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Estimation of economic burden of COVID-19 using Disability-Adjusted Life Years (DALYs) and Productivity Losses in Kerala state, India

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ABSTRACT

Background: The COVID-19 pandemic has had a huge impact on the global economy and stressed the health care systems worldwide. Measuring the burden of disease on health and economy is essential for system preparedness by way of allocation of funds and human resources.

Methods: The present study estimates Disability-Adjusted Life Years (DALYs), Years of Potential Productive Life Lost (YPPLL) and Cost of Productivity Lost (CPL) due to premature mortality and absenteeism, secondary to COVID-19 in Kerala state, India. The impact of disease on various age-gender cohorts has been analyzed. Sensitivity Analysis has been conducted by adjusting six variables with a total of 21 scenarios.

Results: Severity of infection and mortality were higher among older sub-group of patients, and male were more susceptible than female in most of the age groups. DALY for the baseline scenario was 15,924.24 and 8,669.32 for males and females respectively. The CPL due to premature mortality was 26,80,36,179 and 42,510,946 for males and females respectively.

Conclusion: People aged more than 50 were disproportionately affected by the disease, with presence of comorbidities further raising vulnerability.

KEYWORDS

Burden of Disease, Disability-Adjusted Life Years (DALYs), Years of Potential Productive Life Lost (YPPLL), Cost of Productivity Lost (CPL), Years of life lost (YLLs), Years Lived with Disability (YLDs).

INTRODUCTION

Since the first case of COVID-19 was reported in December 2019, COVID-19 has spread across 218 countries infecting 58,099,381 people with 1,380,859 deaths and 40,263,305 recoveries worldwide as on November 21, 2020 [1]. The majority of cases have been reported from Low- and Middle-Income Countries (LMICs) with a significant proportion of people not having access to quality health facilities, being placed at a higher risk [2]. India ranks second with 9,065,301 and 8,491,462 recoveries as on November 21, 2020 [1]. Higher infection rates of the disease has increased the burden on healthcare systems and thus increased the fatality rate [3]. The major impact globally due to COVID-19 has been through attributed mortality. Estimating the mortality due to COVID-19 helps to understand the dynamics of the pandemic. Role of socio-demographic, social determinants and geography are important to assess the differential risk levels to the disease with age, gender and geography [4]. Governments have imposed strict measures to curtail the morbidity and mortality caused by COVID-19. Individual level measures such as self-isolation and social distancing and population level lockdowns are widely adopted to limit spread [2,5,6]. Quantifying the health and economic impact of COVID-19 would reflect on the consequences of the policy decisions taken [7].

In India, the first case of COVID-19 was reported in Kerala. Timely interventions such as contact tracing, testing, quarantine, isolation and treatment had reduced the spread of the disease in Kerala [8]. The number of cases in Kerala has now reached 551,669 with 1997 deaths and 481,718 recoveries as on November 21, 2020. The present study estimates the economic burden and productivity loss using Disability-Adjusted Life Year (DALY), Years of Potential Productive Life Lost (YPPLL) and Cost of Productivity Lost (CPL) [9,10] and the effect of age and gender [4,11] for the state of Kerala

METHODS

Data Collection

Publicly available data from various sources have been used to gather sociodemographic details, information about incidence, death due to COVID-19, information on quarantine, per capita income, etc., for the state of Kerala [9,12,13]. The first reported case of COVID-19 in Kerala dates back to January 30, 2020, from when on the estimates for the present study have been collected [9,13].

The 5-year age-gender population of Kerala, working population in each age-gender cohort and the corresponding life expectancies were obtained from 2011 Census of India [12]. Incidence data documented by Team Collective for Open Data Distribution-Keralam (CODD-K) was till August 20, 2020 was used to classify the incidence of age-gender cohort. Out of 52,199 reported cases till August 20, 2020, data of 7645 patients were excluded as they did not contain information on age and gender

[13]. Recovery time documented by the team for 1,012 patients in Kerala was used from CODD-K [13]. Data for number of deaths were extracted from the Government of Kerala dash board and CODD-K [9,13]. The infections were categorized as mild, moderate and severe/ critical [9,14]. Table I presents the information on various parameters used for the study.

Table I: Parameters used for the study.

Parameters	Values		Reference	Till Date
	Value	Sensitivity Analysis (SA)*		
Number of cases		10% (S12), 20% (S13) and 30% (S14) increase in infected cases	[3,13]	20-Aug-20
Actual	52199			
Valid records	44554			
Number of deaths		10% (S18), 20% (S19) and 30% (S20) increase in deaths	[3,9,13]	15-Nov-20
Actual	1869			
Valid records	1841			
Quarantine		10% (S15), 20% (S16) and 30% (S17) increase in mild cases	[9,13]	29-Aug-20
Home (Mild cases)	158543			
Hospital	14646			
Severity		-	[14]	NA
Moderate	80%			
Severe/ Critical	20%			
Disability weights (average: S3, S4, S5); (lower: S6, S7, S8, upper: S9, S10, S11) – Three methods of DW calculation in each case		(0.032, 0.074)	[3,15–17]	NA
Whooping cough	0.051			
Severe paratyphoid fever	0.133			
Asthma	0.043			
Moderate iron-deficiency anemia	0.052			
Mild diarrheal diseases	0.074			
Mild symptomatic peptic ulcer disease without anemia	0.011			
Pharyngitis	0.070			

Symptomatic tension-type headache	0.037	(0.022, 0.057)		
Moderate angina due to ischemic heart disease	0.080	(0.052, 0.113)		
Moderate symptomatic peptic ulcer disease with mild anemia	0.118	(0.081, 0.163)		
Moderate other mental disorders	0.133	(0.091, 0.186)		
Life Expectancy for age-gender cohort		25% (S1) and 50% (S2) decrease	[3,12]	15-Nov-20
Burden of isolation after discharge/recovery	0	2 weeks isolation (S21)	[3]	NA
Recovery time for age-gender cohort		-	[13]	Available for 1012 patients
Discount rate for value of life	2.90%	-	[18]	NA
Age-gender population	Table S III	-	[12]	NA
Age-gender working population				
Discount rate (Financial Benchmark)	4.25%	-	[19]	6-Nov-20
Stay in Intensive Care Unit (ICU)	8 days	-	[20,21]	NA
Retirement age in Kerala (years)	56	-	[22]	NA
Number of working days in a week	6	-	[23]	NA

Per capita Gross Domestic Product (GDP) in Kerala	225484 INR/year	-	[24]	2020
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*- Scenarios of Sensitivity Analysis have been denoted from S1 to S21. Detailed description is provided in table S IV

Disability-Adjusted Life Year (DALY)

DALYs are standard measures to estimate the burden of a disease in public health and is calculated as the sum of Years Lived with Disability (YLD) and Years of life lost (YLL) [3,7,25]. DALYs take into account the disability caused by the disease (YLD) and the premature mortality (YLL) [7]. Determining YLLs and YLDs and DALYs would allow us to measure the shortfall of the deceased and life years lost. YLLs explain the loss incurred as a result of death due to an event by comparing with the years that they would have lived otherwise. YLLs become high in case of either higher mortality or mortality of younger people or both [4]. Years of Potential Productive Life Lost (YPPLL) and Cost of Productivity Lost (CPL) are widely adopted measures that majorly explain the economic burden due to an event [11].

DALYs were calculated using an incidence based approach [3,18]. DALY estimates were obtained for age-gender split to identify the more vulnerable groups [7]. Though incidence based approaches do not consider the severity of diseases, owing to the diverse impact of COVID-19, severity was considered to assign the Disability Weights (DW) [3]. The YLDs are presented only till August 20, 2020, DALYs estimated in this study are certainly an underestimation. However, YLDs contribute only a minor share to the DALY estimates [3,7,26]. Discounting for the value of life (discount rate of 2.9%) was used in the calculation of DALYs [18]. DALYs with no discounting have also been presented in table II. DWs were chosen based on the symptoms experienced by patients and were varied based on severity of infection. Proportion of home quarantine cases were considered to be mild, whilst the proportion of hospitalized cases were further split into moderate and critical (table I). The symptoms, proportion of people experiencing each symptom, and corresponding DWs are presented in table S II [27].

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

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

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

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

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

Most of the Burden of Disease (BoD) studies do not consider multimorbidity, which might produce inaccurate estimates [25]. Three methods for calculation of Combined Disability Weights (CDW) for multimorbidity as reported by Hilderlink et al (2016) viz. additive, multiplicative and maximum limit methods, were employed in this study [25].

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

$$DW_{ij} = 1 - (1 - DW_i) * (1 - DW_j) \quad (5)$$

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

where 'i' and 'j' indicate the DWs of 'ith' and 'jth' disabilities.

Productivity Losses (YPPLL and CPL)

YPPLL defines the number of productive years an average person would have lived otherwise. Working population proportion of each cohort was multiplied with the YPPLL to estimate the CPL lost due to morbidity and absenteeism. Recovery days for the severe cases were extended by 8 days to account for the ICU stay. Productivity losses were estimated using the Human Capital Approach considering the absenteeism and premature mortality for temporary and permanent losses respectively [7,28]. For calculation of productivity losses, people from age groups 15 to 60 were chosen considering the employment age [29] and retirement age of Kerala [22]. [18,30].

$$YPPLL = \sum_{i=1}^n D_i * w_i * d \quad | \quad i = 1, 2, \dots, n \quad (7)$$

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 value of life as proposed by Reserve Bank of India (RBI) [19]. were selected [19]. These are applicable for every year excluding the first year [31]. CPL for premature mortality and absenteeism were computed as shown in eqn. (8) and (9).

$$CPL = \sum_{j=1}^J YPPLL_j * per\ capita\ GDP * P \quad (8)$$

$$CPL_{absenteeism} = \sum_{j=1}^J S * L_j * N * P \quad (9)$$

where S = average salary per day considering the number of paid working days per week as six; L_j = average recovery time; N = Number of incident cases; P = proportion of working population, in cohort 'j'. For computation of productivity losses, the proportion of working population was considered along with an extended disability period for severe cases to account for the ICU stay [20,21].

Sensitivity Analysis (SA)

A spectrum of scenarios (table 5) was considered to analyze the effect of each parameter on the DALY estimates. The key idea of performing SA is to assist policymakers to anticipate the effects brought in by each of the driving variables. As most of the deceased cases had underlying health conditions that reduce the life expectancy, Scenario 1 (S1) and Scenario 2 (S2) have been developed [4,33]. Increasing the number of mild cases, overall cases and deaths are conservative analysis to help healthcare fraternity and policymakers [3].

RESULTS

From the distribution of cases and deaths (figure S1), it is clear that the older adults are disproportionately vulnerable to be severely affected by the disease. Though the age group of 25 to 30 males and females account for 13.45% and 11.06% of the total number of cases, their Case Fatality Rates (CFR) remain as low as 0.80% and 1.17% respectively. Contrastingly, while the male and female proportion of cases for the age group 65 to 70 is only 2.11% and 2.75% of the overall cases, their CFR remain as high as 17.88% and 13.13% respectively.

DALY estimates calculated using the average DW scores using the additive method was considered as the baseline scenario for Sensitivity Analysis (SA). From table II, it is clear that the YLL are the major proportion of DALYs (Discounted), with Male and Female YLL of age group 60 to 65 cumulating to 16.58% and 16.46% respectively. Since the cohort does not fall into the productive population (considering the employment age), these might not impact the productivity losses. Considering the YLLs and DALYs in productive population, the YLLs and DALYs of Male and Female are the highest for the age group 55 to 60. Comparing the discounted and undiscounted DALYs, we see that the undiscounted DALY estimates of Male and Female are 36.02% and 44.15% higher than those of the discounted ones. Discount rate for value of life was considered as 2.90% for all the scenarios in the study [18]. Also, the DALYs per million was estimated to be 70.92 and based on the projected population of Kerala for the year 2020 which is 34,678,294 [32].

Table II: DALY estimates for the baseline scenario (S3)

Age	Life Expectancy		Discounted						Undiscounted	
	M	F	YLL		YLD (S3)		DALYs		DALYs	
			M	F	M	F	M	F	M	F
0 to 1	72.5	77.9	0.0	92.6	0.1	0.1	0.1	92.7	1.7	235.3
1 to 5	72.3	77.8	0.0	0.0	0.4	0.4	0.4	0.4	8.1	7.8
5 to 10	68.4	73.9	0.0	0.0	0.3	0.3	0.3	0.3	8.6	7.5
10 to 15	63.4	69.0	58.0	29.8	0.4	0.3	58.4	30.1	136.8	76.6
15 to 20	58.6	64.1	56.4	58.2	0.6	0.4	57.0	58.6	133.4	138.9
20 to 25	53.7	59.2	136.1	113.2	1.2	0.7	137.3	113.8	301.3	254.9
25 to 30	48.9	54.4	261.3	191.5	1.4	0.6	262.7	192.2	528.0	398.5

30 to 35	44.2	49.5	124.6	131.4	1.4	0.6	126.0	132.0	258.5	263.7
35 to 40	39.5	44.7	634.9	350.7	1.3	0.5	636.2	351.3	1100.8	640.5
40 to 45	34.8	39.9	898.5	189.1	1.3	0.6	899.7	189.7	1457.1	333.8
45 to 50	30.3	35.1	1149.2	506.5	1.0	0.5	1150.2	507.0	1753.8	821.5
50 to 55	25.9	30.5	1602.7	951.5	1.0	0.5	1603.7	952.0	2303.6	1446.4
55 to 60	21.8	26.2	2342.9	1413.2	0.6	0.4	2343.5	1413.5	3176.5	2027.1
60 to 65	17.9	21.9	2639.1	1426.6	0.4	0.3	2639.5	1426.8	3394.6	1934.7
65 to 70	14.3	17.9	2610.3	1089.2	0.5	0.3	2610.8	1089.5	3197.7	1402.5
70 to 75	11.4	14.3	1669.6	983.3	0.2	0.1	1669.8	983.4	1964.6	1204.5
75 to 80	8.6	11.0	898.2	508.6	0.0	0.0	898.2	508.6	1016.3	595.3
80 to 85	6.2	7.9	556.1	430.7	0.0	0.1	556.2	430.7	608.8	483.2
85+	4.5	5.6	274.2	196.4	0.0	0.0	274.3	196.5	293.3	213.8
Total			15912.0	8662.4	12.2	6.9	15924.2	8669.3	21643.5	12486.6

Figure S2 a) to i) show that on the whole, the DALYs for Male are higher than those of Female except for the age groups 30 to 35, 15 to 20 and less than 10. About 47.69% and 45.34% of overall DALYs for Male and Female respectively are from the age groups 55 to 70. It is highly disproportionate as the number of cases from these age groups pile up to only 11.13% and 13.11% of cases for Male and Female respectively. Figure S2 presents the DALYs calculated for the nine different scenarios (refer Table S III) that involve altering the DW calculation methods and values.

To measure the impact of the disease on productivity of the state, YPPLL and CPL were calculated considering the productive age group to be 15-60 years. It is to be noted that the age groups 25-49 comprise of more working population, which makes them higher contributors of productivity. Fortunately, there is a relatively lesser impact of the infection in terms of prolonged illness and mortality for these age groups which has reduced the losses to some extent. Recovery days mentioned in table S III are exclusive of the ICU stay of severe cases.

Table III shows that the CPL values for people aged from 40-49 years are the highest. They constitute about 51.34% and 41.76% of the total CPL values (for premature mortality) of males and females respectively. CPL values for absenteeism are also the highest for the same age cohort for both male and females accounting up to 26.53% and 31.35% respectively.

Table III: YPPLL, CPL (Mortality and Absenteeism)

Age-Group	Years of Potential Productive Life Lost (YPPLL)		Cost of Productivity Lost (CPL) – Death		Cost of Productivity Lost (CPL) - Morbidity	
	Males	Females	Males	Females	Males	Females
15-19	8.02	16.04	203,230.97	146,399.18	1,215,349.26	301,009.73

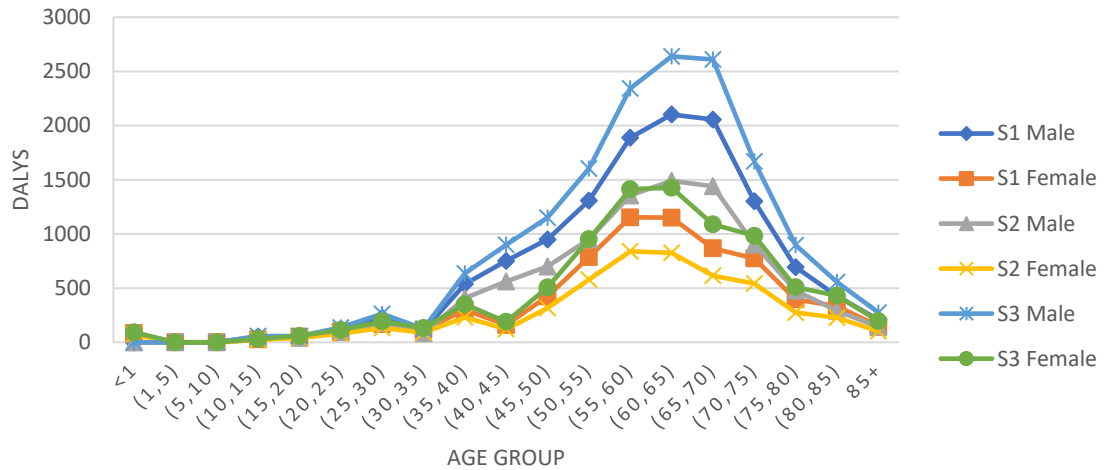
20-24	43.05	25.83	5,089,908.73	863,444.24	12,817,591.45	2,090,146.78
25-29	81.38	54.25	15,633,255.66	2,718,236.03	26,934,024.69	2,864,326.02
30-34	46.07	46.07	9,697,061.65	2,982,038.11	29,762,687.88	3,758,612.46
35-39	197.61	107.79	42,390,802.14	8,762,156.96	26,875,084.33	3,808,862.12
40-49	646.28	215.43	137,633,339.93	17,752,593.13	45,649,032.90	8,479,890.63
50-59	301.17	146.91	57,388,580.03	9,286,078.68	28,756,970.67	5,759,090.26
Total			268,036,179.11	42,510,946.33	172,010,741.18	27,061,938.00

SENSITIVITY ANALYSIS (SA)

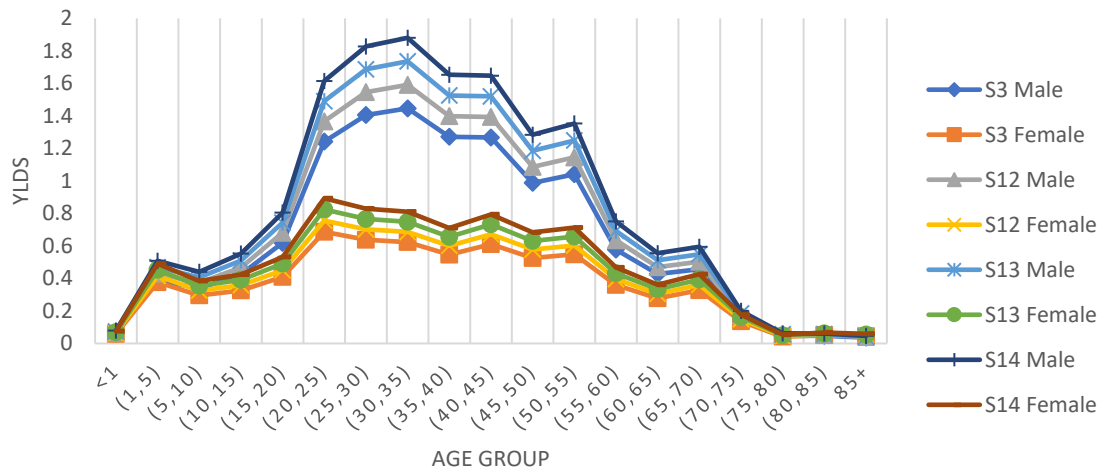
Figure 1 f) provides the comparison of the DALY estimates across all the scenarios, grouped based on the variable adjusted to provide a better interpretation of the changes.

Figure 1 a) to e) presents SA to explain the role of each variable to economic burden. From figure 1 a) it is evident that the reduction in life expectancy by 25% and 50% reduced the DALYs by 19.72% and 42.51% for males and 18.75% and 41.02% for females respectively. For figures 1 b), c) and e), only YLDs were compared as the variables adjusted in these scenarios do not alter the YLLs. Comparing the DALY estimates might not explain the effect of variables clearly. For figures 1 a) and d), the DALY estimates were directly compared. Increasing the overall cases by 10%, 20% and 30% increased the YLDs proportionately equal to the percentage increase in the number of cases. Increase in the mild cases by 10%, 20% and 30% increased the YLDs by 9.15%, 18.31% and 27.46% respectively for both male and female cohorts. Increase in deaths by 10%, 20% and 30% increased the DALYs by 9.91%, 19.91% and 29.9% respectively for both male and female cohorts. Increase of burden of isolation of two weeks increased the YLDs from 12.24 to 48.01 for males and from 6.88 to 26.74 for females.

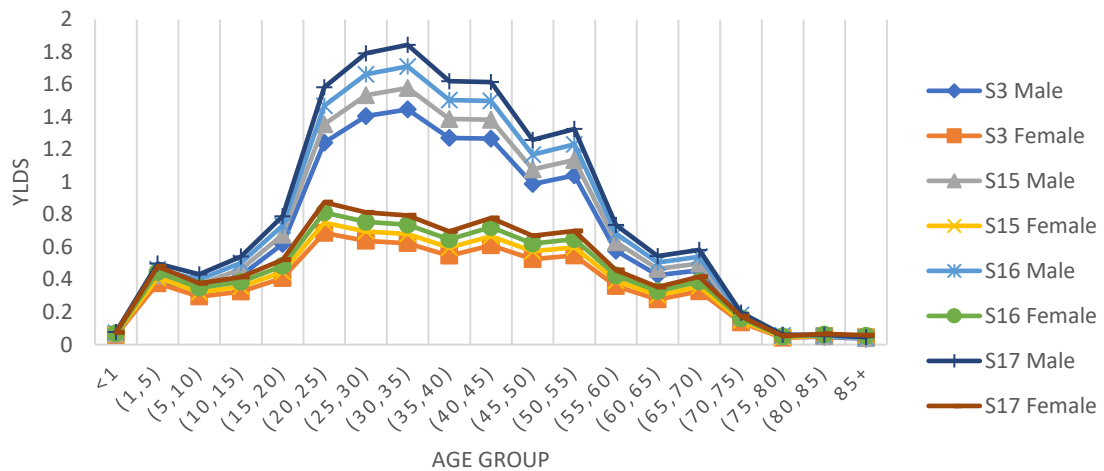
a) Effect of life expectancy on DALYs



b) Effect of increase in cases on YLDs



c) Effect of mild cases on YLDs



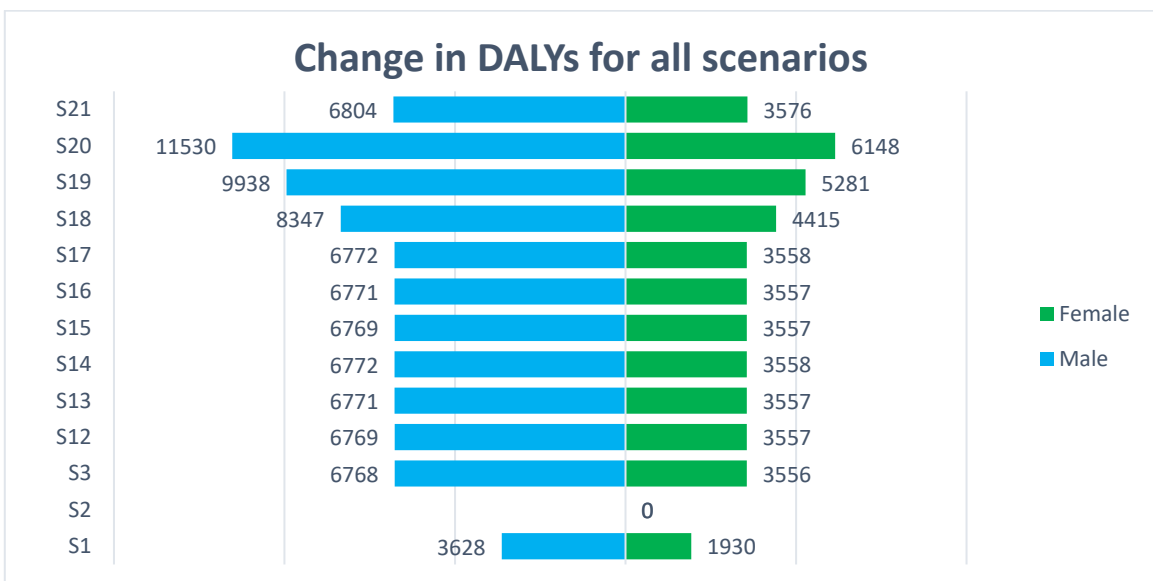
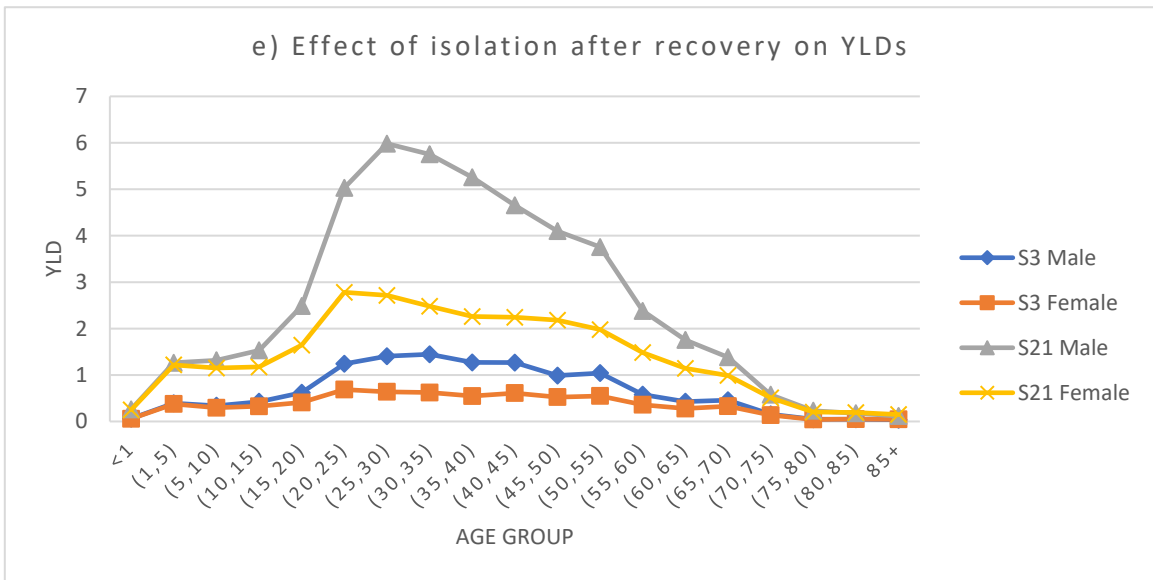
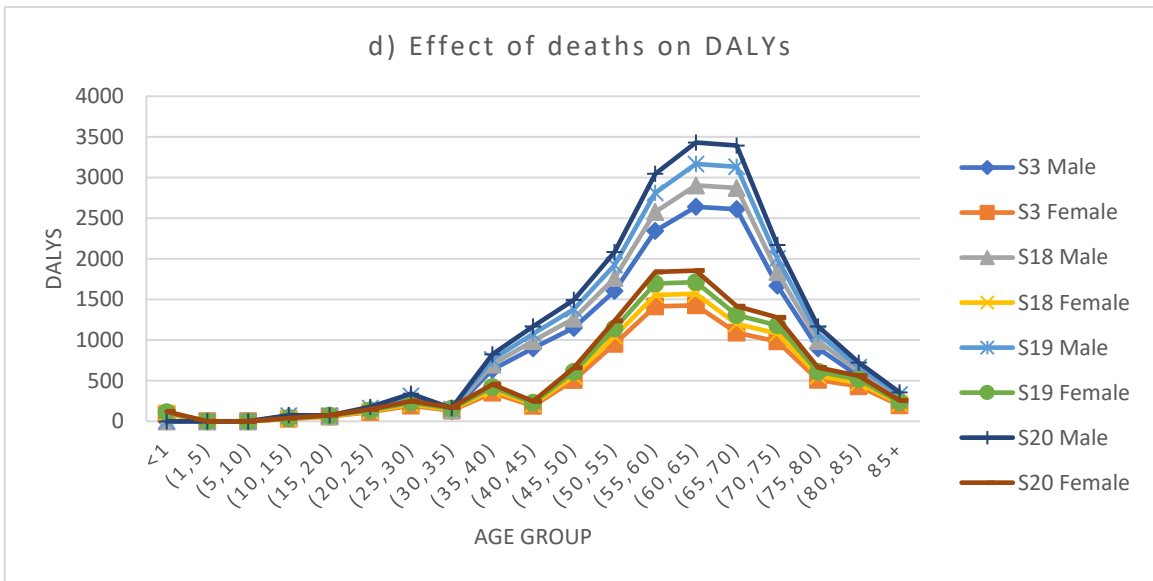


Figure 1: a) Effect of life expectancy on DALYs; b) Effect of increase in cases on YLDs; c) Effect of mild cases on YLDs; d) Effect of deaths on DALYs; e) Effect of isolation after recovery on YLDs; f) Change in DALYs for all scenarios

Three different approaches for average, lower and upper limit values of DW have been used to arrive at YLDs. DALYs are seen to be the highest when the number of deaths is altered. The DALYs increase by 29.9% from that of S3 for both the cohorts when the number of deaths increase by 30%. These values would be still higher if the mortality among younger cohorts are higher owing to their longer life expectancy during the age of death.

DISCUSSION

Main finding of this study

In this study, for the baseline scenario, YLLs were 15912.01 and 8662.44 whilst the YLDs were 12.24 and 6.88 for male and female respectively. DALYs per million was estimated as 70.92 based on the population projected for the year 2020 [32]. The DALYs will be impacted by the quality of the data reported. Based on a article published by the BBC, deaths due to COVID-19 as estimated by the volunteers are 3,356 which is 70.44% higher than the officially reported count 1969 as on November 19, 2020 [9,34]. Considering the effect of asymptomatic cases that act as latent spreaders , DWs due to presenteeism, and unpaid work could increase the losses [35]. These facts are concerning as the actual DALYs might be way higher than those estimated using official figures.

In addition, the productivity losses in terms of YPPLL and CPL for mortality and absenteeism for the productive population (15 to 60 years of age) were estimated. Multimorbidity was taken into account for the calculation of CDW. CPL values (for premature mortality) for younger population less than 25 years of age just 1.97% and 2.37% for male and female respectively. This is because of the lesser proportion of people working in this age group and also lesser impact of the disease in terms of mortality. Considering the CPL due to absenteeism, the values for younger people less than 25 years of age are 8.16% and 8.83% for male and female respectively. This is higher compared to that of the deaths because of relatively lower proportion of people dying due to infection.

What is already known on this topic

Several researchers have been conducting researches to estimate the economic burden and productivity losses of various diseases around the globe such as the estimation of YLLs due to COVID-19 in the US [4], India [26] & Swiss [5], DALYs due to COVID-19 in Korea [3]& Italy [7], YPPLL due to Cancer in Brazil, Russia, India, China, and South Africa (BRICS) [36], YPPLL due to five leading causes of deaths in Iran [11], productivity loss due to Cardiovascular disease and mental illness in India [35], etc.

COVID-19 has created a significant impact around the globe, some of which include 1.2 million YLLs in the US from 1 Feb, 2020 to 11 July, 2020 [4]; 2 million YLL in India as on October 17, 2020 [26]; 1.75 million YLLs due to mass confinement of 3 months in Switzerland [5]; 2531 DALYs in Korea between January 20, 2020 and April 24, 2020 with YLLs and YLDs constituting 89.7% and 10.3% respectively [3]; and 121449 DALYs, productivity losses of EUR 300 million and EUR 100 million due to premature mortality and absenteeism respectively, in Italy [7].

What this study adds

As evident from this study, the disease has impacted the older population to a greater extent. The proportion of cases for the age group 65 to 70 in Kerala is only 2.11% and 2.75% of the overall cases whilst their deaths remain as high as 17.88% and 13.13%. Other studies reveal a similar trend of the disease which provides strong insights for more care to be given to the elderly. Indrayan and Mishra (2020) found that the relative incidence of younger age group (<20) was only 1/3 (12:36)% whereas those of adults aged more than 60 and between 50 to 59 were 1.5 (8:12)% and 1.88 (14.5:7.7)% respectively [26]. This trend prevails even outside the country as Garg et al (2020) concluded that out of 1482 hospitalized patients from March 1 to 28, 2020, across 14 states of the US, 3/4 were aged 50 or more [27].

SA has been vastly adopted by the researchers to depict the influence of one or more variables on the outcome(s) [3,4]. A total of 21 scenarios by adjusting six variables were analyzed in the study. The increase in number of deaths highly increased the DALYs whereas the reduction in life expectancy reduced the DALYs. Reducing life expectancy could be related to practical findings of researchers. Majority of the older patients have had underlying medical conditions such as pneumonia (68.8%), hypertension (34.4%), diabetes mellitus (50%) and chronic obstructive airway disease (15.6%) [37], 89.3% of the older adults (65 or more) contained comorbidities [27].

Limitations of this study

Exclusion of incidence of cases post August 20, 2020 for estimation of DALYs due to unavailability of open data has led to a certain underestimation. Also, psychological impacts of the mitigation strategies are a potential risk that could increase mortality and are not in the scope of present study [5]. Most of the policies have not considered the mental illness and allied problems [5,38,39]. Though YLDs contribute a minor proportion in DALY, including factors such as unpaid work and presenteeism might improve the accuracy. In Kerala, about 30 and 10 percent of recovered patients have experienced post recovery illness and long-term effects, which have not been considered in the study [40].

CONCLUSION

The present study aimed at analyzing the economic burden and productivity losses using common estimates such as DALYs (YLLs and YLDs), YPPLL and CPL (for mortality and absenteeism) for Kerala, India. Public domain data from various resources were merged to form the age-gender cohort data required to calculate the above-mentioned. The study could be integrated with simulation models to project the economic burden and productivity loss using the estimates of simulation [41].

DATA AVAILABILITY STATEMENTS

All data are incorporated into the article and are openly available from the references mentioned.

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DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

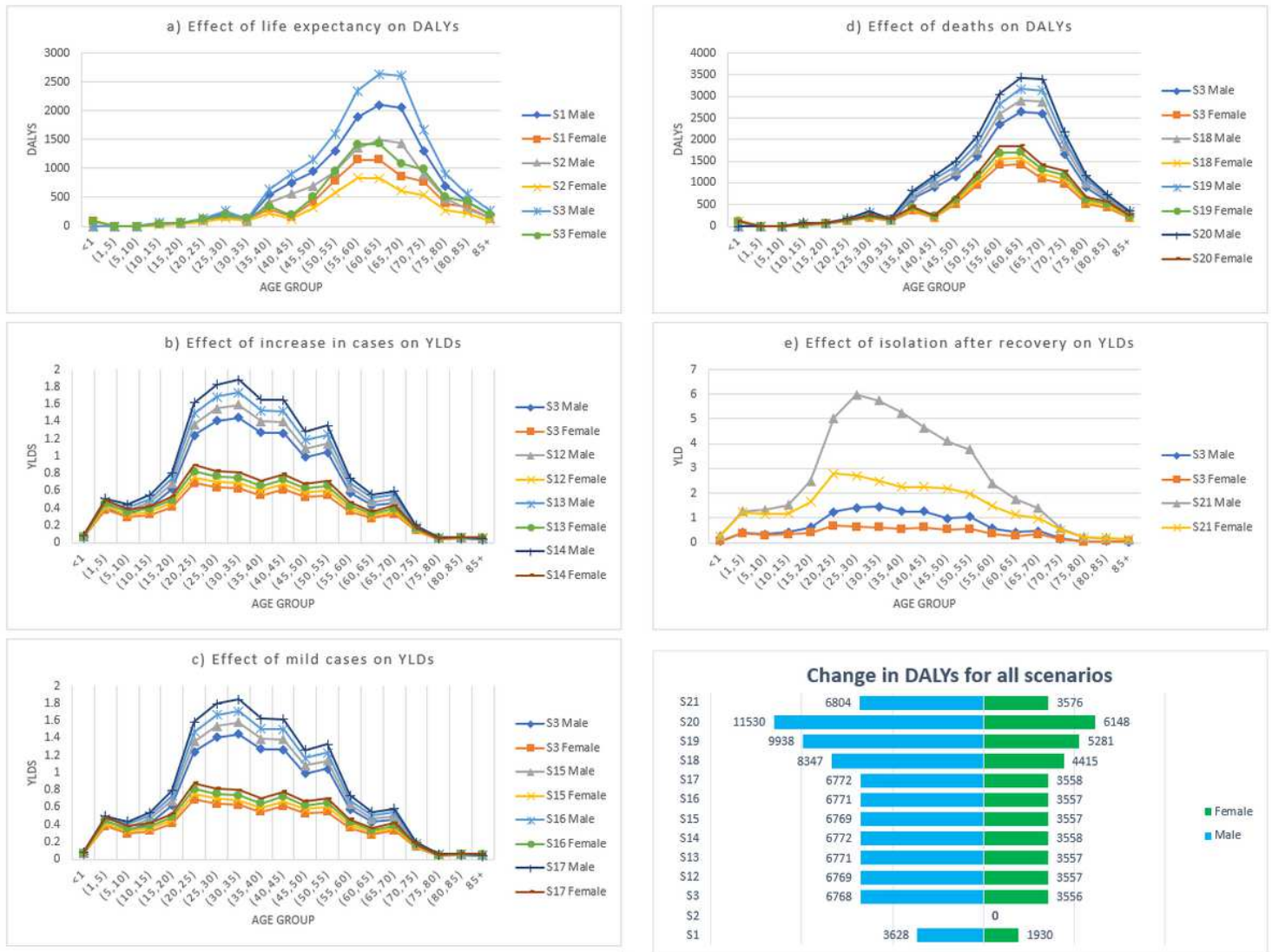


Figure 1

a) Effect of life expectancy on DALYs; b) Effect of increase in cases on 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

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