

Study Profile

Levels and Trends of Child and Adult Mortality Rates in the Islamic Republic of Iran, 1990 – 2013; Protocol of the NASBOD Study

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Abstract

Background: Calculation of burden of diseases and risk factors is crucial to set priorities in the health care systems. Nevertheless, the reliable measurement of mortality rates is the main barrier to reach this goal. Unfortunately, in many developing countries the vital registration system (VRS) is either defective or does not exist at all. Consequently, alternative methods have been developed to measure mortality. This study is a subcomponent of NASBOD project, which is currently conducting in Iran. In this study, we aim to calculate incompleteness of the Death Registration System (DRS) and then to estimate levels and trends of child and adult mortality using reliable methods.

Methods: In order to estimate mortality rates, first, we identify all possible data sources. Then, we calculate incompleteness of child and adult mortality separately. For incompleteness of child mortality, we analyze summary birth history data using maternal age cohort and maternal age period methods. Then, we combine these two methods using LOESS regression. However, these estimates are not plausible for some provinces. We use additional information of covariates such as wealth index and years of schooling to make predictions for these provinces using spatio-temporal model. We generate yearly estimates of mortality using Gaussian process regression that covers both sampling and non-sampling errors within uncertainty intervals. By comparing the resulted estimates with mortality rates from DRS, we calculate child mortality incompleteness. For incompleteness of adult mortality, Generalized Growth Balance, Synthetic Extinct Generation and a hybrid of two mentioned methods are used. Afterwards, we combine incompleteness of three methods using GPR, and apply it to correct and adjust the number of deaths.

Conclusion: In this study, we develop a conceptual framework to overcome the existing challenges for accurate measuring of mortality rates. The resulting estimates can be used to inform policy-makers about past, current and future mortality rates as a major indicator of health status of a population.

Keywords: Adult mortality, child mortality, incompleteness, indirect methods, Iran

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Introduction

Mortality measures are one of the most important indices in calculation of burden of diseases and risk factors. Age and sex specific mortality rates together with other epidemiologic and socioeconomic information generate valuable evidences that can be used for health decision and policy-making.^{1,2} Also, child mortality rate is among the main indicators of population health status, and data on causes of death is a main determi-

nant to estimate the burden of diseases.^{3,4} Nevertheless, the reliable measurement of mortality rates is the main barrier to reach this goal. Complete registration of death is necessary to develop and maintain the mortality data in a given population. As exaggerated by some authors, the health improvements in developed countries is partly dependent on valid mortality and morbidity data.⁵

The best data source to estimate mortality statistics is vital registration system (VRS), which captures all birth and death cases in a population.⁶ Unfortunately, most of the developing countries have either dysfunctional or no vital registration system at all. Therefore, based on VRS, there is no estimate of mortality indicators or they are mostly biased.^{7,8} WHO reported of 192 countries in 2009, only about 60 countries had complete VRS data and the data from remaining countries were incomplete.⁹ Studies have shown that mortality data from VRS are misclassified and under-reported in Iran.^{10,11}

Iran has started a project entitled National and Sub-national Burden of Disease (NASBOD),¹² which aims to estimate the burden of diseases and attributable burden of risk factors from 1990 to 2013. The project has different parts and modules; one of the major components of NASBOD is to estimate the mortality rates by sex and age at the national and provincial levels. Because of in-

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complete death registration system and lack of information about the trends and patterns of mortality in Iran, a variety of demographic and statistical methods have been devised to overcome these limitations. The aim of present study is to provide a conceptual framework to estimate accurate levels and trends of child and adult mortality in Iran.

Materials and Methods

Following the formation of a core team for the burden of disease project, we formed a technical team, including leading academic scholars and independent experts in Demography, Biostatistics, and public health, which guide and help on estimation methods, technical issues, data sources and strategies for data analysis and data quality assessment. Due to the low quality of data from Death Registration System in Iran and to estimate the plausible level of child and adult mortality, we have used data from various sources and applied different methods.

Data sources

Death Registration System

Currently Ministry of Health and Medical Education (MOHME) and National Organization for Civil Registration (NOCR) collect mortality data in Iran. Because of delayed registration and inaccurate recording of cause of deaths in NOCR data, only MOHME data was employed in this study.¹³ The MOHME death registration systems collected by Deputy of Research and Technology from 1996 to 2001 and by Deputy of Public Health from 2001 to 2010. This system registers the death by age, sex, cause of death, date of death, place of residence, and other information.¹⁰ However, there are several records with missing values for age and sex in these data sources. In order to calculate age and sex specific mortality separately for each province, it is necessary to impute for these demographic characteristics. Beside the problem of missing values, death registration systems are subject to underreporting and it is necessary to adjust mortality rates for the percent of incompleteness.

Censuses

The 1956 census was the first attempt to officially calculate the national population of Iran by the office of public statistics. Afterward, censuses are systematically iterated every 10 years, except for two recent censuses that have been conducted over five-year periods. Accordingly, seven censuses have been conducted so far. Since the census 1986, summary birth history questions have been incorporated into the census questionnaires, which provide information on the proportion of the total number of children who have died to the number of children ever born (CD/CEB). This information can be used to indirectly estimate child mortality rates.

Demographic and Health Survey

Iranian Demographic and Health Survey (DHS 2000) is a national survey, based on the international demographic and health surveys. It provides information about demographic, socio-economic and health indicator of population. In addition, it includes summary birth history questions, which can be used for indirect measuring of child mortality rates.

Child mortality is defined as the probability of dying between birth and exact age 5 (5q0). Due to the importance of levels and trends of mortality, alternative methods have been devised to esti-

mate child mortality rates. An overview of child mortality estimation process and data sources is depicted in Figure 1. The data were extracted from a variety of sources, including Death Registration Surveys 1996 – 2010, Iranian Demographic and Health survey (DHS 2000) and censuses 1986, 1996 and 2006.

As mentioned, complete and reliable death registration systems are best data source to estimate mortality statistics. However due to misreporting of sex and age and underreporting the number of death, it is necessary to address these issues first. We deal with missing data using Amelia package II which is a general purpose approach to deal with this problem.¹⁴ In order to take into account incompleteness, there are two indirect methods to measure child mortality rates: full (or complete) birth history (FBH) and summary birth history (SBH). FBH directly calculates mortality rate and incorporates uncertainty into estimation. Nevertheless, this method has several limitations. It is subject to several types of biases and depends on the extent of sample size. Accordingly, SBH data is employed. This method is simple, cost effective and needs answers to two questions asked from the reproductive age women (15 – 49 years old). Women are asked to reply the number of children ever born and number of children surviving. This method is an indirect one, and surmounts most drawbacks existing in FBH.¹⁵

Child mortality estimation

Indirect Methods of child mortality estimation

William Brass first introduced the summary birth history, which takes into account the exposure duration. Nevertheless, Brass method has some assumptions, which may not be fulfilled in practice. For example, it assumes that mortality and fertility trends are constant. Therefore, various versions of Brass method were introduced in which the assumption of constant mortality over time became flexible.¹⁶ In the following part, we explain Maternal Age Cohort (MAC) and Maternal Age Period (MAP) methods to analyze SBH data. Estimates obtained from these two methods are combined using LOESS regression, which is a nonparametric weighted regression. This method was presented in detail elsewhere.¹⁷

Maternal Age Cohort Method

Maternal Age Cohort method modifies UN method by two ways. First, it directly estimates under-five mortality, without any need to convert the probability of dying at age 0 to a probability of dying between birth and age of five, for all maternal age groups. Second, the method captures country and regional variation and allows estimating the rate accurately.^{15,17} The model yields two equations:

$$\text{Logit}(5q0_{ijk}) = \beta_{0i} + U_{ij} + \beta_{1i} \log \left(\frac{CD_{ijk}}{CEB_{ijk}} \right) + \beta_{2i} CEB_{ijk} +$$

$$\beta_{3i} \frac{P(15-19)_{jk}}{P(20-24)_{jk}} + \beta_{4i} \frac{P(20-24)_{jk}}{P(25-29)_{jk}} + \varepsilon_{ijk}$$

$$\text{Reference time}_{ijk} = \beta_{0i} + \beta_{1i} \left(\frac{CD_{ijk}}{CEB_{ijk}} \right) + \beta_{2i} CEB_{ijk} +$$

$$\beta_{3i} \frac{P(15-19)_{jk}}{P(20-24)_{jk}} + \beta_{4i} \frac{P(20-24)_{jk}}{P(25-29)_{jk}} + \varepsilon_{ijk}$$

Where, U is the coefficient for country effect, i = women age group (15 – 19, 20 – 24, 25 – 29... 45 – 49), j = country, k = year in which the survey was conducted, CD = number of children Death, CEB = number of children ever born, and finally $P(i)$ = average parity for women age group i .

Indeed, the first model calculates under-five mortality on logit scale and the second model calculates reference time for every estimate resulted from a former model. Reference time is the date to which the estimate pertains.

Maternal Age Period Method

The MAP method uses the life tables to find the probability distribution of fertility and mortality for every female age group over time, and then it applies the resulted distribution of children ever born and the number of children deaths. At the next stage, proportion of CD/CEB for every female age group is obtained for every year prior to the survey, and finally under-five mortality is estimated by using the following regression model:^{15, 17}

$$\text{Logit}(5q_{0_{ijk}}) = \beta_0^0 + U_{ij} + \beta_1^1 \log \left(\frac{CD_{ijk}}{CEB_{ijk}} \right) + \varepsilon_{ijk}$$

Spatio-temporal Model

For a quality assessment of LOESS estimates, we will draw a scatter plot of observed mortality rate against predicted values based on years of schooling and wealth index. Provinces whose estimates depart largely from predicted values will be dropped out and estimated based on these covariates. However, the ordinary regressions leave much of the variation unexplained and are not the best approach. Since the patterns of unexplained variation are similar for neighboring provinces and nearby time periods, we will employ Bayesian spatio-temporal model. This is a flexible framework which can “borrow information” from neighboring areal units and also capture both linear and non-linear trends over time.¹⁸ Thus, it can be used as a predictive tool for provinces with poor estimates or with no data.

Gaussian Process Regression

Since indirect methods estimate child mortality rates for 25 years before each study, we have different time series for child mortality rates. We utilize Gaussian process regression (GPR) as the final stage in spatio-temporal model. GPR will be used to synthesize these time series and produce unified estimates during the course of the study. Also sampling and non-sampling errors can be incorporated into this method to produce an uncertainty interval for final estimates. Sampling error is based on binomial distribution and is a function of population size and child mortality rate and non-sampling errors will be estimated based on the degree of disagreement between these time series. If these time series would be different, high non-sampling variance will be estimated. This model outperforms alternative synthesizing methods such as LOESS and spline and has better out of sample predictive ability.¹⁷

The final GPR estimates will be used to calculate incompleteness for child mortality. By comparing these estimates with DRS estimates, the percentage of underreporting will be determined. This percentage is used to correct the levels of child mortality and to produce reliable estimates using death registration systems.

Adult mortality Estimation

Adult mortality is defined as the probability of dying between the ages of 15 and 60 (45q15). That is, the probability of a 15-year-old dying before reaching age 60. We use data from the death registration system collected by MOHME from 1996 to 2010. Estimating adult mortality is constrained by the problems related to incomplete death registration, inaccurate enumeration of population, and age and sex misreporting (Figure1). Among alternative methods for adult mortality, death distribution methods (DDMs) estimate the degree of incompleteness of the death registration system are more reliable and valid in the presence of biases.^{19,20}

Death Distribution Methods

Death Distribution Methods (DDMs) include Generalized Growth Balance (GGB), Synthetic Extinct Generation (SEG) and a hybrid of two methods (GGB-SEG). Further explanation of these approaches is presented below.¹⁹

Generalized Growth Balance

This method is based on Demographic Balancing Equation which assumes that the growth rate of a population to be equal to the entry rate due to birth minus the exit rate due to death. In addition, we can use this equation for open-ended age groups ($x+$). Therefore, difference between entry rate $x+$ and the growth rate $x+$ yields an estimate of death rate $x+$. If we calculate the estimated residual which is resulted from two population censuses and then compare it with the registered deaths, the completeness of registered death relative to the population estimate can be calculated. In view of that, Hill showed:

$$\frac{\sqrt{{}_5N_{1_{x-5}} \times {}_5N_{2_x}}}{5 \times \sqrt{N_{1_{x+}} \times N_{2_{x+}}}} - \frac{1}{t} \ln \left(\frac{N_{2_{x+}}}{N_{1_{x+}}} \right) \approx \frac{1}{t} \ln \left(\frac{k_1}{k_2} \right) + \frac{\sqrt{k_1 \times k_2}}{c} \times \frac{D(x+)}{t \times (\sqrt{N_{1_{x+}} \times N_{2_{x+}}})}$$

Where, N_1 and N_2 denote the number of population at the beginning and end of the period, respectively, and D is the number of deaths between two censuses. Also, k_1 , k_2 and c are completeness of enumeration of the first and second census and intercensal death respectively. The rate of the registered death($x+$) is as follows:

$$\frac{D(x+)}{t \times \sqrt{N_{1_{x+}} \times N_{2_{x+}}}}$$

And an estimate of death based on the age distribution of two censuses is

$$\frac{\sqrt{{}_5N_{1_{x-5}} \times N_{2_x}}}{5 \times \sqrt{N_{1_{x+}} \times N_{2_{x+}}}} - \frac{1}{t} \ln \left(\frac{N_{2_{x+}}}{N_{1_{x+}}} \right)$$

Finally, $\frac{\sqrt{k_1 \times k_2}}{c}$ represents the corrected factor for the registered death.^{19,21}

Synthetic Extinct Generation (SEG)

Generally, this method compares $N^d(x)$, number of persons aged x calculated from the age distribution of the registered death with $N^c(x)$, number of persons aged x calculated from the age distribution of two censuses. Then, the ratio of the estimate of population calculated from registered death to estimate resulted from the observed population is calculated. The synthetic estimate of population age x is given by:

$$N(x) = \int_x^{\omega} D(y) e^{\int_x^y r(z) dz} dy$$

Where $N(x)$ is the estimated population aged x , $D(y)$ is the observed number of death at age y and $r(z)$ is the age specific growth rate of the population at age z . In addition, $N^c(x)$ of the census is given by:

$$N^c(x) = t \times 0.2 \times \sqrt{P1(x-5,5)P2(x,5)}$$

Death at ages above x is adjusted for the cumulative population growth rate between x and the age of death to convert them into a stationary population equivalent.^{19,21}

Adjusted synthetic extinct generation method

This method is a combination of previous methods. In this method, first, GGM method is used to obtain changes in coverage of the first census relative to the second one, and then SEG is applied to calculate the adjusted factor to derive number of deaths.^{19,21}

As explained for child mortality, we use spatio-temporal models to predict for provinces with unrealistic estimates and Gaussian process regression to synthesize these three methods.

Dealing with data scarcity for mortality rates

To estimate child mortality for new provinces formed recently, we try to reconstruct those provinces based on district information for the time when they did not exist. Also, there is no data available for the years before the establishment of death registration system in Iran to estimate adult mortality. For these years, unmeasured mortality rates were considered as missing values. The common solution for this problem is using Latent Class Model to estimate these values. In this framework missing data along with model parameters will be considered unknown. These unknown parameters will be estimated via a Bayesian spatio-temporal model that uses information from neighboring areal units, nearby time periods, and covariates which have strong correlation with mortality rate.¹⁸

Discussion

Like other developing countries, Iran's death registration is incomplete, leaving an impact on estimations of mortality rates. Considering the importance of mortality rates as a part of burden of disease project, in this study we aim to estimate corrected child and adult mortality rates using various data sources and reliable methods. These methods are validated and low cost and also incorporate uncertainty into estimates.

There are few studies on the estimation of child mortality in Iran. In the study conducted by Khosravi et al in the year 2004, the child mortality rate was estimated 35 and 30 deaths per 1000 live

birth for male and female respectively. Based on these finding, Sistan and Baluchistan province had highest rate of mortality with 47 deaths per 1000 live birth and Tehran and Gilan provinces had the lowest rate with 25 deaths per 1000 live birth.¹³

In a study investigating the consistency of under-five mortality estimates between complete birth history and summary birth history, it was observed that generally the two estimates are consistent and when a population has a smooth mortality trend, estimates by the two methods are equal.²²

Rajaratnam et al studied the validity of summary birth history for 166 Demographic and Health Survey. They proposed new methods using SBH questions for estimation of under five mortality rates. The finding shows substantial improvement using these new methods. As a result, countries without registration system can use low-cost SBH methods to estimate U5MR. The cohort and period-derived methods act similarly with respect to the average relative error; however, the period-derived methods have the additional benefit of allowing for estimation closer to the time of the survey and further back in time as well.¹⁵ Institute for Health Metrics and Evaluation (IHME) extends these methods and estimated child mortality rates for 187 countries from 1970 to 2010. They used 16,174 measurements of mortality in under-five children using data sources including vital registration, censuses and surveys, and complete birth histories. Results showed that the absolute number of under-five mortality declined from 11.9 million in 1970 to 7.7 million in 2010. A great deal of these mortalities was in sub-Saharan region (49.6 %) and the lowest level of mortality was in high-income countries (less than 1 %). In addition, they declared that the sharp decline had happened from 2000 to 2010 compared with 1990 to 2000.¹⁷

In another paper, the authors compared the estimates produced by United Nations Inter-agency groups for child mortality estimation (UN IGME) and Institute for Health Metrics and Evaluation (IHME). In UN IGME method, indirect methods are based on UN Manual X methodology, and discard recent estimates obtained from women 15 – 19 and 20 – 24 years old, while IHME Methods is based on update of parameter estimates and derivation of indirect estimates from maternal cohort data. Also, UN IGME use LOESS for smoothing under-five mortality rates, while IHME use GPR which surpass LOESS and other existing method to synthesize the results. These results show the estimates are similar at global level but they are different at country level, especially in low-income or HIV high prevalence countries or where there is no registration system.²³

As mentioned in method session, both indirect methods (MAC and MAP) are employed to estimates child mortality rates. We use spatio-temporal model to use additional information of covariate effects to predict for provinces with poor data quality or no data. Also, GPR is used as a final stage of spatio-temporal model to synthesize different data sources and produce uncertainty intervals. Therefore, our methodology is consistent with IHME group, but we extends their result for Iran in two main aspects: The most important aspect is that this study estimates national and subnational mortality rates which can reveal major differences between provinces, crucial to identify inequalities and set priorities in our country. The second aspect is the wide variety of national and subnational data sources which has been collected in NASBOD study that empower our estimates compared to IHME estimates.

There are several studies on the estimation of adult mortality rates which have been conducted in Iran. In order to construct

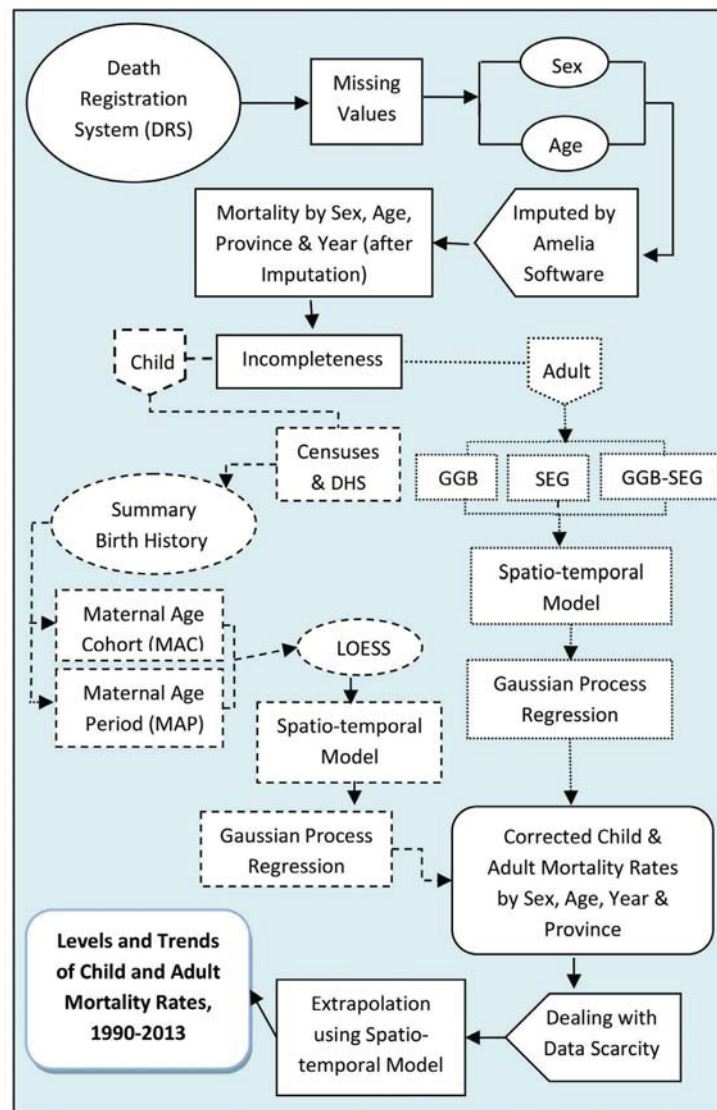


Figure 1. An Overview of Mortality Estimation Process

life tables for Iranian population, Pourmalek et al calculated incompleteness of death registration by 0.85 in the year 2003. The unadjusted number of deaths was 213000 deaths, while the adjusting number was estimated 250589. To calculate under-counting of death, Brass method was used which has limitations on its assumptions. Also, the number of provinces was limited to 23 rather than 28 provinces.²⁴

In a study published in 2007, the researchers used Brass Growth Balance method for the assessment of completeness of the death registration system of Iran. They estimated death registration completeness for adults aged five years and above is 76 % for the period 2001 – 2004. The authors of the study estimated the risk of death for adult mortality in 2004 to be 0.124 and 0.175 for females and males, respectively. The study had some limitations. First, they didn't use individual data and their estimations were based on a systematic review of other studies. Also, they used Brass Method for estimation of adult mortality which has assumptions may not hold.¹⁰

Farzadfar et al assessed the incompleteness of the death registration system and estimated adult mortality using death distribu-

tion methods. In this study, GGB-SEG was selected as the best method for adjusting the registered deaths. The corrected number of deaths occurred during the year 2005 was estimated 352000. However, the study was limited to deaths occurred in 2005, while we cover the deaths occurred during 1990 to 2013.²⁵

Rajaratnam in her study investigated mortality of 15-59 years old men and women worldwide from 1970 to 2010. She used 3889 measurements related to adult mortality for 187 countries using vital registration data and census and survey data for deaths in the household corrected for completeness, and sibling history data from surveys corrected for survival bias. She reported that adult mortality varied across the world and over time. Iceland and Cyprus had the lowest rate of mortality for men and women, respectively. Swaziland and Zambia had the highest rate of mortality for men and women, respectively.²⁶

Although, in the present study, we are using the latest methods to estimate mortality statistics, there are still some limitations as follow: The methods don't work at places where there are extreme changes of fertility. Another limitation, which may arise, is when we use data sources other than DHS, in which the method of data

collection is different. As a result, estimates from two data sources may be different.^{13,17} In term of adult mortality, these methods are potentially affected by selection bias, particularly in the presence of migration, and therefore may not work correctly.

In this study, we developed a conceptual framework to estimate the level and trends of child and adult mortality rates at the national and sub national levels of Iran. To do this, various data and up-to-date methods will be used to achieve plausible estimates.

Policy implications

We will present our results to the MOHME and other related organizations. The results can be used to show how well the death registration system works, and accordingly policy-makers consider ways to improve the system.

Abbreviation

SBH: summary birth history; U5MR: under-five mortality rate; MAP: maternal age period method; MAC: maternal age cohort method; GGB: generalized growth balance; SEG: synthetic extinct generation; CBH: complete birth history; MOHME: Ministry of Health and Medical Education

Competing interests: The authors declare that they have no competing interests.

Author's contribution

FF, KY, AK were involved in the study conception and design. The study data were collected and cleaned by YM, AK and the staff of Ministry of Health and Medical Education and Statistical Center of Iran.

All authors were involved in data analysis and interpretation. FF, KY, AK, YM wrote the manuscript, which was finally approved by all the authors. All authors read and confirmed the final study profile.

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