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Original Article

Trend and Projection of Premature Mortality in Iran through 2030: A Modeling Study

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Abstract

Background: Projection of mortality rates is essential for policy making and planning of health services. Premature mortality, as an important index, commonly refers to deaths occurring before 70 years of age. This study was conducted to estimate the trend of premature deaths from 2006-2015 and to project premature deaths for the 2016-2030 period.

Methods: We used national mortality data collected by the Ministry of Health and Medical Education's Deputy of Health, and population data from the Statistical Center of Iran. Mortality and population data were categorized based on sex and 5-year age groups. The Bayesian hierarchical model was used to project future premature mortality rates through 2030.

Results: Age-standardized all-cause premature mortality declines from 414.3 per 100000 persons in 2010 to 300.3 per 100000 persons in 2030 (27.5%) for men, and from 230.6 per 100000 persons in 2010 to 197.2 per 100000 persons in 2030 (14.5%) for women. In all age groups, the percent reduction of premature mortality was greater for men than women.

Conclusion: Overall, it is projected that premature mortality will witness a declining trend in both sexes in Iran. Accordingly, we would expect to achieve less than a third reduction in premature mortality by 2030, which is one of the Sustainable Development Goals.

Keywords: Bayesian hierarchical model, Premature mortality, Projection, Sustainable Development Goals

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Introduction

Mortality rates are not merely suggestive of a health system's development, but also indicators of assessing the socioeconomic development of a society.[1] Premature mortality is an important index whose reduction has been considered a Sustainable Development Goal (SDG) by the World Health Organization (WHO).[2] Premature mortality is usually designated to deaths occurring before 70 years of age.[3,4] It can be associated with worsening of economic status and mental health in the family.[5,6] Moreover, more than 85% of premature deaths occur in low- or middle- income countries.[7]

Projection of future morbidity and mortality rates are essential for policy making and planning of health services, social security, and insurance systems.[8,9] Different approaches are taken to project the probability of future deaths. Among the most commonly applied models are the Lee-Carter and the age-period-cohort models.[10] Policy makers often need comparable and correct data on mortality projection in subgroups, such as mortality rate by different causes, age groups, and gender. One of the difficulties in projecting mortality in subgroups is the presence of small populations, wherein the variation in death counts among the subgroups are relatively high. Thus, under these circumstances, the use of methods such as age-period-cohort and Lee-Carter may not yield accurate results.[11]

Hence, we need a different approach toward estimating and projecting mortality rates in small populations. One such model that has been introduced to resolve this issue is the Bayesian hierarchical model.[11] One of the advantages of this method is its ability in accurately estimating past trends and projecting future mortality rates in various subgroups of small populations. Furthermore, by taking into account linear and non-linear time trends, it allows for smoothing past trends and extrapolating them to the future.[8] Additionally, when the objective is to project mortality rates for multiple causes of death and/or age subgroups, unlike age-period-cohort and Lee-Carter models, Bayesian hierarchical model with conditional auto-regressive components can share and borrow information over time, age groups and causes of death.[11]

Thus far, different methods have been applied to examine mortality trends and to project mortality rates in Iran.[12,13] Nevertheless, to our knowledge, these studies have not used the Bayesian hierarchical model to project

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future mortality rates. Moreover, most of them have projected the overall mortality rate and/or mortality rates due to specific causes, and to our knowledge, no Iranian study has projected premature mortality – considered in 25–69 year-olds in this study.[3]

Therefore, our objective is to project premature mortality and age- and sex-specific mortality rates for individuals aged 25–69 years through 2030, using the Bayesian hierarchical model. The results of this study may prove beneficial to evidence-based decision making and in particular, to assess the achievement of one of the SDGs – which is to reach a 40% reduction in premature mortality by 2030.

Materials and Methods

Data

Mortality Data

This study was conducted using the national mortality data for 2006–2015 collected by the Ministry of Health and Medical Education's Deputy of Health and its Death Registration System (DRS), as well as the data obtained from Tehran and Isfahan cemeteries. Although Iran has a national Death Registry System, the data for Tehran and Isfahan cities were not registered in this system before 2014. Therefore, the data of the two cemeteries of Behesht-e-Zahra in Tehran and Bagh-e-Rezvan in Isfahan for these years were added to the DRS. In this system, data are registered based on age, sex, date of death, cause of death, province, and county. The DRS collects the mortality data from all the cities, including Tehran and Isfahan, since 2014.

The mortality data sources in Iran include hospitals, Legal Medicine Organization, urban health centers, rural health centers, and clinics. The data collected from the above sources are sent to county health centers. Eventually, after examining the quality and applying the necessary modifications, the data are registered in the DRS. Nevertheless, before data analysis, data cleaning and examination were done to check for duplicates.

To estimate the completeness percentage of the DRS for 2006–2015, three common approaches were applied to correct undercounting: synthetic extinct generation, generalized growth balance, and a combination of the two, i.e. generalized growth balance -synthetic extinct generation.[12] Eventually, the estimates obtained from these three approaches were combined using LOESS regression. The incompleteness percentage obtained from these analyses was applied to the overall number of deaths to calculate the corrected number of deaths.

Population data

To calculate mortality rates for age and sex groups in each year from 2006 to 2015, the population data provided by the Statistical Center of Iran were used. These data were categorized for age and sex groups and were considered as the population at risk in the middle of each year. These data are extracted from national censuses. Moreover, to project mortality rates from 2016 through 2030, we used population projections performed by the Statistical Center of Iran annually until 2030 for different age and sex groups as the population at risk in the middle of each year.

Statistical Analysis

Mortality and population data were categorized according to sex and 5-year age groups (25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, and 65–69 years). To calculate mortality rates between 2006 and 2015, the corrected number of deaths in that year in each sex and age group was divided by the population in the middle of that year.

A Bayesian hierarchical model was used to project future mortality rates. This model borrows data from different age groups and times and uses estimated trends to project future mortality.[8] It is composed of two separate sections, piecewise linear and nonlinear time trend. The number of deaths was estimated according to the Poisson likelihood distribution. In the piecewise linear section, appropriate cut-points were selected based on the lowest root mean square error value. In addition to piecewise linear terms in this model, flexible random effects were added to consider nonlinear trends. Furthermore, the results of this model were used to estimate age-standardized premature mortality for the age group 25–69 years. Iran's population in 2015 was used for standardization. Markov chain Monte Carlo was used for sampling of posterior probability distributions, point estimates and 90% uncertainty intervals. Statistical programming was done in R (version 3.5.1) and Rstan (version 2.17.3) environment.

Results

As evident in Table 1, between the years 2006 and 2015, premature mortality rate had a declining trend in all age groups; a similar trend was observed for age-standardized premature mortality in men and women. It is projected that between 2010 and 2030, age-standardized all-cause premature mortality will decline by 27.5% in men (from 414.3 per 100 000 persons in 2010 to 300.3 per 100 000 persons in 2030) and by 14.5% in women (from 230.6 per 100 000 persons in 2010 to 197.2 per 100 000 persons in 2030).

It is also projected that in 65–69 year-old men, all-cause premature mortality will decline from 1937.1 per 100 000 persons in 2010 to 1676.5 per 100 000 persons in 2030 (13.5% reduction). According to this projection, in women of the same age-group, all-cause premature mortality will decline from 1346.7 per 100 000 persons in 2010 to 1241.8 per 100 000 persons in 2030 (7.8% reduction) (Table 1).

The results showed that the percent reduction of premature mortality between 2010 and 2030 is greater for

Table 1. All-Cause Premature Mortality Rate for 2006–30 at the Most Recently Observed Mortality Rate (2006 to 2015) and at the Model-Projected Rate, Rate Per 100,000 (95% Uncertainty Interval for Rate)

	Age- group	2006	2010	2015	2020	2025	2030	%change[a]
Women	25 to 29	84.1(81.2 to 87.2)	93.8(90.9 to 96.7)	58.8(56.4 to 60.8)	55.3(21.5 to 141.7)	52.2(13.4 to 195.5)	49.3(8.8 to 254.8)	-47.4
	30 to 34	84.7 (81.7 to 88.1)	83.6(80.7 to 86.2)	65.1(63.4 to 68.2)	59.5(44.5 to 80.7)	54.1(32.8 to 86.8)	49.5(24.3 to 91.3)	-40.8
	35 to 39	90.9(86.4 to 92.9)	79.3(77.2 to 81.8)	79.1(76.7 to 81.6)	77.8(66.7 to 88.7)	76.6(59.9 to 93.4)	75.4(54.1 to 98.3)	-4.9
	40 to 44	124.9(119.6 to 127.6)	112.2(109.5 to 115.3)	110.3(106.6 to 113.0)	107.1(93.6 to 120.7)	104.4(84.7 to 125.5)	101.8(76.4 to 131.0)	-9.3
	45 to 49	184.2(178.6 to 188.5)	171.0(167.2 to 175.2)	166.4(161.7 to 170.2)	160.9(144.5 to 178.2)	156.3(131.2 to 184.4)	151.9(119.5 to 189.9)	-11.2
	50 to 54	299.9(292.1 to 308.7)	287.8(280.7 to 294.8)	275.4(265.2 to 279.9)	260.5(215.3 to 315.9)	250.1(184.8 to 333.7)	239.7(158.0 to 349.7)	-16.7
	55 to 59	529.4(514.2 to 541.2)	483.2(471.4 to 493.3)	461.4(447.5 to 468.8)	439.2(363.9 to 533.0)	422.9(310.4 to 567.1)	407.7(263.6 to 600.6)	-15.6
	60 to 64	865.8(844.7 to 879.1)	805.9(789.0 to 815.3)	802.9(789.3 to 815.5)	797.8(729.0 to 858.1)	793.1(683.4 to 889.7)	788.3(643.5 to 923.5)	-2.2
	65 to 69	1447.8(1424.4 to 1474.1)	1346.7(1330.6 to 1370.0)	1320.2(1302.2 to 1342.9)	1295.6(1195.8 to 1388.2)	1268.0(1111.9 to 1423.5)	1241.8(1033.1 to 1457.8)	-7.8
Age-standardized[b]		244.9(238.1 to 250.5)	230.6(225.5 to 235.6)	215.7(210.4 to 220.2)	208.8(177.6 to 253.1)	202.8(158.4 to 273.9)	197.2(142.0 to 295.4)	-14.5
Men	25 to 29	181.2(177.2 to 185.6)	174.0(170.3 to 177.7)	138.9(134.5 to 141.5)	116.0(91.2 to 153.2)	97.9(65.3 to 154.5)	82.9(46.9 to 153.1)	-52.4
	30 to 34	199.9(194.8 to 204.6)	189.1(184.5 to 192.7)	151.4(148.9 to 156.3)	128.9(103.7 to 162.5)	109.1(75.7 to 158.9)	92.5(55.7 to 156.0)	-51.1
	35 to 39	223.1(216.5 to 227.6)	210.9(203.5 to 214.1)	180.7(177.0 to 185.9)	161.9(128.1 to 201.1)	144.3(98.9 to 205.6)	128.6(76.9 to 207.3)	-39.0
	40 to 44	280.2(273.5 to 286.3)	257.8(251.9 to 262.5)	234.1(228.3 to 238.8)	212.2(185.3 to 244.6)	193.1(153.6 to 242.9)	175.7(127.5 to 242.3)	-31.8
	45 to 49	385.2(379.6 to 396.6)	373.9(365.2 to 379.0)	334.1(327.5 to 341.1)	301.9(265.2 to 345.5)	272.9(218.6 to 340.0)	246.6(181.3 to 334.1)	-34.0
	50 to 54	614.3(603.5 to 628.1)	581.2(569.1 to 589.9)	525.4(511.6 to 532.5)	472.6(396.2 to 570.3)	428.8(321.2 to 577.4)	389.0(259.2 to 586.5)	-33.1
	55 to 59	976.8(955.8 to 995.1)	873.8(857.8 to 889.3)	861.6(843.5 to 873.1)	804.9(618.7 to 1028.8)	753.1(493.8 to 1114.4)	704.5(398.5 to 1193.8)	-19.4
	60 to 64	1429.9(1400.9 to 1454.1)	1306.4(1284.9 to 1330.6)	1339.3(1321.6 to 1363.9)	1296.3(1035.9 to 1553.7)	1248.1(869.3 to 1672.9)	1206.0(736.2 to 1800.8)	-7.7
	65 to 69	2171.2(2133.1 to 2204.9)	1937.1(1907.9 to 1973.7)	1952.4(1926.1 to 1991.1)	1863.7(1460.1 to 2312.1)	1771.1(1186.9 to 2491.7)	1676.5(987.9 to 2694.5)	-13.5
Age-standardized		447.6(438.6 to 456.8)	414.3(405.7 to 421.6)	385.2(377.7 to 392.7)	353.9(285.8 to 434.2)	325.7(229.5 to 452.4)	300.3(186.3 to 470.8)	-27.5

[a] Excess or reduction (percentage of change) in all-cause premature mortality rate in 2030 relative to the 2010.
[b] Iranian population in 2015 used as the standard population for standardization.

men than women for all other age groups. The greatest reduction in mortality during 2010 to 2030 for both sexes is projected to occur in the 25–29 age group (Table 1); this reduction is projected to be 52.4% in men and 47.4% in women.

Figure 1 illustrates the mortality trend of each age and sex group as well as age-standardized mortality trend between 2006 and 2030. Each of these graphs shows the calculated mortality rates based on the observed mortality data and Iran's population for the years 2006–2015. The estimated levels using Bayesian hierarchical model have also been shown for 2016–2030.

Also, Supplementary file 1 containing Tables S1-S2 shows the crude number of deaths, mortality rates and population for each age and sex for 2006 to 2030.

Discussion

Based on our findings, there was a declining trend in all-cause mortality in all age and sex groups during 2006-2015 which is projected to continue during 2016–2030. In all age groups, the percent reduction in the mortality rate in 2030 was higher in men than women compared to 2010. The highest and lowest percent reduction in the mortality rate in 2030 (compared to 2010) was projected in 25–29 year-old men (52.4%) and in 60–64 year-old women (2.2%), respectively.

One study examined premature mortality using the data and life tables provided by the UN Population Development (UNDP) which had studied the trend of premature mortality (under 70 years) for 1970–2010 and projected its changes for 2010–2030 all over the world, in 25 highly populated countries and also for four World Bank income groups.[4] Except for South Africa, a declining trend was observed for premature mortality in all the countries under study and in all income groups, although the reduction rate was different for different countries and income groups.[4] Premature mortality reduction in this study was higher compared to our study. One reason for this discrepancy may be differences in the definition of premature deaths in the two studies. We defined premature death as deaths in 25 to 69 years of age, whereas in that study, premature death was defined as deaths before the age of 70 years.

Similar to our results, a study in the US that examined premature mortality among 25–69 year-olds using the age-period-cohort approach, found that 1990–2016 all-cause-mortality had a declining trend in all races of American men, and projected that this trend would continue from 2017 through 2030.[3] The percent reduction in the premature mortality of men over time was lower in this study in comparison to our study (18.9% vs. 27.5%). Moreover, premature mortality reduction was higher in

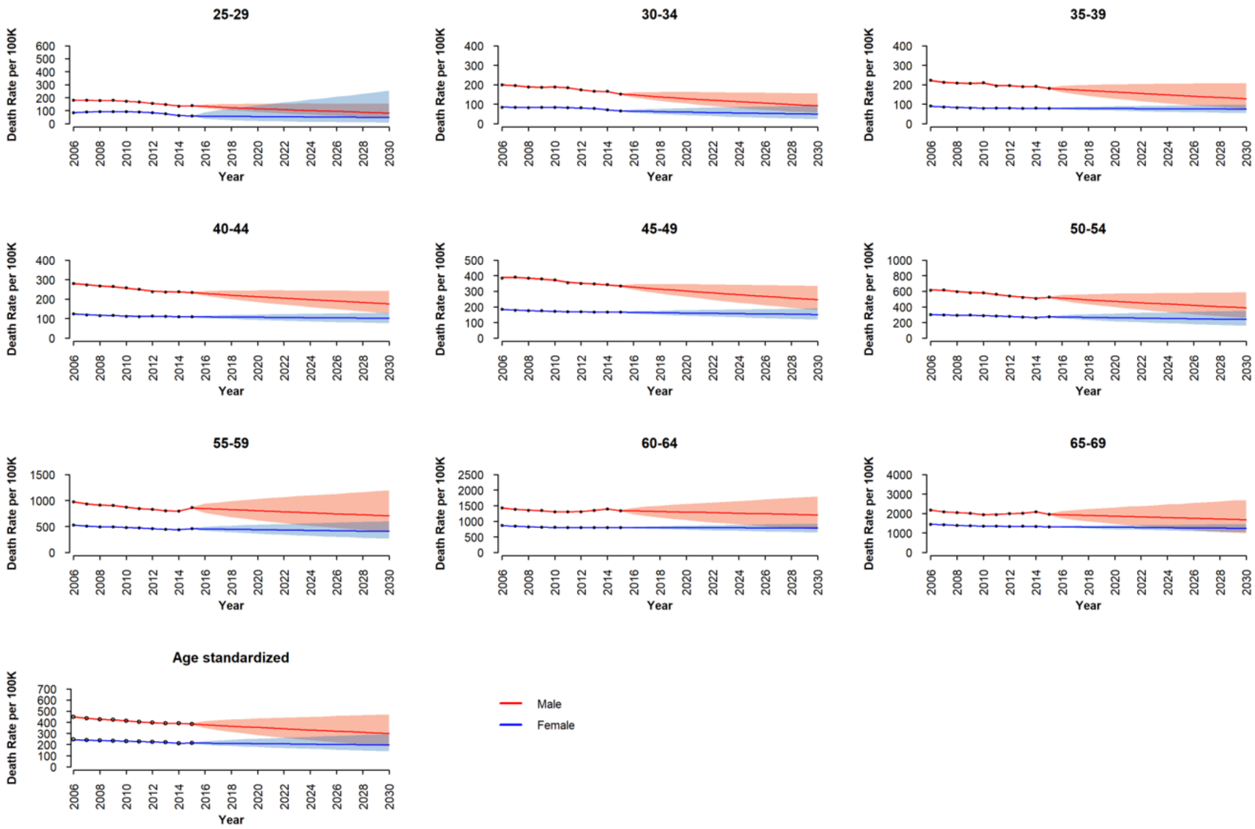

Figure 1. Observed and Projected All-Cause Premature Mortality Rate and Age-Standardized All-Cause Premature Mortality Rates for Those Aged 25–69 Years by Age-Group and Sex. Observed rates are for 2006–2015 and projected rates to 2030. Shaded areas denote pointwise 95% UIs for mortality rates.

women in this study compared to our study (19.2% vs 14.5).[3]

Consistent with previous studies, the result of this study projected that the all-cause mortality difference between men and women is narrowing in recent years. A possible reason behind the difference in reduction of mortality rates between men and women is due to the lower baseline premature mortality rates in women. "Also, one of the possible causes for narrowing of the mortality gap between men and women could be the change of risk factors pattern in women".[14,15]

A study conducted in Iran projected the crude mortality rate by 2035 using the Lee-Carter approach; although a declining mortality trend was observed for different age groups (consistent with the current study) the mortality percent change between 2010 and 2030 was different for most age groups compared to the current study.[16] As a case, the study projected that all-cause mortality rate decline in 65–69 year-old people from 1717 per 100 000 persons in 2011 to 1402 per 100 000 persons in 2031 (a 18.3% reduction). One of the possible reasons for this difference (which is seen more often in younger age groups) is the application of different projection models in the two studies. Among Lee-Carter's limitations are lack of accurate projections of mortality rates in subgroups of small populations and considering the ratio of mortality rate variation across different age groups over time to be consistent, both of which may result in inaccurate estimates.[17,18] It also seems that in this study, unlike our study, incompleteness of mortality was not corrected.

A large proportion of premature deaths are due to non-communicable diseases.[4] Literature in Iran indicates a declining trend for deaths due to major non-communicable diseases such as cardiovascular diseases and cancers.[13] Thus, a large part of the trend observed in this study may be interpreted as a drop in deaths due to non-communicable diseases. Although emphasis has been placed on the measurement and projection of all-cause mortality,[19] projection of premature mortality by causes of death, provinces and determinant factors such as socioeconomic status in future studies can help plan more accurate and focused interventions and better clarify the causes of this reduction.

This study had certain strengths and limitations. One of its strengths was the use of the Bayesian hierarchical approach on Iran's mortality data for the first time and the use of the data of ten years for projection purposes. Like other health registry systems, Iran's DRS may have certain flaws such as incompleteness. In this study, we attempted to overcome this shortcoming through appropriate approaches. Moreover, the mortality data from Tehran and Isfahan were gathered from cemetery organizations. However, certain changes have been introduced in the national DRS since 2014, and data from the whole country are gathered by a single integrated system ever since. Therefore, part of the changes we observed in the mortality trend in 2014 and 2015 may be due to DRS changes.

In conclusion, based on the results of this study, it is projected that premature mortality will have a declining trend in Iran. Therefore, we expect to achieve a less than one third reduction in premature mortality by 2030 in most age and sex groups. However, since the reduction in premature mortality by 2030 is different for different sex and age groups, we recommend that in addition to planning and intervening at a macro level, policy makers should focus on interventions specific to age and sex groups, as well.

Authors' Contribution

VB, SN, MAM and AF made substantial contributions to the study conception and design, analysis and interpretation of data, drafting the manuscript and revising the manuscript critically for important intellectual content. MP and HRA participated in statistical analysis, interpretation of data and revising the manuscript critically for important intellectual content. All authors agreed on the final manuscript prior to submission. All authors agreed to be accountable for all aspects of this work.

Conflict of Interest Disclosures

None.

Ethical Statement

This study has been ethically approved by the Ethics Committee of Tehran University of Medical Sciences with code number: IR.TUMS.SPH.REC.1397.4985.

Supplementary Materials

Supplementary file 1 contains Tables S1-S2.

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