in India,[46] etc. Some reported findings in YLL include 1.8 million years in Switzerland,[7] 2 million years in India until 17 October 2020[26] and 1.2 million years in the USA between February 2020 and July 2020.[6] Some of the BoD estimates computed by researchers in Italy include 121 449 years with a total of €400 million productivity losses due to absenteeism and premature mortality,[20] 2531 years from January 2020 to April 2020 in Korea of which the YLL had a major share of 89.7%,[24] 305 641 years in Germany during 2020,[53] productivity losses of US$1 791 172 in Iran from March 2020 to July 2020,[54] 83 853.0 and 56 628.3 years for males and females, respectively, in Kerala, India until June 2021 with the corresponding CPL of the cohorts being INR1 419 557 903.8 and INR278 275 495.3,[18] etc. QALY due to COVID-19 had been reported as 3.9 and 3.5 for the death of a male and a female, respectively, in the Netherlands,[55] ranging from 2295 to 4525 in Ukraine,[56] 810 000 in the USA until July 2020,[57] etc.

What this study adds

The present work reveals that the disease has impacted the elderly population disproportionately to a larger extent. This is directly evident from the proportion of cases and deaths in the elderly population. The share of cases among the males and females of the 61–75 years age group is 20.3% and 16.9%, respectively, whereas their corresponding shares of mortality are 42.6% and 40.0%. This is contrary to the case of 16–30 years age group where their proportion of cases is 17.5 and 23.6 for males and females with the mortality shares being 1.6% and 1.9%, respectively. This complements the results of Indrayan *et al*[26] and John *et al*.[18] The former indicated that the rate of incidence among youngsters was one-third of that of the elderly aged greater than 60. A similar trend is observed outside India as more than three-fourths of the 1482 admitted cases in the USA were more than 50 years of age.[27]

The subgroup analyses considering age-gender cohorts would provide granular details to assist policymaking effectively to shield the most vulnerable groups. The positive association between age and case fatality rate (CFR) helps the healthcare fraternity to allocate resources and vaccines effectively.[58] These have been proven effective in curtailing the CFR in Kerala, thereby reducing the BoD.[59] Evidence in the past and also those of the ongoing pandemic emphasises the need to effectively administer vaccines to reduce the premature mortality and transmission rate.[10 13] With this in view, the study also presented the time trend of estimates against the vaccinations in the state of West Bengal. The results were as expected as the slope of the curves governed by mortality reduced significantly with increased vaccination.

Also, the SA conducted across 21 scenarios by altering the number of cases, life expectancy, deaths and burden of isolation showed death to be the variable contributing maximum to the losses. The scenarios of shortening the life expectancy shall be attributed to the presence of comorbidities among the older infected patients such as diabetes mellitus (50%), hypertension (34.4%), pneumonia (68.8%) and others.[60] Around 89.3% of the elderly were comorbid.[27] Also, the study addressed several estimates such as DALY (YLL and YLD), YPPLL, CPL (premature mortality and absenteeism), YPLL, PYPLL, WYPLL and VSL considering multimorbidity to improve the accuracy of results across the age-gender cohorts.

Limitations

The present study considered the age-gender cohorts in age group of 15 per the data available. The age-wise recovery time and proportion of home-quarantined to hospitalised cases of Kerala were used for the study owing to the unavailability in open domains. The exclusion of SDH surely indicates an underestimation of the indirect losses incurred. The mental illness triggered by the disease that could increase the risk of mortalities is excluded in the present study.[7] Associated psychological problems faced amidst the pandemic have not been considered largely for policymaking.[7 61 62] Despite the lower contribution of YLDs, the inclusion of presenteeism and unpaid work could enhance the accuracy of the estimates. Long-term health implications of postrecovery illness are not within the scope of the study. The former and latter were reported by 10% and 30% of recovered cases in Kerala.[63] More specific insights could be obtained using VSL by including the risk levels and wages earned across different jobs ranging from high-risk physical work to low-risk corporate jobs.

Estimation of the excess deaths across 74 countries including 31 LMICs revealed significantly high deaths across the territories.[64] Similarly, the projections of WHO stated that there could be over 4 million excess deaths in India.[65–67] The estimates of deaths portray over 10-fold figures in West Bengal.[64 68] Though some published articles and preprints support these estimates, the Government of India objects to the approach employed to compute the same owing to the risk of bias.[65] Nonetheless, there are claims by WHO analysts that extensive validation has been performed to minimise the bias.[65] Though it is rational to accept the fact that the extrapolations and estimates generated by models might be subject to some degree of bias, the fact that there are certain excess deaths during the tenure needs to be seriously investigated. Given this, the estimates have been computed considering the excess deaths to be 11 times the actual numbers (online supplemental table S6).[64 67 69] The values in this table have all increased by 11-fold as all of them are linearly proportional to deaths.

CONCLUSIONS

This study estimates various estimates such as DALY (YLL and YLD), YPPLL, CPL (premature mortality and absenteeism), YPLL, PYPLL, WYPLL and VSL to portray the health and economic losses in West Bengal due to COVID-19. The human capital approach using multimorbidity was employed in the study to incorporate the effects of most of the symptoms experienced. YPPLL and VSL were determined based on the retirement age (60) and life expectancy, respectively. Males and females aged greater than 45 contributed more than 80% of the DALYs in their respective groups. CPL of 46–60 was the highest considering premature mortality and that of 31–45 was the highest considering morbidity. These estimates could be helpful to devise localised policies and effectively shield the most vulnerable cohorts to minimise the economic and health burden in West Bengal.

The SA employed by adjusting the variables would help anticipate the damages that could be incurred on alteration of one or more of the governing variables. The comparison of time trends of estimates with the vaccination proves the effectiveness of the vaccine in reducing the mortality rate through the decrease in the slope of the CPL–premature mortality and VSL curves. The method adopted is reproducible by researchers for other states as well as other developing countries wherever the data required are available. Longitudinal studies of these estimates as done in the present study could help compare the effectiveness of measures that are being adopted across states or locations. These could serve as the base for effective utilisation of the health resources under limited resource settings.

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Patient consent for publication Not applicable.

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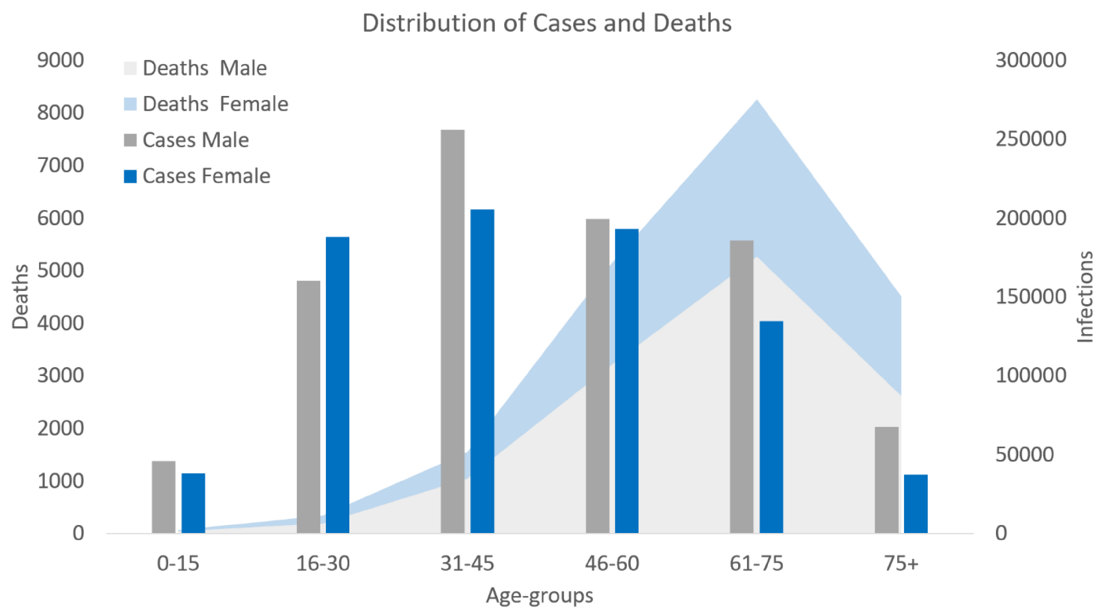

Figure S1: Distribution of cases and deaths

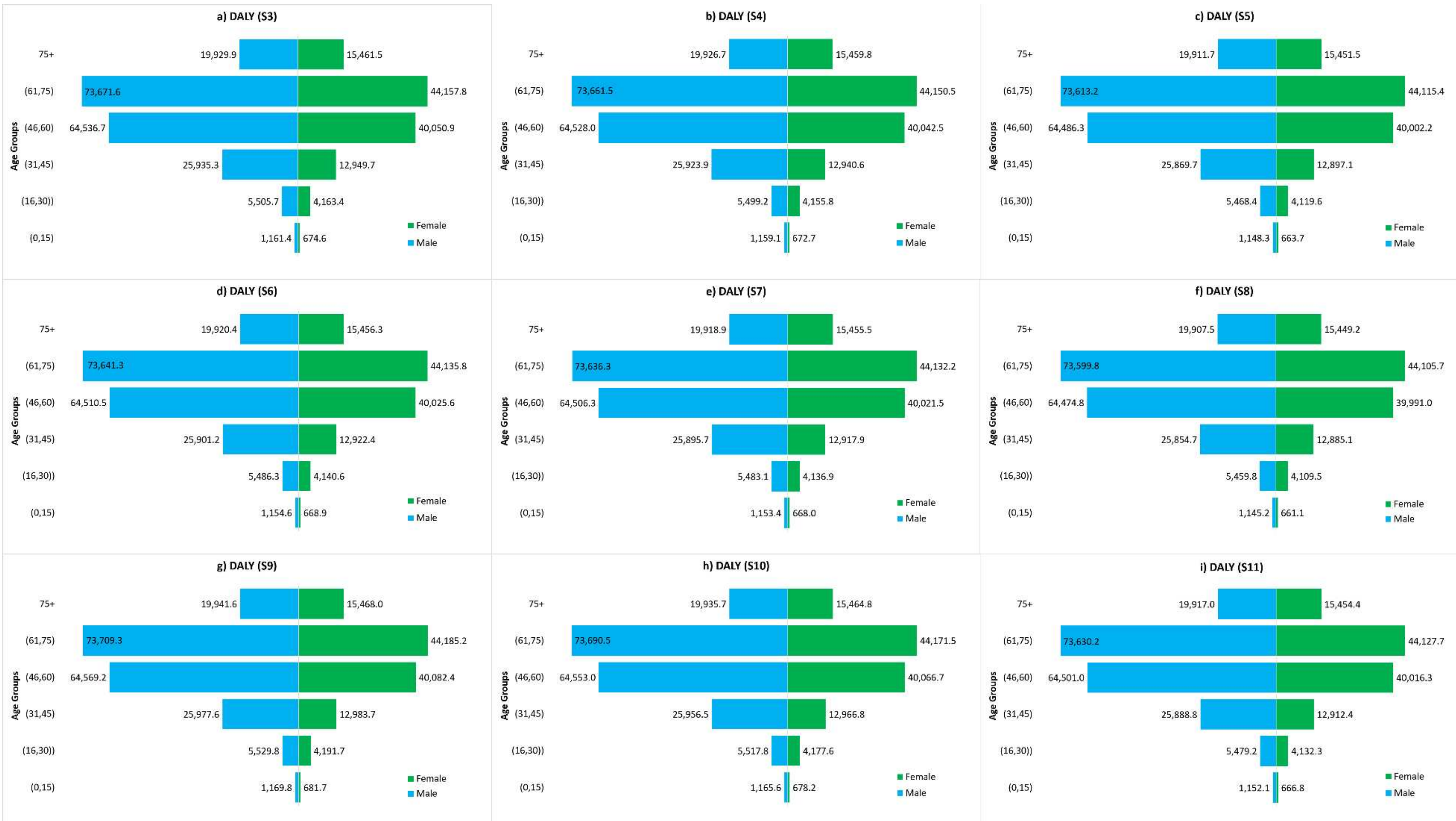

Figure S2: Sensitivity Analyses: A) DALY for S3; B) DALY for S4; C) DALY for S5; D) DALY for S6; E) DALY for S7; F) DALY for S8; G) DALY for S9; H) DALY for S10; I) DALY for S11

Table S 1: Symptoms and Associated Disability Weights

Health condition chosen	Symptom experienced by patients	DW (Average)	Proportion of people (%)	Adjusted DWs as per proportion of people
Whopping cough	Cough	0.051	86.1	0.0439
Severe paratyphoid fever	Fever/ Chills	0.133	85	0.1131
Asthma	Shortness of breath	0.043	80	0.0344
Moderate iron-deficiency anemia	Myalgia	0.052	34.4	0.0179
Mild diarrheal diseases	Diarrhea	0.074	26.7	0.0198
Mild symptomatic peptic ulcer disease without anemia	Nausea/ Vomiting	0.011	24.4	0.0027
Pharyngitis	Sore throat	0.07	17.8	0.0125
Symptomatic tension-type headache	Headache	0.037	16.1	0.006
Moderate angina due to ischemic heart disease	Chest pain	0.08	15	0.012
Moderate symptomatic peptic ulcer disease with mild anemia	Abdominal pain	0.118	8.3	0.0098
Moderate other mental disorders	Altered mental status/ Confusion	0.133	6.1	0.0081

Table S 2: Working population and Time to recovery

Age-Group	Working Population (%)		Recovery days (Average)
	M	F	
16-30	62.28	21.25	13.64
31-45	95.24	31.55	14.29
46-60	92.70	29.39	14.21

Table S 3: Variations in DALY estimates across scenarios – Sensitiviy Analysis

Variable adjusted	Scenarios	Notation	DALYs (years)		% change	
			Male	Female	Male	Female
Life Expectancy	reduced by 25 %	S1	155,412	95,930.39	-18.5218	-18.328
	reduced by 50 %	S2	113,151.5	70,047.74	-40.6778	-40.3636
Disability Weights	DW method 1 - Average value	S3	190,740.6	117,458.1	0	0
	DW method 2 - Average value	S4	190,698.5	117,422	-0.02206	-0.03076
	DW method 3 - Average value	S5	190,497.6	117,249.5	-0.12739	-0.17762
	DW method 1 - Lower value	S6	190,614.3	117,349.7	-0.06622	-0.09233
	DW method 2 - Lower value	S7	190,593.7	117,332	-0.07704	-0.10741
	DW method 3 - Lower value	S8	190,442	117,201.7	-0.15657	-0.21831
	DW method 1 - Upper value	S9	190,897.3	117,592.7	0.082171	0.11457
	DW method 2 - Upper value	S10	190819.2	117525.6	0.041193	0.057435
	DW method 3 - Upper value	S11	190,568.1	117,310	-0.09042	-0.12608
Confirmed cases	Increase by 10 %	S12	190,781.4	117,493.1	0.021365	0.029788
	Increase by 20 %	S13	190,822.1	117,528.1	0.042729	0.059577
	Increase by 30 %	S14	190,862.9	117,563.1	0.064094	0.089365
Mild cases	Increase by 10 %	S15	190,777.9	117,490.1	0.019558	0.027269

	Increase by 20 %	S16	190,815.2	117,522.2	0.039116	0.054539
	Increase by 30 %	S17	190,852.5	117,554.2	0.058673	0.081808
Deaths	Increase by 10 %	S18	209,773.9	129168.9	9.978635	9.970212
	Increase by 20 %	S19	228,807.2	140,,879.8	19.95727	19.94042
	Increase by 30 %	S20	247,952.5	152,686.7	29.99458	29.99244
Burden of isolation	2 weeks isolation after recovery	S21	192,329	118,834.3	0.832748	1.171635

Table S 4: Incidence and Mortality of age-gender cohorts

	Cases		Deaths	
	Male	Female	Male	Female
0-15	45,744	38,260	38	22
16-30	160,102	188,113	194	144
31-45	256,164	205,648	1,042	507
46-60	199,442	192,895	3,217	1,928
61-75	185,719	134,708	5,269	2,994
75+	67,700	37,463	2,614	1,895
Total	914,870	797,087	12,374	7,490

Table S 5: YLL and YLD estimates (Base Scenario)

Age	Estimates till Jan 7, 2022					
	YLL (Undiscounted) (years)		YLL (discounted) (years)		YLD (S3) (years)	
	M	F	M	F	M	F
0-15	2,681.10	1,573.23	1,139.37	656.22	22.01	18.41
16-30	11,247.35	8,640.47	5,443.12	4,089.90	62.59	73.55
31-45	45,556.91	23,266.70	25,825.37	12,861.51	109.91	88.24
46-60	96,503.84	61,117.00	64,452.19	39,969.17	84.54	81.76
61-75	94,314.43	57,493.66	73,573.64	44,086.75	98.00	71.08
75+	22,483.90	17,620.90	19,899.41	15,444.68	30.46	16.85
Total	272,787.53	169,711.96	190,333.10	117,108.23	407.51	349.89

Table S 6: Comparison of the actual and the excess deaths' estimates

	Actual estimates (Officially reported)		Based on excess deaths approach	
	Male	Female	Male	Female
Deaths	19,864		218,504	
Discounted DALY	190,740.61	117,458.12	2,094,061.01	1,288,522.82
Undiscounted DALY	273,195.04	170,061.85	3,001,046.21	1,867,138.19
YPPLL	28,715.70	16,355.43	315,858.20	179,908.10
CPL – Death	3,198,259,616.00	583,397,335.10	35,180,501,252.00	6,417,350,687.00
YPLL	229,509.30	142,050.20	2,524,580.10	1,562,511.10
Standardized YPLL	151,703.90	90,966.74	1,668,680.55	1,000,487.73
PYPLL	118,766.10	78,163.90	1,371,748.45	903,574.68
Standardized PYPLL	94,694.30	58,299.10	1,063,416.99	658,196.84
WYPLL	54,333.93	30,942.23	597,655.00	340,335.00
Standardized WYPLL	43,471.32	25,496.36	478,150.26	280,377.14
VSL	882,936.37		9,712,255.83	