Excess deaths during the COVID-19 pandemic in Iran

Milad Ahmadi Gohari\textsuperscript{a},\textsuperscript{d}, Maryam Chegeni\textsuperscript{b},\textsuperscript{*},\textsuperscript{c} Ali Akbar Haghdoosta\textsuperscript{a},\textsuperscript{e} Firoozeh Mirzaee\textsuperscript{c},\textsuperscript{e} Lisa White\textsuperscript{d}, Polychronis Kostoulas\textsuperscript{e},\textsuperscript{f} Ali Mirzazadeh\textsuperscript{f},\textsuperscript{h} Mohammad Karamouzian\textsuperscript{g},\textsuperscript{h},\textsuperscript{†} Yunes Jahani\textsuperscript{a},\textsuperscript{i} and Hamid Sharifi\textsuperscript{h},\textsuperscript{i}

\textsuperscript{a}Modeling in Health Research Center, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran; \textsuperscript{b}Molecular and Medicine Research Center, Khomein University of Medical Sciences, Khomein, Iran; \textsuperscript{c}Department of Midwifery, Razi School of Nursing and Midwifery, Kerman University of Medical Sciences, Kerman, Iran; \textsuperscript{d}Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, University of Oxford, Oxford, UK; \textsuperscript{e}Faculty of Public Health, University of Thessaly, Volos, Greece; \textsuperscript{f}Department of Epidemiology and Biostatistics, Institute for Global Health Sciences, University of California San Francisco, San Francisco, CA, USA; \textsuperscript{g}Department of Epidemiology, School of Public Health, Brown University, Providence, RI, USA; \textsuperscript{h}HIV/STI Surveillance Research Center, and WHO Collaborating Center for HIV Surveillance, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

ABSTRACT

\textbf{Background:} The actual number of deaths during the COVID-19 pandemic is expected to be higher than the reported deaths. We aimed to estimate the number of deaths in Iran during the COVID-19 pandemic from December 22, 2019 to March 20, 2022.

\textbf{Methods:} We compared the number of age- and sex-specific deaths reported by Iran’s Bureau of Vital Statistics with the predicted deaths estimated using an improved Lee-Carter model. We estimated the number of all-cause excess deaths in three scenarios, including the baseline scenario (without any undercounting of deaths) and 4\% and 8\% undercounting of all-cause deaths.

\textbf{Results:} We estimated 282,378 (95\% confidence intervals [CI]: 225,439; 341,951) excess deaths in the baseline model. This number was 303,148 (95\% CI: 246,417; 357,823) and 308,486 (95\% CI: 250,607; 364,417) in the 4\% and 8\% scenarios, respectively. During the same period, Iran reported 139,610 deaths as being directly related to COVID-19. The ratio of reported COVID-19 deaths to total excess deaths ranged from 45.2\% to 49.4\% in the various scenarios. Most excess deaths occurred in the baseline scenario in males (157,552 [95\% CI: 125,142; 191,265]) and those aged $\geq$75 years (102,369 [95\% CI: 93,894; 111,188]).

\textbf{Conclusions:} The reported number of COVID-19 deaths was less than half of Iran’s estimated number of excess deaths. The results of this study will be helpful for health policymakers’ planning, and call for strengthening the timeliness and accuracy of Iran’s death registration systems, planning for more accurate monitoring of epidemics, and planning to provide support services for survivors’ families.

KEYWORDS

COVID-19 excess death Lee-Carter model Iran

ARTICLE HISTORY

Received 15 March 2022
Revised 31 August 2022
Accepted 2 September 2022

CONTACT

Yunes Jahani
\texttt{u.jahani@kmu.ac.ir, yonesjahani@yahoo.com}
Modeling in Health Research Center, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

Hamid Sharifi
\texttt{hsharifi@kmu.ac.ir, sharifihami@gmail.com}
HIV/STI Surveillance Research Center, and WHO Collaborating Center for HIV Surveillance, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

\textsuperscript{*}Present address: Department of Public Health, Khomein University of Medical Sciences, Khomein, Iran

\textsuperscript{†}Present address: Centre on Drug Policy Evaluation, Saint Michael’s Hospital, Toronto, ON, Canada

\textsuperscript{©} 2022 Society for Scandinavian Journal of Infectious Diseases

Supplemental data for this article is available online at https://doi.org/10.1080/23744235.2022.2122554.
Introduction

From the first report of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in December 2019 in Wuhan, China, to August 29, 2022, around 606 million people have been infected with the virus worldwide [1]. COVID-19 pandemic has been the most significant global public health crisis of the past century, leading to about 6.48 million deaths [1]. Studies suggest that a significant percentage of individuals with COVID-19 are asymptomatic [2]. At the beginning of the pandemic, laboratory-confirmed cases represented only about 10% to 15% of all infections [3].

Excess deaths refer to extra deaths more than expected over a period of time. Estimates suggest that there were 14.9 million excess deaths related to the COVID-19 pandemic worldwide in 2020 and 2021. These excess deaths may have been directly caused by COVID-19 or occurred indirectly as a result of COVID-19-related effects on other health disorders, health systems, or the community [4]. Numerous reasons have been suggested for the underestimation of COVID-19-related deaths. One of the most important reasons is the countries’ limited access to diagnostic tests and other diagnostic facilities, especially at the beginning of the pandemic. Another reason may be the low sensitivity of available diagnostics. If sampling is not performed correctly or if the virus is only present in samples in small quantities, the number of false-negative results could increase [5]. Many countries do not consider deaths that occurred without a confirmed antemortem COVID-19 test to be COVID-19-related deaths [6], and these cases are therefore not reported in the official COVID-19 mortality statistics. A severe lack of hospital capacity during outbreaks of COVID-19 forced hospitals to admit only critically ill patients [6]. Therefore, some deaths due to COVID-19 may have occurred outside of hospitals and were reported as non-COVID-19-related deaths.

Conversely, some of the deaths during the pandemic were due to other causes but were indirectly linked to COVID-19. For example, people with chronic health conditions may not have sought care or chose to delay treatment due to a fear of infection [7]. Other indirectly linked deaths may have occurred due to restricted access to services, mainly emergency services and intensive care units, as well as the high workload and fatigue of medical staff. Hence, it seems that communities may have also experienced an increase in mortality for reasons indirectly linked to the COVID-19 pandemic.

Given these challenges, it is expected that the number of deaths will be under-reported by official authorities. Typically, if there are questions or uncertainties around mortality due to a specific cause, such as COVID-19 during an epidemic, the excess mortality index can be used to estimate the impact of that epidemic more accurately than the number of reported deaths [8–11]. In the present study, we aimed to estimate the number of direct and indirect deaths in Iran during the COVID-19 pandemic from December 22, 2019, to March 20, 2022, overall and stratified by age and sex groups.

Materials and methods

The number of deaths in Iran was estimated by age and sex without considering the COVID-19 pandemic, for the period from March 20, 2019, to March 20, 2023. The Lee-Carter (LC) model and its extended version, the Poisson improvement rate (PIR) model, were used for this estimation [12–14]. By estimating the population size and mortality rate, the number of deaths in Iran, from December 22, 2019, to March 20, 2022, was estimated and presented separately for three different periods. The first period was from December 22, 2019, until the end of March 19, 2020, coinciding with the winter in Iran and the onset of the COVID-19 pandemic. The second period was from March 20, 2020, to the end of March 20, 2021. The third period was from March 21, 2021, to March 20, 2022. The number of deaths during the first period was calculated as the proportion of deaths in a similar period, December 22, until March 19, to the total number from 2013 to 2017, multiplied by the estimated number of deaths. For the second and third periods, the total number of deaths was obtained from the Bureau of Vital Statistics of Iran. This organisation reports the number of deaths by age and sex. The age- and sex-specific numbers of excess deaths were calculated as the difference between the reported and predicted deaths.

Data collection

The data for the number of deaths and the at-risk population in this study were retrieved from the Iranian Statistics Centre and Bureau of Vital Statistics from 2006 to 2016. For each calendar year, the number of deaths and the population in the sex groups (male, female) and age groups (0–4, 5–9, 10–15, 16–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69,
Lee-Carter and Poisson improvement rate models (direct estimation)

The Lee-Carter model has been used for mortality predictions since 1992 [16]. We chose this model because one of its strengths is the ability to implement models based on current mortality trends in different age groups [17]. This model combines demographic and time-series statistical models [18].

In recent years, researchers have begun to use mortality improvement rate modelling. Studies have shown that the mortality rate is prone to overdispersion [19,20]. Therefore, in this study, the improvement rate was used for modelling. The StMoMo and iMoMo packages in R software were used to estimate the model parameters [12,21].

Outcome

Excess deaths were calculated by subtracting the two definitions of death (excess deaths = deaths reported by Iran’s Bureau of Vital Statistics – predicted deaths). Reported deaths were deaths that occurred during the study period, stratified by age and sex. Predicted deaths were deaths that were calculated to have occurred during the study period, based on population modelling and forecasting.

The goodness of fit and model selection

In this study, the Akaike information criterion (AIC) and Bayesian information criterion (BIC) indices were used to evaluate the goodness of fit. The AIC and BIC values by sex for both the LC and PIR models are shown in Table 1 in the Supplementary Material. The AIC and BIC values for both sexes showed that the PIR model fitted better. Thus, the results of this model were selected.

Model validation

To check the model’s validity, historical data for estimating two years (2017 and 2018) by sex were used. Then, the model outputs were compared with the recorded data (Tables 2 and 3 in the Supplementary Material). The root means square deviation (RMSE) values were calculated for the reported and predicted mortality rates for males and females in 2017 and 2018. The results showed that the RMSE values in 2017 and 2018 were 0.001 and 0.0017 for males and 0.0064 and 0.0067 for females, respectively. The RMSE values were insignificant and negligible, indicating that the PIR model had good predictive power and fit.

Sensitivity analysis

Previous studies have shown that Iran has incomplete mortality data [22], with the completeness of mortality data varying from 92% to 99% [22,23]. To assess this issue, sensitivity analysis was performed in three scenarios, including the baseline scenario (0% undercounting of deaths) and 4% and 8% undercounting of all-cause deaths by Iran’s Bureau of Vital Statistics. The most pessimistic scenario, 8%, assumed that the completeness of mortality data in Iran is 92%, while 0% assumed complete mortality data, and 4% was considered to be the middle scenario. To achieve this, 4% and 8% of the total

Table 1. Predicted all-cause deaths, reported all-cause deaths, and forecast excess deaths in the baseline scenario (December 22, 2019 to March 20, 2022).

| Age group | Predicted number of all-cause deaths (95% CI) | Reported number of all-cause deaths | Forecast excess number of death (95% CI) |
|-----------|-----------------------------------------------|-------------------------------------|----------------------------------------|
|           | Male        | Female                              | Male        | Female                              | Male        | Female                              |
| 0–4       | 11,192 (9103;13586) | 10,023 (8,102;12,248) | 14,026     | 17,417                              | 2,833 (743;923) | 7,393 (5,170;9,315) |
| 5–9       | 3,043 (2,075;4,359) | 2,612 (1,729;3,793)  | 3,852      | 4,024                               | 809 (0,177)  | 1,412 (441,2,295) |
| 10–14     | 2,668 (1,774;3,783) | 2,202 (1,438;3,238) | 3,591      | 3,093                               | 923 (116;1,817) | 891 (81;1,665) |
| 15–19     | 7,459 (6,031;9,136) | 2,860 (2,017;3,932) | 8,533      | 4,049                               | 1,167 (722,503) | 1,189 (310;2,033) |
| 20–24     | 8,865 (7,313;10,670) | 3,021 (2,168;4,165) | 10,197     | 3,843                               | 1,336 (412;883) | 822 (401;1,674) |
| 25–29     | 10,170 (8,339;12,286) | 3,859 (2,766;5,255) | 12,264     | 4,850                               | 2,094 (462;926) | 1,024 (108;2,084) |
| 30–34     | 12,396 (10,175;15,044) | 6,149 (4,597;8,088) | 15,926     | 7,455                               | 3,530 (1,461;751) | 1,339 (187;2,857) |
| 35–39     | 14,762 (12,353;17,601) | 7,232 (5,552;9,280) | 19,349     | 9,886                               | 4,587 (2,267;6,996) | 2,654 (1,037;3,334) |
| 40–44     | 14,878 (12,663;17,349) | 7,608 (6,069;9,432) | 20,958     | 11,378                              | 6,079 (3,906;2,95) | 3,770 (2,302;5,310) |
| 45–49     | 18,004 (15,839;20,424) | 8,722 (7,232;10,412) | 24,526     | 13,756                              | 6,522 (4,384;6,687) | 5,034 (3,602;6,523) |
| 50–54     | 22,767 (20,444;25,279) | 11,699 (10,073;13,553) | 32,089     | 18,216                              | 9,322 (7,099;11,645) | 6,518 (5,055;14,834) |
| 55–59     | 32,888 (30,384;35,525) | 16,816 (15,018;18,749) | 41,693     | 24,767                              | 8,806 (6,466;11,309) | 7,950 (6,373;9,749) |
| 60–64     | 40,683 (38,122;43,384) | 23,478 (21,516;25,556) | 56,122     | 36,239                              | 15,439 (12,824;18,000) | 12,762 (10,958;14,721) |
| 65–69     | 43,990 (41,715;46,370) | 31,618 (29,673;33,652) | 62,685     | 47,117                              | 18,695 (16,337;20,970) | 15,499 (13,599;17,443) |
| 70–74     | 44,131 (42,311;46,004) | 37,999 (36,282;39,785) | 58,575     | 53,164                              | 14,444 (12,858;16,263) | 15,166 (13,479;16,882) |
| ≥75       | 199,581 (195,027;204,208) | 204,510 (200,245;208,849) | 260,547     | 245,913                              | 60,966 (56,339;65,520) | 41,403 (37,555;45,668) |
| Total     | 487,477 (453,668;525,008) | 380,408 (354,478;409,996) | 644,933     | 505,167                              | 157,552 (125,142;191,265) | 124,826 (100,297;150,686) |
number of annual deaths were calculated and then added to the number of reported deaths, based on sex and age groups.

**Results**

*Predicting mortality rates by age and sex*

We estimated what the mortality rates in Iran up to 2023 would have been in the absence of the COVID-19 pandemic, stratified by age and sex (Figure 1). The estimated mortality rates for 2019 to 2023 by age group for males and females are shown in Table 4 in the Supplementary Material. As shown in Figure 1, the mortality rate in both sexes in the ≥75 years age group is higher than that of other age groups. Mortality rates for females between the ages of 20 and 59 are lower than for males. Focusing on the mortality rate reported in the age range of 0–19 years, the mortality rate at birth and up to 4 years of age in both sexes was higher than that of other age groups in this age range.

*Forecast excess deaths under different scenarios*

**The entire period (December 22, 2019, to March 20, 2022)**

Overall, over the entire study time, a total of 282,378 (95% CI: 225,439; 341,951) excess deaths were forecast in the baseline scenario (Table 1). Also, 303,148 (95% CI: 246,417; 357,823), and 308,486 (95% CI: 250,607; 364,417) excess deaths in the 4% and 8% undercounting scenarios, respectively, were forecast to have occurred for both sexes in Iran (Table 1). For the same period, Iran’s Ministry of Health (MOH) reported 139,610 deaths due to COVID-19 (Figure 2). The ratio of reported COVID-19 deaths to the total number of excess deaths varied from 45.2% to 49.4% for the various scenarios of estimated excess deaths. More details are shown in Tables 7–9 in the Supplementary Material.

**Second period (March 20, 2020, to March 20, 2021)**

In the period March 20, 2020, to March 20, 2021, the excess deaths were forecast to be 126,530 (95% CI: 101,454; 150,445), 134,995 (95% CI: 109,281; 159,275), and 137,580 (95% CI: 111,309; 162,496) in the baseline scenario and the 4% and 8% undercounting scenarios, respectively, for both sexes. However, during this period, only 60,440 deaths due to COVID-19 were reported by Iran’s MOH. Reported deaths due to COVID-19 ranged from 43.9% in the 8% scenario to 47.8% in the baseline scenario of estimated excess deaths. More details are shown in Tables 10–12 in the Supplementary Material.

**Third period (March 21, 2021, to March 20, 2022)**

The excess number of deaths during the period March 21, 2021, to March 20, 2022, were forecast to be 149,143 (95% CI: 122,739; 173,154), 160,903 (95% CI: 134,084; 185,251), and 163,567 (95% CI: 136,182; 188,636) in the baseline scenario and the 4% and 8% undercounting scenarios, respectively, for both sexes. There were 77,886 deaths directly linked to COVID-19 reported by Iran’s MOH. During this period, reported deaths due to COVID-19 ranged from 47.6% in the 8% scenario to 52.2% in the scenario of 0% estimated excess deaths. More details are shown in Tables 13–15 in the Supplementary Material.

**Discussion**

This study showed that over a period of about 27 months (December 22, 2019, to March 20, 2022) there were 282,378 (95% CI: 225,439; 341,951), 303,148 (95% CI: 246,417; 357,823), and 308,486 (95% CI: 250,607; 364,417) excess deaths in Iran in the baseline scenario.
Figure 1. Estimated mortality rates by age and sex groups in Iran (2019–2023). The 95% confidence intervals are shown in the coloured ranges. Confidence intervals are not plotted for some age groups due to an overlap in mortality rates. The Y-axes in the left and right plots are male and female mortality rates, respectively.

Figure 2. Deaths due to COVID-19 were reported by the Iranian Ministry of Health and forecast excess deaths under different scenarios. R: Reported deaths due to COVID-19 by MOH. A, B and C are excess deaths under 0%, 4% and 8% undercounting reported all-cause death respectively.
and the 4% and 8% undercounting scenarios, respectively. Most excess deaths occurred in males and in the ≥75 years age group. Meanwhile, Iran’s MOH reported 139,610 direct COVID-19-related deaths in the country during the same period. Officially reported COVID-19 deaths ranged from 45.2% to 49.4% of the forecast excess deaths in the country. The ratio of reported COVID-19 deaths to the total of excess deaths has increased consistently over time. This increase was from 17.5% to 19.1% in the first period, from 43.9% to 47.8% in the second period, and from 47.6% to 52.2% in the third period, under different scenarios.

We found that the reported deaths due to COVID-19 comprised around half of all excess deaths in different scenarios. In a study in the USA, conducted for the first ten months of 2020, 66% of excess deaths were directly linked to COVID-19. In Ecuador, the officially reported deaths attributed to COVID-19 accounted for 21% of excess deaths [24]. We do not have information about the causes of deaths not attributed to COVID-19 in Iran. Therefore, we cannot investigate the leading causes of the excess deaths that were not reported to have been caused by COVID-19. However, we are certain that some of them were likely to have been directly related to COVID-19 but were not detected and therefore, not reported by the surveillance system. There are several reasons why direct deaths due to COVID-19 may not have been detected in Iran. First, COVID-19 cases reported in Iran (and many other countries) only include those with a positive PCR test [25], with varying sensitivities from 47% to 100% [26]. Second, the limited capacity in Iran for performing diagnostic tests for COVID-19 and the reluctance of physicians to send samples for PCR testing could have led to the under-reporting of cases [27]. Furthermore, increased deaths indirectly linked to COVID-19 may be attributable to other health conditions. The COVID-19 pandemic has caused problems caring for patients with other diseases, especially chronic diseases, such as diabetes, cancer, and cardiovascular problems. Patients with these diseases may not have received the necessary medical services due to their fear of contracting COVID-19 or occupying hospital beds [28]. Indeed, fear of contracting COVID-19 has resulted in many people who need essential medical services (for both COVID-19 and other diseases) avoiding attending such services. Additionally, some people were unable to access prevention and treatment because health systems were overburdened by the pandemic [4,7].

The reporting of COVID-19 deaths in Iran during these three periods has improved, from about 17.5% to 19.1% in the baseline scenario to the 8% undercounting scenario of estimated excess deaths in the first period, to about 47.6% to 52.2% in the baseline scenario to the 8% undercounting scenario of estimated excess deaths in the third period. One of the reasons for the observed improvement could be the initially late diagnosis and reporting of the epidemic in Iran. The first COVID-19 death in Iran was reported on February 19, 2020 [22,29]. However, there is various evidence to suggest that COVID-19 and its associated deaths had occurred about four months before February 19, 2020, in the country.
The absence of specific clinical symptoms for COVID-19, its flu-like symptoms, and the coincidence of the first cases with the influenza season in Iran made it impossible for the country’s healthcare system to detect SARS-CoV-2 promptly. The late detection of the COVID-19 pandemic is not unique to Iran. Reports have indicated that other countries were unable to detect SARS-CoV-2 in a timely fashion [30,31]. Another reason may be the lack of adequate diagnostic facilities in Iran, especially the unavailability of diagnostic tests during the first period. The difference between reported deaths due to COVID-19 and the actual mortality rate has also become more pronounced in other countries due to the low number of diagnostic tests. In several states in the USA, many deaths occurred before there was increased access to COVID-19 diagnostic tests, and these deaths were not counted in official COVID-19 mortality reports. Thus, there were considerable disparities among states regarding the difference between the official COVID-19 mortality rate and estimated excess deaths [31].

The results of our study indicated that over time, as people’s knowledge improved through extensive informational campaigns and because of the increased number of diagnostic tests, it is likely that a higher number of positive COVID-19 cases and directly linked deaths were diagnosed. In Iran, during the second and third periods of the epidemic, official statistics were more in line with mortality estimates; the gap between them was reduced by nearly half, and about half of all cases were identified. It is important to note that monitoring changes in mortality for all reasons can also provide essential information about the severity of an epidemic, as evidenced during the third phase of the epidemic. Due to the expansion of general vaccination and an increase in diagnostic tests compared with previously, with the arrival of the highly contagious Delta and Omicron strains in Iran, the number of officially reported deaths increased dramatically [32].

The highest number of excess deaths occurred in both sexes in the ≥75 years age group. One of the reasons for the under-reporting of cases in the older age groups was the higher case fatality of COVID-19 in these age groups [33]. Other reasons for this difference can be attributed to increased deaths due to other diseases, such as cancer, diabetes, cardiovascular disease, and other respiratory infections [34,35]. This finding is consistent with the experience in other countries [36]. The lack or low rates of excess death in younger age groups may be due to reasons, such as a reduction in unintentional injuries (including drowning and car accidents) and a lower burden of cardiovascular and respiratory diseases potentially associated with a change in lifestyle or environmental factors during the periods of lockdown [37,38]. However, long-term statistics on the causes of deaths might be needed to observe these outcomes, because lockdowns could also have had other unintended consequences (e.g., worsening mental health), which may take longer to affect overall mortality [39].

Limitations

This study had four limitations. The first and most important is the strong dependency of the findings on the official death reports and the extent of their coverage. This may influence the accuracy of the estimations in different age and sex groups. Small changes in population estimates can result in changes in the estimate of excess deaths. Second, in our sensitivity analysis to account for undercounting of deaths, we assumed that it was distributed uniformly across all age groups. While we did not have better evidence available to account for age-specific missing deaths, it is important to note that this is not an ideal approach as most missed deaths are concentrated in old and very young age groups. Third, in Iran, as in other countries, health protocols (e.g., wearing masks, maintaining social distancing, staying at home, and banning or reducing travel) were put in place to control the COVID-19 epidemic, and some causes of death, such as seasonal influenza and accidents, decreased compared with their numbers in previous years. Therefore, given a reduction in deaths due to these causes, it may be possible that excess deaths due to COVID-19 in this study were slightly underestimated and that the actual number of excess deaths was slightly higher. Fourth, due to the lack of information about the number of deaths related to different diseases in previous years, we could not differentiate the number of excess deaths directly attributable to COVID-19. Although COVID-19 was probably responsible for most of the additional deaths during the epidemic, not all cases of excess deaths may be directly attributable to COVID-19.
Conclusion

From the results of this study, it appears that directly reported deaths cannot fully explain the increase in deaths due to COVID-19. As COVID-19, both directly and indirectly, caused additional deaths in Iran, the estimated number of excess deaths may be a better measure to determine the extent and severity of COVID-19 in the country. Excess deaths were higher among males, and the ≥75 years age group was much more affected than other age groups. The results of this study can be used by policymakers to underscore the severity of the COVID-19 pandemic in Iran and to plan supportive and psychological services for survivors’ families. Strengthening the timeliness and accuracy of death registration systems is of great importance for the country’s health policies, especially during a pandemic, and could provide better and more accurate monitoring of an epidemic and its consequences. For future studies, it is recommended that the proportion of excess deaths directly caused by COVID-19 in Iran is estimated.

Ethical issues

The proposal of the present study was approved by the ethics committee of Kerman University of Medical Sciences, Kerman, Iran (reference 98001239). The Ethical approval code is IR.KMU.REC.1398.735.

Disclosure statement

The authors declare no conflict of interest, real or perceived.

Funding

This work was supported by the International COVID-19 Modelling (CoMo) Consortium. The CoMo Consortium was supported by the Oxford University COVID-19 Research Response Fund (ref: 0009280). Lisa White is funded by the Li Ka Shing Foundation. Mohammad Karamouzian is supported by a Banting Postdoctoral Fellowship.

ORCID

Milad Ahmadi Gohari http://orcid.org/0000-0003-1998-9157
Maryam Chegeni http://orcid.org/0000-0002-5411-624X
Ali Akbar Haghdoot http://orcid.org/0000-0003-4628-4849
Firoozeh Mirzaee http://orcid.org/0000-0002-1114-0813
Lisa White http://orcid.org/0000-0002-6523-185X
Polychronis Kostoulas http://orcid.org/0000-0001-7051-1541
Ali Mirzazadeh http://orcid.org/0000-0002-0478-3220
Mohammad Karamouzian http://orcid.org/0000-0002-5631-4469

References

[1] COVID-19 CORONAVIRUS PANDEMIC. August 28, 2022. Available from: https://www.worldometers.info/coronavirus/WHO/COVID-19-Related-Deaths-

[2] Pollock AM, Lancaster J. Asymptomatic transmission of covid-19. BMJ 2020;371. DOI:10.1136/bmj.m4851

[3] Noh J, Danuser G. Estimation of the fraction of COVID-19 infected people in US states and countries worldwide. PLOS One. 2021;16(2):e0246772.

[4] 14.9 Million excess deaths associated with the COVID-19 pandemic in 2020 and 2021. World Health Organization; 2022. Available from: https://www.who.int/news/item/05-05-2022-14.9-million-excess-deaths-were-associated-with-the-covid-19-pandemic-in-2020-and-2021

[5] Healy B, Khan A, Meteai H, et al. The impact of false positive COVID-19 results in an area of low prevalence. Clin Med. 2021;21(1):e54–e56.

[6] The Economist. Tracking covid-19 excess deaths across countries. 2021. Available from: https://www.economist.com/graphic-detail/coronavirus-excess-deaths-tracker

[7] Santos-Burgoa C, Sandberg J, Suárez E, et al. Differential and persistent risk of excess mortality from hurricane maria in Puerto Rico: a time-series analysis. Lancet Planet Health. 2018;2(11):e478–e88.

[8] Woolf SH, Chapman DA, Sabo RT, et al. Excess deaths from COVID-19 and other causes, March-July 2020. JAMA. 2020;324(15):1562–1564.

[9]Olson DR, Huynh M, Fine A, et al. Preliminary estimate of excess mortality during the COVID-19 outbreak—New York City, March 11–May 2, 2020. 2020. Available from: https://www.cdc.gov/mmwr/volumes/69/wr/mm6919e5.htm

[10] Kiang MV, Irizarry RA, Buckee CO, et al. Every body counts: measuring mortality from the COVID-19 pandemic. Ann Intern Med. 2020;173(12):1004–1007.

[11] Hunta A, Villegas A. Mortality improvement rates: modeling, parameter uncertainty and robustness. Living to 100. 2002;3(1):100–107.

[12] Timonin S, Klimkin I, Shkolnikov VM, et al. Excess mortality in Russia and its regions compared to high income countries: an analysis of monthly series of 2020. SSM-Population Health. 2022;17:101006.

[13] Voghera S, Tepe O. The COVID-19 pandemic and its effects on Swedish mortality. 2021;1–41.

[14] Bank TW. Population- Iran, Islamic Rep. 2021. Available from: https://data.worldbank.org/country/IR

[15] Basellini U, Camarda CG. Extending the Lee-Carter model to the three components of human mortality. No. AWRktu7T8IN2zFb8rQP. 2018.

[16] Booth H, Hyndman RJ, Tickle L, et al. Lee-Carter mortality forecasting: a multi-country comparison of variants and extensions. DemRes. 2006;15:289–310.
Kamaruddin HS, Ismail N. Forecasting selected specific age mortality rate of Malaysia by using Lee-Carter model. J Phys: Conf Ser. 2018;974:012003.

Mitchell D, Brockett P, Mendoza-Arriaga R, et al. Modeling and forecasting mortality rates. economics. 2013;52(2):275–285.

Bergeron-Boucher M-P, Kjaergaard S. Mortality forecasting at age 65 and above: an age-specific evaluation of the Lee-Carter model. 2022;1:64–79. DOI:10.1080/03461238.2021.1928542

Villegas A, Kaishev VK, Millossovich P. editors. StMoMo: An R package for stochastic mortality modelling. 7th Australasian Actuarial Education and Research Symposium; 2015.

Ghafari M, Kadivar A, Katzourakis A. Excess deaths associated with the Iranian COVID-19 epidemic: a province-level analysis. Int J Infect Dis. 2021;107:101–115.

Karlinsky A. International completeness of death registration 2015-2019. medRxiv; 2021. DOI:10.1101/2021.08.12.21261978

Cuéllar L, Torres I, Romero-Severson E, et al. Excess deaths reveal unequal impact of COVID-19 in Ecuador. BMJ Glob Health. 2021;6(9):e006446.

Hannah Ritchie EM, Rodés-Guirao L, Appel C, et al. Coronavirus pandemic (COVID-19). Published online at OurWorldInData.org. Available from: https://ourworldindata.org/coronavirus [Online Resource]

Mair MD, Hussain M, Siddiqui S, et al. A systematic review and meta-analysis comparing the diagnostic accuracy of initial RT-PCR and CT scan in suspected COVID-19 patients. Br J Radiol. 2021;94(1119):20201039.

Lau H, Khosrawipour T, Kocbach P, et al. Evaluating the massive underreporting and undertesting of COVID-19 cases in multiple global epicenters. Pulmonology. 2021;27(2):110–115.

French G, Hulse M, Nguyen D, et al. Impact of hospital strain on excess deaths during the COVID-19 pandemic—United States, July 2020–July 2021. MMWR Morb Mortal Wkly Rep. 2021;70(46):1613–1616.

Sharifi H, Jahani Y, Mirzazadeh A, et al. Estimating COVID-19-related infections, deaths, and hospitalizations in Iran under different physical distancing and isolation scenarios. Int J Health Policy Manag. 2022;11(3):334–343.

Docherty KF, Butt JH, de Boer RA, et al. Excess deaths during the covid-19 pandemic: an international comparison. 2020. DOI:10.1101/2020.04.21.20073114

Shiels MS, Almeida JS, Garcia-Closas M, et al. Impact of population growth and aging on estimates of excess US deaths during the COVID-19 pandemic, March to August 2020. Ann Intern Med. 2021;174(4):437–443.

Worldmeter Iran coronavirus. 2021. Available from: https://www.worldometers.info/coronavirus/country/iran/?ref=qatarliving

Levin AT, Hanage WP, Owusu-Boaitey N, et al. Assessing the age specificity of infection fatality rates for COVID-19: systematic review, meta-analysis, and public policy implications. Eur J Epidemiol. 2020;35(12):1123–1138.

Wadhera RK, Shen C, Gondi S, et al. Cardiovascular deaths during the COVID-19 pandemic in the United States. J Am Coll Cardiol. 2021;77(2):159–169.

Rand J, Zhao S, Han L, et al. Increase in diabetes mortality associated with COVID-19 pandemic in the US. Diabetes Care. 2021;44(7):e146–e147.

Kontopantelis E, Mamas MA, Deanfield J, et al. Excess mortality in England and Wales during the first wave of the COVID-19 pandemic. J Epidemiol Community Health. 2021;75(3):213–223.

Chen K, Wang M, Huang C, et al. Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. Lancet Planet Health. 2020;4(6):E210–E212.

Son J-Y, Fong KC, Heo S, et al. Reductions in mortality resulting from reduced air pollution levels due to COVID-19 mitigation measures. Sci Total Environ. 2020;744:141012.

Beaney T, Clarke JM, Jain V, et al. Excess mortality: the gold standard in measuring the impact of COVID-19 worldwide? J R Soc Med. 2020;113(9):329–334.