

Years of Potential Life Lost Due to COVID-19 in Sonora, Mexico: A Cross-Sectional Study on Premature Mortality

Años de Vida Potencial Perdidos por COVID-19 en Sonora, México: Estudio Transversal sobre Mortalidad Prematura

Diego I. Álvarez-López¹, Elizabeth Ferreira-Guerrero², Miguel A. García-Salcido³, Jorge Laureano-Eugenio⁴, Maria del Carmen Candia-Plata⁵, and Gerardo Álvarez-Hernández^{5*}

¹ Department of Population and Public Health Sciences, Keck School of Medicine, University of Southern California, Los Angeles, California, United States.

² Centro de Investigación sobre Enfermedades Infecciosas, Instituto Nacional de Salud Pública, Cuernavaca, Morelos, México.

³ Comisión Coordinadora de Institutos Nacionales de Salud y Hospitales de Alta Especialidad, Secretaría de Salud, Ciudad de México, México.

⁴ Subsecretaría de Servicios de Salud Colectiva, Secretaría de Salud Pública del Estado de Sonora, Hermosillo, México.

⁵ Departamento de Medicina y Ciencias de la Salud, Universidad de Sonora, Hermosillo, México.

ABSTRACT

Background: Estimating years of potential life lost (YPLL) emphasizes causes of death that disproportionately affect younger populations, contributing to a more comprehensive understanding of the COVID-19 pandemic burden. This study estimated the YPLL due to COVID-19 in the state of Sonora, Mexico, from 2020 to 2022. **Methods:** We conducted an observational, cross-sectional study using mortality data from 2020 to 2022. YPLL was estimated following the methodology of the Global Burden of Disease (GBD) Study. Results were stratified by selected sociodemographic characteristics. **Results:** A total of 12,021 COVID-19 deaths were recorded in Sonora, resulting in 171,173.25 YPLL. Men experienced higher YPLL than women across most age groups. Adults aged 55–69 accounted for 39.0 % of total YPLL. Among individuals aged ≤40 years, YPLL rose from 6,889 in 2020 (7.7 %) to 7,742 in 2021 (11.5 %). Higher average YPLL was observed among individuals with partners (15.10), without entitlement to health services (15.3), with high school education (17.69) and those residing in urban areas (14.33). **Conclusion:** These findings underscore the value of YPLL estimation in capturing premature mortality that traditional death counts may overlook. This approach offers a more nuanced understanding of the pandemic's impact and supports the need for more equitable and targeted public health interventions, particularly in regional contexts such as northwestern Mexico.

Keywords: Years of potential life lost; Premature mortality; Disease burden; COVID-19; Mexico.

RESUMEN:

Antecedentes: La estimación de los Años de Vida Potencial Perdidos (AVPP) permite identificar causas de muerte que afectan de manera desproporcionada a poblaciones más jóvenes, contribuyendo a una comprensión más integral de la carga de la pandemia por COVID-19. Este estudio estimó los AVPP atribuibles a COVID-19 en el estado de Sonora,

México, durante el periodo 2020–2022. **Métodos:** Se realizó un estudio observacional transversal utilizando datos de mortalidad de 2020 a 2022. Los AVPP se calcularon siguiendo la metodología del Estudio de Carga Global de Enfermedad (GBD, por sus siglas en inglés). Los resultados se estratificaron según características sociodemográficas seleccionadas. **Resultados:** Se registraron 12,021 defunciones por COVID-19 en Sonora, que generaron un total de 171,173.25 AVPP. Los hombres presentaron mayores AVPP que las mujeres en la mayoría de los grupos de edad. Los adultos de 55–69 años concentraron el 39.0 % del total de AVPP. En personas ≤40 años, los AVPP aumentaron de 6,889 en 2020 (7.7 %) a 7,742 en 2021 (11.5 %). Se observaron mayores promedios de AVPP en individuos con pareja (15.10), sin derechohabiente (15.3), con educación media superior (17.69) y residentes en áreas urbanas (14.33). **Conclusión:** Estos hallazgos destacan la utilidad de estimar AVPP para captar la mortalidad prematura que las métricas tradicionales pueden pasar por alto. Este enfoque ofrece una mejor comprensión del impacto de la pandemia y respalda la necesidad de intervenciones de salud pública más equitativas y focalizadas, especialmente en contextos regionales como el noroeste de México.

Palabras clave: Años de vida potencial perdidos; Mortalidad prematura; Carga de enfermedad; COVID-19; México.

INTRODUCTION

The COVID-19 pandemic, one of the most consequential public health crises in modern history, has been widely assessed using standard epidemiological indicators, such as incidence, case-fatality (CF), and mortality rates (MR) (Pitlik, 2020). While these measures offer valuable insights into the scope of a disease, they fall short in capturing its full societal impact. Because the majority of COVID-19 deaths during the pandemic occurred among adults aged 65 and older (WHO, 2025), conventional methods of mortality analysis are unlikely to reflect the broader population-level burden of the pandemic (Mittra *et al.*, 2020).

*Author for correspondence: Gerardo Álvarez-Hernández
e-mail: gerardo.alvarez@unison.mx

Received: November 7, 2025

Accepted: January 27, 2026

Published: March 3, 2026

Premature deaths, those occurring before the average age of death in a given population (National Cancer Institute, 2025), impose a significant burden across social, economic and public health domains. Among the several metrics developed to quantify premature mortality, Years of Potential Life Lost (YPLL), is one of the most widely used (Gardner y Sanborn, 1990). YPLL prioritizes deaths occurring at younger ages by assigning greater weight to them, under the assumption that these represent a greater loss to society in terms of productivity, family life, and community contribution. While different methods have been proposed for its estimation, they all involve identifying the number of deaths at each age and the corresponding expected remaining years of life (Romed y McWhinnie, 1977). This measure has been widely adopted to assess the burden of infectious and non-communicable diseases and is particularly useful for identifying health inequities and guiding resource allocation (Foreman *et al.*, 2018).

Estimates of YPLL due to COVID-19 have contributed to a better understanding of the disease burden, mainly in country-specific and international contexts (Mitra *et al.*, 2020; Islam *et al.*, 2021; Chan *et al.*, 2021; Rommel *et al.*, 2021; Quast *et al.*, 2022). Although less common, local-level assessments have revealed important disparities in premature mortality across specific sociodemographic groups, as well as the economic impact of the lives lost during the pandemic (Lilly *et al.*, 2021; Pierce *et al.*, 2021; Zheng *et al.*, 2022). During a public health crisis, such local insights are crucial for recommending targeted interventions and optimizing resource allocation in response to the unequal burden of premature mortality across populations.

In this context, we conducted a population-based study to estimate YPLL due to COVID-19 in the state of Sonora, located in northwestern Mexico, from 2020 to 2022. Specifically, we sought to estimate the total burden and variations of premature mortality due to COVID-19 by year, age group, sex, and key sociodemographic characteristics. This study aimed to improve understanding of the pandemic's impact in Sonora and to identify disparities that can help inform future public health planning and targeted interventions.

METHODS

Study design

An observational, cross-sectional study was conducted based on secondary data analysis.

Data source and collection

Data were obtained from the Epidemiological and Statistical Subsystem of Deaths (SEED), a nationwide digital platform managed by the Sonora State Health Services. SEED compiles preliminary data from death certificates using an active epidemiological surveillance approach. It includes: (a) information about the deceased and the cause(s) of death; (b) details on accidental and violent deaths; and (c) data on the informant, certifier, and civil registry. This system supports periodic mortality characterization and real-time public

health decision-making (Gobierno de México, 2025a).

The study period spanned from March 1, 2020, through December 31, 2022. All deaths attributable to COVID-19 among individuals of any age and sex residing in Sonora were included. COVID-19 deaths were defined as those with an underlying cause coded as "COVID-19, virus identified" (U07.1) or "COVID-19, virus not identified" (U07.2), according to the International Classification of Diseases, 10th Revision (ICD-10) (WHO, 2019a). Records with insufficient data on residence or poor-quality coding were excluded.

Measurement and variables

COVID-19 mortality was characterized using frequencies and percentages, stratified by: sex, age group (in 5 and 10-year age categories), health district of residence, municipal level of social marginalization according to the National Population Council (Gobierno de México, 2020), type of locality (urban vs rural, cutoff: 2,500 inhabitants), indigenous language speaker status, marital status, educational attainment, health service entitlement, and occupation.

YPLL estimation

Years of Potential Life Lost (YPLL) were estimated following the Global Burden of Disease (GBD) methodology (Institute for Health Metrics, 2024). Deaths were grouped into 19 age intervals: 17 five-year groups (1–4 to 80–84), plus <1 year and ≥85 years. Standard life expectancy values for each age group were obtained from WHO's 2019 life tables for Mexico (WHO, 2019b). For deaths occurring within an age interval x to $x + n$, the crude estimation of YPLL was calculated using:

$${}_nY_x = ({}_nD_x) ({}_ne_x^s)$$

where ${}_nD_x$ is the number of deaths recorded in the age interval x to $x + n$, and ${}_ne_x^s$ is the standard life expectancy for that interval. A 3% annual time discount rate was applied to crude YPLL estimates, as per GBD methodology (Institute for Health Metrics, 2024). Final YPLL values were stratified by the sociodemographic variables listed above.

Statistical Analyses

All analyses and visualizations were performed using R software (version 4.2.2) and Microsoft Excel. The R package 'yll', developed by Antoine Soetewey and based on methods by Aragón *et al.* (2008) was used to compute standardized YPLL.

RESULTS

As of December 31, 2022, a total of 12,021 COVID-19 deaths were registered in Sonora. Of these, 51.8 % (6,227) occurred in 2020. Most deaths were among men (57.2 %) and individuals aged 60 years and older (68.6 %). Notably, one in four deaths occurred in the 60–69 age group, which contributed the most to the overall mortality burden. Regarding education and employment, two-thirds of deaths were among individuals with at most a secondary education, and 54.4 %

occurred among those unemployed or engaged in unpaid work (Table 1).

During the study period, COVID-19 accounted for a total of 171,173.25 YPLL in Sonora, with an average of 14.2 years

lost per death. Of the total YPLL, 55.0 % occurred in 2020 (90,006 years), while by 2022 the proportion had declined to 8.2 % (14,013 years). To further characterize the impact of the pandemic, we analyzed the distribution of YPLL by sex

Table 1. Sociodemographic characteristics of COVID-19 deaths, Sonora, Mexico, 2020-2022

Tabla 1. Características sociodemográficas de muertes por COVID-19, Sonora, México, 2020-2022

Characteristic	2020 N= 6227 (%)	2021 N= 4663 (%)	2022 N= 1131 (%)
Gender			
Male	3625/6221 (58.27)	2596/4657 (55.74)	656 (58.00)
Female	2596/6221 (41.73)	2061/4657 (44.26)	475 (42.00)
Age group (years)			
0-9	1 (0.02)	9 (0.19)	2 (0.18)
10-19	6 (0.10)	14 (0.30)	4 (0.35)
20-29	64 (1.03)	66 (1.42)	9 (0.80)
30-39	203 (3.26)	214 (4.59)	19 (1.68)
40-49	605 (9.72)	454 (9.74)	70 (6.19)
50-59	1154 (18.53)	752 (16.13)	126 (11.14)
60-69	1663 (26.71)	1185 (25.41)	249 (22.02)
70-79	1520 (24.41)	1098 (23.55)	316 (27.94)
80+	1011 (16.24)	871 (18.68)	336 (29.71)
Health District			
Hermosillo (I)	2194/6225 (35.24)	1564 (33.54)	400 (35.37)
Caborca (II)	190/6225 (3.05)	125 (2.68)	43 (3.80)
Santa Ana (III)	1050/6225 (16.87)	472 (10.12)	118 (10.43)
Ciudad Obregón (IV)	1674/6225 (26.89)	1436 (30.80)	276 (24.40)
Navojoa (V)	541/6225 (8.69)	710 (15.23)	189 (16.71)
San Luis Río Colorado (VI)	576/6225 (9.25)	356 (7.63)	195 (9.28)
Municipal Marginalization Level			
Very low	5833/6225 (93.70)	4127 (88.51)	995 (87.98)
Low	365/6225 (5.86)	450 (9.65)	111 (9.81)
Moderate	24/6225 (0.39)	74 (1.59)	22 (1.95)
High	3/6225 (0.05)	12 (0.26)	3 (0.27)
Type of locality			
Urban	5432/6143 (88.43)	4002/4632 (86.40)	940/1128 (83.33)
Rural	711/6143 (11.57)	630/4632 (13.60)	188/1128 (16.67)
Speaker of an Indigenous Language			
Yes	189/5767 (3.28)	197/4364 (4.51)	56/1050 (5.33)
No	5578/5767 (96.72)	4167/4364 (95.49)	994/1050 (94.67)
Marital status			
Lives with a partner	3449 (55.39)	2430 (52.11)	503 (44.7)
Lives without a partner	2051 (32.94)	1595 (34.21)	513 (45.36)
Not applicable (<12 years old)	4 (0.06)	9 (0.19)	4 (0.35)
Unknown	723 (11.61)	629 (13.49)	111 (9.81)
Educational Attainment			
No formal education	376 (6.04)	313 (6.71)	114 (10.08)
Preschool	10 (0.16)	6 (0.13)	1 (0.09)
Primary school	2391 (38.40)	1856 (39.80)	542 (47.92)
Secondary school	1336 (21.45)	991 (21.25)	197 (17.42)
High school	743 (11.93)	549 (11.77)	91 (8.05)
University degree or higher	862 (13.84)	631 (13.53)	123 (10.88)
Not applicable (<4 years old)	1 (0.02)	5 (0.11)	1 (0.09)
Unknown	508 (8.16)	312 (6.69)	62 (5.48)
Entitlement to health services			
Yes	4827 (77.52)	3526 (75.62)	829 (73.30)
No	1088 (17.47)	864 (18.53)	241 (21.31)
Unknown	312 (5.01)	273 (5.85)	61 (5.39)
Occupation (Economic Sector)			
Primary	305 (4.90)	249 (5.34)	90 (7.96)
Secondary	318 (5.11)	231 (4.95)	50 (4.42)
Tertiary	1242 (19.95)	826 (17.71)	147 (13.00)
Unspecified	1152 (18.50)	706 (15.14)	151 (13.35)
Not employed	1495 (24.01)	1240 (26.59)	345 (30.50)
Unpaid workers	1712 (27.49)	1402 (30.07)	345 (30.50)
Not applicable	3 (0.05)	9 (0.19)	3 (0.27)

and age group. In most age categories, men experienced higher YPLL than women, except in the <1, 5–9, and 15–19 age groups. Adults aged 55–69 contributed 39.0 % of total YPLL, making them the most affected group. Among men, the 65–69 age category represented the largest percentage of YPLL (13.6 % of male YPLL), whereas among women, the 60–64 stratum contributed the most (13.6 % of female YPLL) (Table 2, Figure 1). These sex-specific differences in YPLL, beyond reflecting the higher number of male deaths, help identifying demographic subgroups with disproportionate premature mortality, which is essential for guiding targeted public health responses for this disease.

Significant annual variations in YPLL were observed across age groups. In 2020, individuals under 40 years of age accounted for 6,889 YPLL, 7.7 % of that year's total, increasing to 7,742 YPLL (11.5 %) in 2021—a 3.9 % proportional rise ($p < 0.05$). Although total deaths were higher in 2020, seven age groups (1–4, to 35–39 years) recorded more unadjusted YPLL in 2021. In contrast, the proportion of YPLL from adults aged 60 and older declined slightly but significantly from 53.6 % in 2020 to 52.5 % in 2021 ($p < 0.05$) (Table 3).

Sociodemographic analysis revealed differences in average YPLL across subgroups. Individuals living with a partner lost an average 15.1 years, compared to an average of 12.9 years among those without a partner. By educational attainment, those with no formal education had the lowest average YPLL (10.9 years), while individuals with a high school had the highest (17.7 years). Among occupational groups, unemployed individuals—despite accounting for one-quarter of COVID-19 deaths—had the lowest average

YPLL (11.8 years). Those with entitlement to health services contributed the highest total YPLL but had a lower average per death (13.9 years) compared to the uninsured (15.3 years). Urban residents lost an average 14.3 years, slightly more than rural residents (13.6) (Figure 2).

DISCUSSION

The COVID-19 pandemic has been one of the most devastating public health crises in recent history, with substantial impacts globally (Msemburi *et al.*, 2023) and in regions such as Sonora, Mexico (Comisión Independiente de Investigación sobre la Pandemia de COVID-19 en México, 2025). This study identified disparities in the pandemic's impact across population groups and revealed that the mortality burden among younger individuals was greater than previously documented (Islam *et al.*, 2021; Chan *et al.*, 2021; Msemburi *et al.*, 2023).

During the study period, the 12,021 COVID-19 deaths recorded in Sonora resulted in a total of 171,173.25 YPLL. On average, each death represented a loss of 14.2 years. Despite methodological differences in YPLL estimation, our findings indicate a lower average loss compared to the national estimate of 19.9 YPLL per death (Jiang *et al.*, 2022). The average YPLL per death in Sonora was comparable to that reported in countries such as the United States (13.4), Israel (13.9), Argentina (14.6), and China (14.8) (Jiang *et al.*, 2022).

Individuals aged 45 to 69 accounted for 57.7% of total YPLL, a pattern consistent with national (Salinas-Escudero *et al.*, 2021) and international data (Ugarte *et al.*, 2022). Temporal analysis revealed a marked increase in YPLL among individuals under 40 years in 2021, based on mortality data from

Table 2. Years of Potential Life Lost (YPLL) due to COVID-19 by sex and age group, Sonora, Mexico, 2020-2022.

Tabla 2. Años Potenciales de Vida Perdidos por COVID-19, según sexo y grupo de edad, Sonora, México, 2020-2022.

Age group (years)	Males		Females		Overall	
	Deaths (%)	YPLL (%)	Deaths (%)	YPLL (%)	Deaths (%)	YPLL (%)
<1	1 (0.01)	29.62 (0.03)	1 (0.02)	30.20 (0.04)	2 (0.02)	59.85 (0.03)
1-4	5 (0.07)	148.08 (0.16)	2 (0.04)	60.39 (0.08)	7 (0.06)	209.43 (0.12)
5-9	1 (0.01)	29.16 (0.03)	2 (0.04)	59.62 (0.08)	3 (0.02)	88.50 (0.05)
10-14	4 (0.06)	113.99 (0.12)	1 (0.02)	29.25 (0.04)	5 (0.04)	144.46 (0.08)
15-19	6 (0.09)	166.40 (0.18)	13 (0.25)	371.76 (0.49)	19 (0.16)	535.54 (0.31)
20-24	25 (0.36)	672.04 (0.71)	21 (0.41)	584.88 (0.78)	46 (0.38)	1259.97 (0.74)
25-29	48 (0.70)	1245.02 (1.32)	43 (0.84)	1160.77 (1.54)	92 (0.77)	2437.53 (1.42)
30-34	110 (1.60)	2735.87 (2.90)	75 (1.46)	1950.48 (2.59)	185 (1.54)	4712.17 (2.75)
35-39	145 (2.11)	3430.30 (3.64)	104 (2.03)	2586.38 (3.44)	250 (2.08)	6074.24 (3.55)
40-44	261 (3.80)	5818.18 (6.18)	187 (3.64)	4407.55 (5.86)	449 (3.74)	10311.74 (6.02)
45-49	391 (5.69)	8123.16 (8.62)	283 (5.51)	6254.71 (8.32)	676 (5.62)	14516.88 (8.48)
50-54	524 (7.62)	10000.41 (10.61)	357 (6.96)	7299.62 (9.71)	883 (7.35)	17488.15 (10.22)
55-59	659 (9.58)	11373.32 (12.07)	487 (9.49)	9070.06 (12.06)	1147 (9.54)	20622.61 (12.05)
60-64	835 (12.14)	12785.50 (13.57)	616 (12.00)	10252.83 (13.63)	1452 (12.08)	23264.03 (13.59)
65-69	965 (14.03)	12786.88 (13.57)	672 (13.09)	9766.39 (12.99)	1637 (13.62)	22815.70 (13.33)
70-74	843 (12.26)	9447.70 (10.03)	659 (12.84)	8143.77 (10.83)	1504 (12.51)	17790.70 (10.39)
75-79	811 (11.79)	7381.50 (7.83)	619 (12.06)	6263.83 (8.33)	1431 (11.90)	13816.39 (8.07)
80-84	640 (9.31)	4556.97 (4.84)	485 (9.45)	3847.56 (5.12)	1125 (9.36)	8527.68 (4.98)
85+	603 (8.77)	3371.40 (3.58)	505 (9.84)	3056.88 (4.07)	1108 (9.22)	6497.69 (3.80)
Total	6877	94215.49	5132	75196.92	12009	171173.25

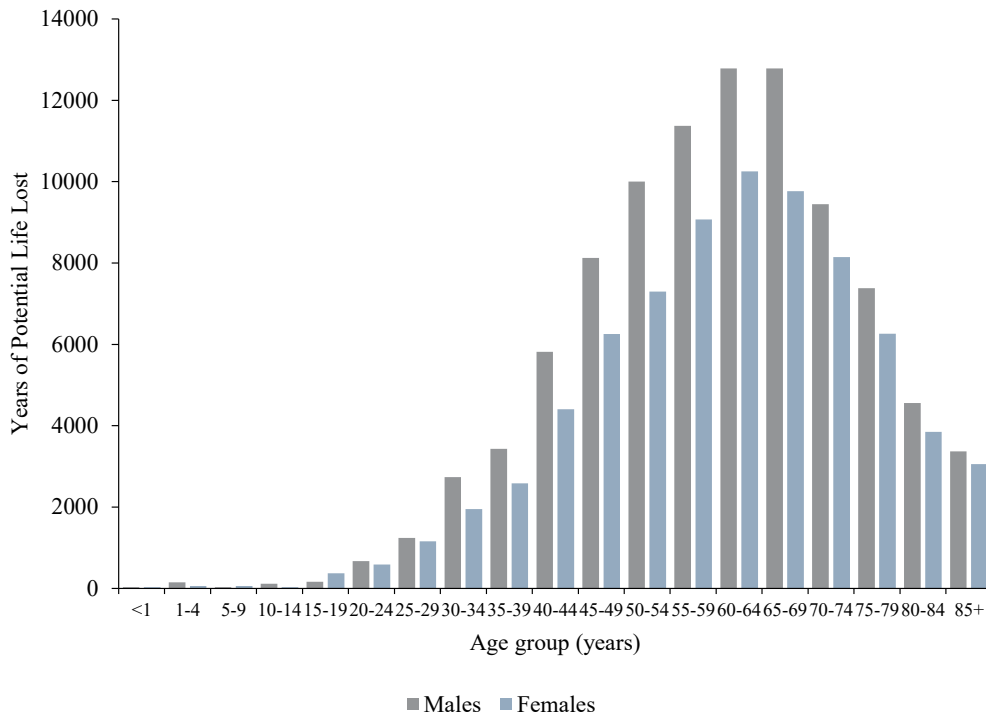


Figure 1. Years of Potential Life Lost (YPLL) due to COVID-19 by sex and age group, Sonora, Mexico, 2020-2022.

Figure 1. Años Potenciales de Vida Perdidos por COVID-19, según sexo y grupo de edad, Sonora, México, 2020-2022.

Table 3. Years of Potential Life Lost (YPLL) due to COVID-19 by year of occurrence and age group, Sonora, Mexico, 2020-2022
 Tabla 3. Años Potenciales de Vida Perdidos por COVID-19, según año de ocurrencia y grupo de edad, Sonora, México, 2020-2022

Age group (years)	2020		2021		2022	
	Deaths (%)	YPLL (%)	Deaths (%)	YPLL (%)	Deaths (%)	YPLL (%)
<1	1 (0.02)	29.92 (0.03)	0 (0)	0.00 (0.00)	1 (0.09)	29.92 (0.21)
1-4	0 (0.00)	0 (0.00)	7 (0.15)	209.43 (0.31)	0 (0.00)	0.00 (0.00)
5-9	0 (0.00)	0 (0.00)	2 (0.04)	59.00 (0.09)	1 (0.09)	29.5 (0.21)
10-14	0 (0.00)	0 (0.00)	2 (0.04)	57.78 (0.09)	3 (0.27)	86.67 (0.62)
15-19	6 (0.10)	169.12 (0.19)	12 (0.26)	338.23 (0.5)	1 (0.09)	28.19 (0.20)
20-24	18 (0.29)	493.03 (0.55)	24 (0.51)	657.38 (0.98)	4 (0.35)	109.56 (0.78)
25-29	45 (0.72)	1,192.27 (1.32)	42 (0.90)	1,112.79 (1.66)	5 (0.44)	132.47 (0.95)
30-34	82 (1.32)	2,088.64 (2.32)	92 (1.97)	2,343.35 (3.49)	11 (0.97)	280.18 (2.00)
35-39	120 (1.93)	2,915.64 (3.24)	122 (2.62)	2,964.23 (4.41)	8 (0.71)	194.38 (1.39)
40-44	235 (3.77)	5,397.02 (6.00)	193 (4.14)	4,432.44 (6.60)	21 (1.86)	482.29 (3.44)
45-49	367 (5.89)	7,881.21 (8.76)	260 (5.58)	5,583.42 (8.31)	49 (4.33)	1,052.26 (7.51)
50-54	496 (7.97)	9,823.47 (10.91)	336 (7.21)	6,654.61 (9.91)	51 (4.51)	1,010.08 (7.21)
55-59	656 (10.53)	11,794.63 (13.1)	416 (8.92)	7,479.52 (11.14)	75 (6.63)	1,348.47 (9.62)
60-64	817 (13.12)	13,090.02 (14.54)	541 (11.60)	8,667.94 (12.91)	94 (8.31)	1,506.07 (10.75)
65-69	844 (13.55)	11,763.26 (13.07)	638 (13.68)	8,892.13 (13.24)	155 (13.7)	2,160.31 (15.42)
70-74	808 (12.98)	9,557.77 (10.62)	555 (11.90)	6,565.05 (9.78)	141 (12.47)	1,667.88 (11.90)
75-79	713 (11.45)	6,884.06 (7.65)	547 (11.73)	5,281.32 (7.86)	171 (15.12)	1,651.02 (11.78)
80-84	554 (8.90)	4,199.41 (4.67)	425 (9.11)	3,221.57 (4.80)	146 (12.91)	1,106.70 (7.90)
85+	465 (7.47)	2,726.92 (3.03)	449 (9.63)	2,633.09 (3.92)	194 (17.15)	1,137.68 (8.12)
Total	6,227	90,006.38	4,663	67,153.27	1,131	14,013.64

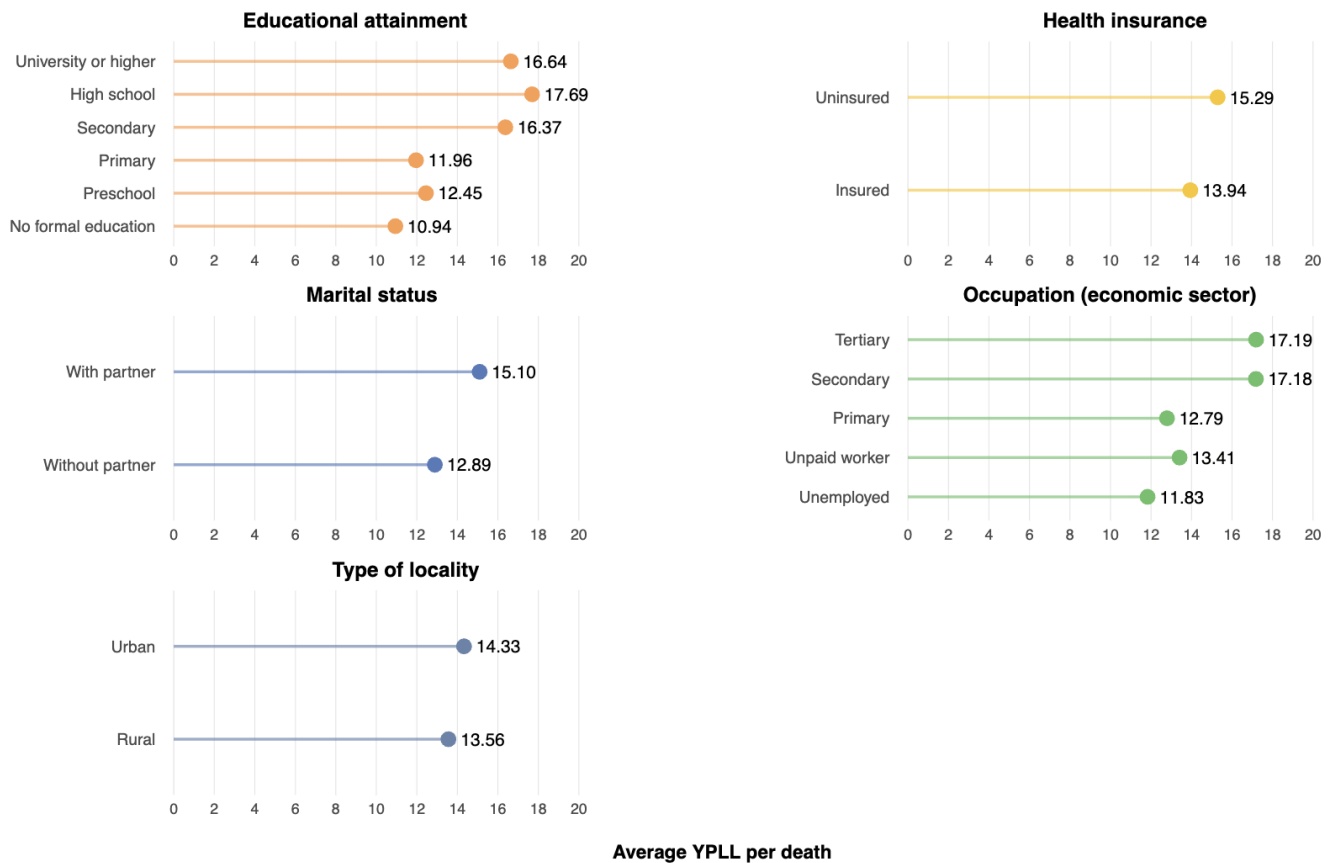


Figure 2. Average Years of Potential Life Lost (YPLL) per COVID-19 death by selected sociodemographic variables, Sonora, Mexico, 2020–2022.

Figura 2. Años Promedio de Vida Potencial Perdidos (AVPP) por defunción por COVID-19 según variables sociodemográficas seleccionadas, Sonora, México, 2020–2022.

Sonora. Since life expectancy values were held constant, the 12.4% proportional increase observed in this group reflects a real rise in deaths from 2020 to 2021. This pattern mirrors observations in the U.S. and several European countries, where COVID-19 mortality also increased among younger populations in 2021 (Williams *et al.*, 2022; Torres *et al.*, 2023). In Sonora, this shift may be explained by two key factors: (a) the national COVID-19 vaccination strategy, and (b) the emergence of more lethal SARS-CoV-2 variants.

In Mexico, age was the primary criterion guiding the federal COVID-19 vaccination strategy. It was assumed that vaccinating individuals aged 50 and older could prevent up to 80% of COVID-19–related deaths. Under this approach, adults under 40 years were the last group to be vaccinated, with this phase beginning in mid-2021 (Gobierno de México, 2021). In Sonora, the increase in YPLL due to COVID-19 among individuals under 40 between 2020 and 2021 may reflect the limited adaptability of this age-based strategy during earlier phases of the pandemic. Although by July 2021 the state had unofficially achieved good vaccination coverage among adults over 60 and those with comorbidities (El Economista, 2021), it fell short of the national goal of reducing 80% of COVID-19 mortality through vaccination (Gobierno de México, 2021), suggesting that protection of

younger populations remained limited during this period. This pattern did not persist in 2022, when COVID-19 mortality declined substantially, likely reflecting expanded vaccination coverage, accumulated population immunity, and changes in epidemic dynamics.

Moreover, the emergence of new SARS-CoV-2 variants—particularly Delta and Omicron—posed significant challenges for health services (Papanikolaou *et al.*, 2022; Firouzabadi *et al.*, 2023). Delta was associated with increased severity and fatal outcomes, while Omicron, despite being more transmissible and generally less severe (Liu *et al.*, 2021), coincided with epidemic peaks that led to increased hospitalizations and deaths among younger populations in Sonora, likely due to low vaccination coverage and other contextual factors (Domínguez-Ramírez *et al.*, 2022). The epidemic waves driven by the Delta variant in the summer of 2021 and the Omicron variant in the winter of 2021 coincided with low vaccination coverage among younger populations in Mexico. Consequently, these epidemic peaks were accompanied by a raise in hospitalizations and COVID-19-related deaths among individuals under 40 years of age (Domínguez-Ramírez *et al.*, 2022). Additionally, the basic reproduction number (R_0) of these variants was considerably higher than that of the ancestral strain, indicating greater transmissibility (Liu *et al.*,

2021; 2022). The convergence of these factors should have been carefully considered in the planning and implementation of vaccination strategies targeting younger age groups in Sonora.

Another noteworthy finding from our study arises from the stratified analysis of YPLL due to COVID-19 by sociodemographic variables, an approach scarcely explored at national or international levels. In Sonora, individuals who lost the most years of potential life per COVID-19 death were those living with a partner, with at least high school education, employed in the secondary or tertiary economic sectors, and with no entitlement to health services. However, these results should be interpreted with caution, as they may reflect differences in age distribution across subgroups. For example, although greater YPLL was observed among individuals living with a partner, this group is generally associated with better adherence to preventive measures (e.g. mask-wearing and hand hygiene) and higher vaccine uptake, both linked to lower mortality risk (Zhang *et al.*, 2021; Rahman *et al.*, 2021).

In this context, the higher premature mortality from COVID-19 among individuals employed in Sonora's secondary and tertiary economic sectors highlights the broader socioeconomic impact of the pandemic. This disproportionate burden likely reflects the challenges of implementing effective non-pharmaceutical interventions and safety protocols in occupations involving direct human interaction. Our findings underscore the need to protect workers in these sectors through equitable vaccine access, workplace safety protocols, and financial support during restrictions as recommended by WHO (WHO, 2021a; 2021b). Furthermore, given that activities such as commerce, real estate services, machinery manufacturing, and construction represent a substantial share of the state's Gross Domestic Product (Gobierno de México, 2025b), future research should assess the economic impact of COVID-19-related deaths in these areas.

These findings have important implications for public health planning in Sonora. Strategies that rely solely on age-based prioritization may be inadequate in contexts where younger, economically active populations experience high exposure and limited access to health services. Integrating occupational risk, healthcare accessibility, and local epidemic dynamics into vaccination and mitigation strategies, could help reduce premature mortality and address health inequities during future public health emergencies (Voigt *et al.*, 2022).

Notably, we observed significant disparities in premature mortality among individuals without entitlement to health services, whether public or private, highlighting the critical role of health coverage in mitigating the impact of public health crises. Evidence shows that people without health insurance encounter greater barriers to accessing care (Shi, 2001). The COVID-19 pandemic further amplified these disparities, as structural barriers—such as socioeconomic status, urban planning, education, cultural norms, and limited access to medical care—increased the vulnerability of certain groups to SARS-CoV-2 exposure (Eijkemans, 2025).

In Sonora, individuals facing barriers to health services likely experienced limited access to testing, diagnosis, treatment, and specialized care, which may have increased their risk of severe disease and fatal outcomes.

Our study has several limitations, primarily related to its cross-sectional design, which precludes causal inferences between COVID-19 and YPLL. Potential information bias may have arisen from the quality of the secondary data source and the death certificates used. Additionally, underreporting of COVID-19 deaths, particularly in rural communities, could have affected the accuracy of age-at-death data and, consequently, YPLL estimates. The use of WHO life tables for Mexico, while facilitating international comparisons, may not accurately reflect the demographic and health characteristics of Sonora's population, potentially leading to bias of YPLL estimation.

CONCLUSIONS

This study underscores the importance of assessing the burden of YPLL due to COVID-19 in Sonora, Mexico, and highlights substantial disparities in premature mortality across demographic and socioeconomic groups. By applying the YPLL metric at a subnational level, our findings provide a more nuanced understanding of the pandemic's impact and complement existing national and international analyses.

Our results indicate that the vaccination strategy may have had a differential effect on COVID-19 mortality, potentially exacerbating existing health disparities. Specifically, prioritizing older age groups alone may not have been sufficient to uniformly reduce premature COVID-19 mortality across all vulnerable age categories in Sonora, particularly during the early phases of the pandemic. Institutionalizing YPLL analysis as part of routine health surveillance could inform more equitable and targeted public health interventions.

Beyond its local relevance, this study demonstrates how YPLL can serve as a valuable tool for assessing epidemic impacts in other regions of Latin America with comparable demographic and health system characteristics. By presenting a case study from Sonora, we contribute to the broader regional dialogue on health equity and pandemic preparedness, emphasizing the need for coordinated efforts between government and society to strengthen responses to future public health crises.

FUNDING

This research received no external funding.

ETHICS STATEMENT

The study protocol was conducted in accordance with the Declaration of Helsinki 2024 and approved by the Institutional Research Ethics Committee of the Department of Medicine and Health Sciences of the Universidad de Sonora (DMCS/CEIDMCS/D-129) and the Committee of Research Ethics of the Instituto Nacional de Salud Pública (CI:827) prior to implementation.

INFORMED CONSENT STATEMENT

Unsought.

DATA AVAILABILITY STATEMENT

Due to local constraints on the time allowed for retaining data related to this study, the original data is not available.

ACKNOWLEDGMENTS

We would like to express our gratitude to the authorities of the Sonora Public Health Secretariat for granting us access to the data that made this study possible.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS:

Conceptualization: D.I.A.L., E.F.G., G.A.H. Data curation: D.I.A.L., J.L.E., G.A.H. Formal analysis: D.I.A.L., M.A.G.S. Investigation: D.I.A.L., G.A.H. Methodology: D.I.A.L., E.F.G., M.A.G.S., G.A.H. Resources: J.L.E., M.C.C.P., G.A.H. Software: D.I.A.L., M.A.G.S. Supervision: G.A.H. Validation: D.I.A.L., M.A.G.S. Visualization: D.I.A.L., M.A.G.S. Writing – original draft: D.I.A.L., E.F.G., J.L.E., M.C.C.P., G.A.H. Writing – review & editing: All authors.

ABBREVIATIONS

The following abbreviations are used in this manuscript:

COVID-19	Coronavirus 19 disease
YPLL	Years of potential life lost
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
WHO	World Health Organization
GBD	Global Burden of Disease Study

KEY MESSAGE

This study highlights the disproportionate impact of COVID-19 on younger populations in Sonora, Mexico, revealing a greater burden of premature mortality than previously recognized. By applying the Years of Potential Life Lost metric at a subnational level, it offers a more nuanced understanding of pandemic-related mortality. These findings underscore the value of YPLL as a tool for evaluating epidemic impacts and health inequities in Latin American regions with similar demographic and health system profiles.

REFERENCES

- Aragón, T.J., Lichtensztajn, D.Y., Katcher, B.S., Reiter, R. and Katz, M.H. 2008. Calculating expected years of life lost for assessing local ethnic disparities in causes of premature death. *BMC Public Health*. 8: 116. <https://doi.org/10.1186/1471-2458-8-116>
- Chan, E.Y.S., Cheng, D. and Martin, J. 2021. Impact of COVID-19 on excess mortality, life expectancy, and years of life lost in the United States. *PLoS One*. 16(9): e0256835. <https://doi.org/10.1371/journal.pone.0256835>
- Comisión Independiente de Investigación sobre la Pandemia de Covid-19 en México. 2025. Muertes en exceso, muertes en exceso atribuidas a Covid-19 y muertes registradas por Covid-19 por semana epidemiológica [Internet]. México: Comisión Independiente. Disponible en: <https://www.comisioncovid.mx/>
- Domínguez-Ramírez, L., Solís-Tejeda, I., Ayon-Aguilar, J., Mayoral-Ortiz, A., Sosa-Jurado, F., Pelayo R., *et al.* 2022. Decrease in COVID-19 adverse outcomes in adults during the Delta and Omicron SARS-CoV-2 waves, after vaccination in Mexico. *Frontiers in Public Health*. 10: 1010256. <https://doi.org/10.3389/fpubh.2022.1010256>
- Eijkemans, G. 2025. The importance of identifying solutions for populations in situations of vulnerability related to COVID-19 and public health measures [Internet]. Disponible en: https://campus.paho.org/sites/default/files/covid_and_groups_in_vulnerable_situations.pdf
- El Economista. 2021. México supera las 50 millones de vacunas contra Covid-19 aplicadas [Internet]. Ciudad de México: El Economista. Disponible en: <https://www.eleconomista.com.mx/politica/Mexico-supera-las-50-millones-de-vacunas-contra-Covid-19-aplicadas-20210710-0021.html>
- Firouzabadi, N., Ghasemiyeh, P., Moradishooli, F. and Mohammadi-Samani, S. 2023. Update on the effectiveness of COVID-19 vaccines on different variants of SARS-CoV-2. *International Immunopharmacology*. 117: 109968. DOI:10.1016/j.intimp.2023.109968
- Foreman, K.J., Marquez, N., Dolgert, A., Fukutaki, K., Fullman, N., McGaughey, M., *et al.* 2018. Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: reference and alternative scenarios for 2016–40 for 195 countries and territories. *The Lancet*. 392(10159): 2052–2090. DOI:10.1016/S0140-6736(18)31694-5
- Gardner, J.W. and Sanborn, J.S. 1990. Years of potential life lost (YPLL)—what does it measure? *Epidemiology*. 1(4): 322–329. DOI:10.1097/00001648-199007000-00012
- Gobierno de México. 2020. Índices de marginación 2020 [Internet]. México: Secretaría de Gobernación, Consejo Nacional de Población. Disponible en: <http://www.gob.mx/conapo/documentos/indices-de-marginacion-2020-284372>
- Gobierno de México. 2021. Política nacional de vacunación contra el virus SARS-CoV-2, para la prevención de la COVID-19 en México [Internet]. México: Secretaría de Salud. Disponible en: https://coronavirus.gob.mx/wp-content/uploads/2021/04/28Abr2021_13h00_PNVx_COVID_19.pdf
- Gobierno de México. 2025a. Subsistema Epidemiológico y Estadístico de Defunciones (SEED) [Internet]. México: Dirección General de Información en Salud, Secretaría de Salud. Disponible en: http://www.dgis.salud.gob.mx/contenidos/sinais/s_seed.html
- Gobierno de México. 2025b. Información Económica y Estatal. Sonora [Internet]. México: Secretaría de Economía. Disponible en: https://www.gob.mx/cms/uploads/attachment/file/157946/sonora_2016_1024.pdf
- Institute for Health Metrics and Evaluation. 2024. Global burden of diseases, injuries, and risk factors study (GBD) protocol [Internet]. Seattle: IHME. Disponible en: <https://www.healthdata.org/sites/default/files/2024-06/GBD%20Protocol%20060424.pdf>
- Islam, N., Jdanov, D.A., Shkolnikov, V.M., Khunti, K., Kawachi, I., White, M., *et al.* 2021. Effects of covid-19 pandemic on life expectancy and premature mortality in 2020: time series analysis in 37 countries. *BMJ*. 375: e066768. DOI:10.1136/bmj-2021-066768

- Jiang, S., Cai, D., Chen, D. and Jiang, Y. 2022. An analysis of life-year lost due to COVID-19 – 34 countries, December 2019–March 2021. *China CDC Weekly*. 4(23): 494-498. DOI:10.46234/ccdcw2022.109
- Lilly, D., Akintorin, S., Unruh, L.H., Dharmapuri, S. and Soyemi, K. 2021. Years of potential life lost secondary to COVID-19: Cook County, Illinois. *Annals of Epidemiology*. 58: 124-127. DOI:10.1016/j.annepidem.2021.03.005
- Liu, Y. and Rocklöv, J. 2021. The reproductive number of the Delta variant of SARS-CoV-2 is far higher compared to the ancestral SARS-CoV-2 virus. *Journal of Travel Medicine*. 28: taab124. <https://doi.org/10.1093/jtm/taab124>
- Liu, Y. and Rocklöv, J. 2022. The effective reproductive number of the Omicron variant of SARS-CoV-2 is several times relative to Delta. *Journal of Travel Medicine*. 29: taac037. <https://doi.org/10.1093/jtm/taac037>
- Mitra, A.K., Payton, M., Kabir, N., Whitehead, A., Ragland, K.N. and Brown, A. 2020. Potential years of life lost due to COVID-19 in the United States, Italy, and Germany: an old formula with newer ideas. *International Journal of Environmental Research and Public Health*. 17(12): 4392. <https://doi.org/10.3390/ijerph17124392>
- Msemburi, W., Karlinsky, A., Knutson, V., Aleshin-Guendel, S., Chatterji, S. and Wakefield, J. 2023. The WHO estimates of excess mortality associated with the COVID-19 pandemic. *Nature*. 613(7942): 130–137. DOI:10.1038/s41586-022-05522-2
- National Cancer Institute. 2025. Definition of premature death - NCI dictionary of cancer terms [Internet]. Bethesda (MD): National Cancer Institute. Disponible en: <https://www.cancer.gov/publications/dictionaries/cancer-terms/def/premature-death>
- Papanikolaou, V., Chrysovergis, A., Ragos, V., Tsiambas, E., Katsinis, S., Manoli, A., *et al*. 2022. From Delta to Omicron: S1-RBD/S2 Mutation/Deletion Equilibrium in SARS-CoV-2 Defined Variants. *Gene*. 814: 146134. DOI:10.1016/j.gene.2021.146134
- Pierce, J.B., Harrington, K., McCabe, M.E., Petito, L.C., Kershaw, K.N., Pool, L.R., *et al*. 2021. Racial/ethnic minority and neighborhood disadvantage leads to disproportionate mortality burden and years of potential life lost due to COVID-19 in Chicago, Illinois. *Health & Place*. 68: 102540. DOI:10.1016/j.healthplace.2021.102540
- Pitlik, S.D. 2020. COVID-19 Compared to other pandemic diseases. *Rambam Maimonides Medical Journal*. 11(3): e0027. doi: 10.5041/RMMJ.10418.
- Quast, T., Andel, R., Gregory, S., Storch, E.A. 2022. Years of life lost associated with COVID-19 deaths in the USA during the first year of the pandemic. *Journal of Public Health*. 44(3): e20-e25. DOI:10.1093/pubmed/fdab123
- Rahman, M.M., Chisty, M.A., Sakib, M.S., Quader, M.A., Shobuj, I.A., Alam, M.A., *et al*. 2021. Status and perception toward the COVID-19 vaccine: A cross-sectional online survey among adult population of Bangladesh. *Health Science Reports*. 4: e451. DOI:10.1002/hsr.2451
- Romeder, J.M., McWhinnie, J.R. 1977. Potential years of life lost between ages 1 and 70: an indicator of premature mortality for health planning. *International Journal of Epidemiology*. 6(2): 143–151. <https://doi.org/10.1093/ije/6.2.143>
- Rommel, A., von der Lippe, E., Plaß, D., Ziese, T., Diercke, M., an der Heiden, M., *et al*. 2021. The COVID-19 disease burden in Germany in 2020—years of life lost to death and disease over the course of the pandemic. *Deutsches Ärzteblatt International*. 118(9): 145–151. DOI:10.3238/arztebl.m2021.0147
- Salinas-Escudero, G., Toledano-Toledano, F., García-Peña, C., Parra-Rodríguez, L., Granados-García, V., Carrillo-Vega, M.F. 2021. Disability-adjusted life years for the COVID-19 pandemic in the Mexican population. *Frontiers in Public Health*. 9: 686700. <https://doi.org/10.3389/fpubh.2021.686700>
- Shi, L. 2001. The convergence of vulnerable characteristics and health insurance in the US. *Social Science & Medicine*. 53: 519–529. DOI:10.1016/S0277-9536(00)00357-9
- Torres, C., García, J., Meslé F., *et al*. 2023. Identifying age- and sex-specific COVID-19 mortality trends over time in six countries. *International Journal of Infectious Diseases*. 128: 32–40. <https://doi.org/10.1016/j.ijid.2022.12.004>
- Ugarte, M.P., Achilleos, S., Quattrocchi, A., *et al*. 2022. Premature mortality attributable to COVID-19: potential years of life lost in 17 countries around the world, January–August 2020. *BMC Public Health*. 22: 54. <https://doi.org/10.1186/s12889-021-12377-1>
- Voigt, A., Omholt, S. and Almaas, E. 2022. Comparing the impact of vaccination strategies on the spread of COVID-19, including a novel household-targeted vaccination strategy. *PLoS One*. 17(2): e0263155. <https://doi.org/10.1371/journal.pone.0263155>
- Williams, G., Spencer, A., Farragher, T., Gittins, M. and Verma, A. 2022. Years of life lost to COVID-19 in 20 countries. *Journal of Global Health*. 12: 05007. <https://doi.org/10.7189/jogh.12.05007>
- World Health Organization. 2019a. International statistical classification of diseases and related health problems. 10th revision [Internet]. Geneva: WHO. Disponible en: https://icd.who.int/browse10/Content/statichtml/ICD10Volume2_en_2019.pdf
- World Health Organization. 2019b. World health statistics 2019: monitoring health for the SDGs, sustainable development goals [Internet]. Geneva: WHO. Disponible en: <https://apps.who.int/iris/bitstream/handle/10665/324835/9789241565707-eng.pdf?ua=1>
- World Health Organization. 2021a. COVID-19: Occupational Health and Safety for Health Workers: Interim Guidance, 2 February 2021. Geneva: WHO.
- World Health Organization. 2021b. Preventing and Mitigating COVID-19 at Work: Policy Brief, 19 May 2021. Geneva: WHO.
- World Health Organization. 2025. COVID-19 deaths. WHO COVID-19 dashboard [Internet]. Geneva: WHO. Disponible en: <https://data.who.int/dashboards/covid19/cases>
- Zhang, L., Zhu, S., Yao, H., Li, M., Si, G. and Tan, X. 2021. Study on factors of people's wearing masks based on two online surveys: Cross-sectional evidence from China. *International Journal of Environmental Research and Public Health*. 18: 3447. <https://doi.org/10.3390/ijerph18073447>
- Zheng M., Lui, B., Komlan, A.-G.A., Bonaparte, C.R., White, R.S. and Hoyler, M.M. 2022. Economic burden of lives lost due to COVID-19 in California State. *Journal of Comparative Effectiveness Research*. 11(7): 489–498. <https://doi.org/10.2217/cer-2021-0245>