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# Mathematical Models to Estimate the Maternal Mortality

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**Abstract:** The main aim of this paper is to apply mathematical model to estimate maternal mortality ratio using two Demographic and Health Surveys data of Nepal. We applied Bhat et al. [7] model to estimate maternal mortality for Nepal. The modification was also made by assuming the sex-ratio of mortality rates (excluding maternal causes of death) specific to women aged between 15 and 49 years might be equal to some constant K. The proposed method provided consistent estimates of maternal mortality ratio of 588 deaths per 100000 live births in 1996 and 351 deaths per 100000 live births in 2006 against the observed value of 539 and 281 deaths per 100000 live births respectively.

**Key words:** model, indirect technique, ratio, parameters, mortality, deaths.

## 1. INTRODUCTION

Maternal mortality is an important health indicator of a country [1]. Childbearing is taken as highly valued as well as an inevitable part of a woman's life. Maternal deaths continue to be a leading cause of death during the reproduction process due to less access to quality health care [2]. Maternal deaths were mainly occurred :(i) within the pregnant period, (ii) at the time of pregnancy ended, and (iii) after giving birth of a child [3,4]. Maternal cases were often taken as hidden events and mostly were undercount. This situation is not mainly because of a lack of clarity in defining a maternal death, but because of an inherent weakness in the health information and recording systems. Hence it is difficult to know the maternal mortality level in a country from the limited data. It is being rare occurrence events [2]. It needs a large population base and a sufficient number of observations for direct estimation of maternal deaths.

The level of maternal mortality in Nepal is known to be alarmingly high where it was 551 in 1991, 539 in 1996, 415 in 2001 and 281 per 100000 live births in 2006 [2,3,4]. However, figures show that maternal mortality ratio declined rapidly over time. Since, hospital-based studies tend to be highly localized and suffered from the problems of non-random case selection, inadequacies of sample size, and incomparable reference periods [1, 2]. Most of the births in Nepal do not take place in hospitals and therefore, the reported figures do not accurately reflect the number of deaths cases during pregnancy or childbirth [2].

Measurement of maternal mortality suffers seriously from under/over-reporting and misclassification of data [1]. Most of the surveys data were subject to wide variability and it needed to develop and graduate new technique to estimate the maternal mortality from limited data. Indirect techniques may be an appropriate tool to diagnose in such a situation. In fact, an indirect method of estimation has its origin and produce estimates of certain parameters on the basis of information, which is only related to its value indirectly [2].

Generally, estimation of demographic parameters has been done on the basis of data collected by census or by vital registration system or sample surveys [4]. Unfortunately, however, in many countries today, the data collection by these systems either do not exist or their quality is so poor [1, 2, 5]. The estimates based on such defective data yielded inconsistent results. Blum and Fergues [5] developed a technique to estimate maternal mortality ratio based on sex ratio differential and female age specific mortality rates. Devaraj *et al* [6] proposed a technique to estimate maternal mortality ratio through regression methodology by taking maternal mortality ratio as the dependent variable and infant mortality rate and total fertility rate as taking explanatory variables. Bhat *et al.* [7] proposed procedures to compute maternal mortality ratio based on sex differentials in mortality. Likewise, Aryal [1, 2] graduated the techniques to estimate the maternal mortality ratio from the data of sex differentials of mortality.

This paper tries to estimate maternal mortality ratio through different indirect techniques. The data were taken from Nepal Family Health Surveys 1996 and Nepal Demographic and Health Survey 2006 as well as other sources of data. The suitability of model proposed by Bhat *et al.* [7] was tested to the Nepal data. Under some assumptions, the modification on this model has also been proposed.

## 2. MODELS

The force of female deaths rate at age x from all causes (maternal and non-maternal) of death can be expressed in the following relations.

(1) $D_f(x) = D_f^0(x) + D_f^a(x)$

Where $D_f^0(x)$ and $D_f^a(x)$ denote the female death rate at age x from obstetric causes (maternal related death rates) and other than maternity causes (non-maternal related death rates) respectively.

Since mortality risk at age x from obstetric causes of deaths would be the product of the risk of giving birth at that age and the risk of dying from giving the birth [1]. Symbolically it is given below.

(2) $D_f^0(x) = \omega(x)\, f(x)$

Where $\omega(x)$ and $f(x)$ denote the age pattern of maternal mortality and age specific fertility rate respectively.

It is well-established fact that maternal related deaths are most likely occurring at the early ages of life (before age 20 years and later ages of life (after age 35 years). Let the ratio of maternal deaths to live births at any conveniently chosen age of 20-24 be denoted as ω [1, 2, 7]. However, in 20-24 age group, maternal mortality ratio was observed minimum and out of this age interval, the risk of mortality increases linearly. In such a situation, the normalized maternal mortality ratio (as maternal mortality ratio of age 20-24 is made equal to 1) at age x would be written as:

$w(x) = \frac{\omega(x)}{\omega}$, $for\ \omega > 0$,, for ω>0, equivalently it is given as.

(3) $\omega(x) = \omega\, w(x)$

Where ω and w(x) denote the measure of the level of maternal mortality and the normalized maternal mortality ratio at age x respectively.

As from equations (2) and (3), we have the relation as: $D^0(x) = \omega\, w(x)\, f(x)$, then we substitute it to the equation (1), and we finally get the following equation.

(4) $D_f(x) = \omega\, w(x)\, f(x) + D_f^a(x)$

On simplification, we get the force of male mortality rate, $D_m(x)$, at age x from all causes of deaths as below.

$$\frac{D_f(x)}{D_m(x)} = \frac{\omega\ w(x)f(x)}{D_m(x)} + \frac{D_f^a(x)}{D_m(x)}, \quad \text{equivalently} \quad R_x = \frac{\omega\ w(x)f(x)}{D_m(x)} + \frac{D_f^a(x)}{D_m(x)} \text{ and}$$

finally we get the following model.

$$(5) \quad R_x = G(x) + \omega Z_x$$

Where, $R_x = \frac{D_f(x)}{D_m(x)}$ denotes the sex ratio of mortality risk, $G(x) = \frac{D_f^a(x)}{D_m(x)}$ denotes the sex ratio of mortality in the absence of maternal mortality and $Z_x = \frac{w_x f_x}{D_m(x)}$ {where $w_x = w(x)\ and\ f_x = f(x)$}.

In model (5), G(x) is one of the functional parameter and ω is the slop parameter of the model and it is the level of maternal mortality at age interval 20-24.

Previous studies documented that the sex ratio of death rates among women of reproductive age in the absence of maternal mortality follows a linear function of age x [2, 7]. Then it follows the equation (5) as below.

$$(6) \quad R_x = \alpha + \beta x + \omega Z_x$$

Where $\alpha\ and\ \beta$ denote the regression coefficients of the model and other symbols have their usual meanings.

We can solve the equation (6) using least square principle, and once ω is estimated, an overall maternal mortality ratio (MMR) and maternal mortality rate would be computed from following relations.

$$(7) \quad \text{MMR} = \omega \frac{\sum w_x f_x n_x}{\sum f_x n_x} \quad \text{and} \quad \text{Maternal mortality rate} = \omega \frac{\sum w_x f_x n_x}{\sum n_x}$$

Where $n_x$ denotes the number of women at age x.

Since maternal mortality is usually estimated as maternal mortality ratio (it is the number of maternal deaths from maternal causes, divided by the total number of live births and expressed per 100000 live births) and maternal mortality rates (it is the number of maternal deaths from maternal causes, divided by the number of women in the population aged 15 to 49 years and expressed per 1000 women).

Model (6) provides the better estimates of maternal mortality for Indian data [7] but it fails to provide consistent estimates of maternal mortality ratio for Nepal data [1, 2]. This may perhaps be due to the irregular pattern of sex ratio of mortality or age specific death rate among females. Usually the sex ratio and female death rate corresponding to age interval (20-24) has been found significantly low in comparison with those of neighboring ages. Among others, a possible reason might be either the excess mortality among men due to accidents and violence or underreporting of the female deaths, and the assumption of a linear form for G(x) may be worthless [2]. Choosing G(x) is more critical for the estimation of maternal mortality ratio. Dummy variable, D, was introduced to balance such effects in switching the slope of G(x) beginning at the ages 20-24. [2, 7]. Hence the model (6) reduced to be:

$$(8) \quad R_x = \alpha + \beta x + \omega Z_x + D; \quad D = 0, \text{ for } 15-19 \text{ and } 20-24 \text{ and } D = x; \text{ otherwise.}$$

Since this model is also applied to Nepal as well as Indian data. Model gave better estimates for Indian data but it failed to give better estimates for Nepal data [1, 2, 7].

Finally keeping these limitations, we introduce the concept that the sex ratio of mortality rates (excluding the maternal causes of death) specific to women aged between 15 and 49 might be equal to some constant K.

Symbolically the sex ratio is, $\frac{D_f(x)}{D_m(x)} = G(x) = K$ and finally the model (6) reduces to the following equation.

$$(9) \quad R_x = K + \omega Z_x$$

This model may provide better estimate of MMR if there exist a different pattern in sex ratio of mortality by excluding maternal deaths of a population.

## 3. APPLICATION OF THE MODELS

We need the data for the application of the models (6) and (9) in order to estimate maternal mortality ratio (MMR). Data on age and sex specific death rates from all causes of deaths, and data on age specific fertility rate were taken from MOH [3,4]. The standardized age pattern of MMR was taken from Bhat *et al.* [7]. Since, this age pattern is universally accepted [1, 2, 5, 8]. The used data were presented in Tables 1 and 2.

**Table 1: Data used for estimation of MMR (NFHS 1996)**

| Age group (x) | Re-scaled x | MDR/ 1000$D_m$ | FDR/ 1000$D_f$ | SR of $D_f/D_m$ | ASFR $f_x$ | No. of exposure $n_x$ | Relative MMR* $w_x$ | $Y=w_x f_x$ | $Z=Y/D_m$ |
|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15-19 | 1 | 2.05 | 2.84 | 1.39 | 127 | 19627 | 1.9 | 241.33 | 117.70 |
| 20-24 | 2 | 2.37 | 2.29 | 0.97 | 266 | 20576 | 1.0 | 266.10 | 112.24 |
| 25-29 | 3 | 1.89 | 3.7 | 1.96 | 229 | 18107 | 1.2 | 274.80 | 145.40 |
| 30-34 | 4 | 2.4 | 3.12 | 1.3 | 160 | 14556 | 1.4 | 224.04 | 93.33 |
| 35-39 | 5 | 2.45 | 3.77 | 1.54 | 94 | 10818 | 1.8 | 169.20 | 69.06 |
| 40-44 | 6 | 4.52 | 5.13 | 1.13 | 37 | 6513 | 2.0 | 74.10 | 16.37 |
| 45-49 | 7 | 8.6 | 7.7 | 0.90 | 15 | 3964 | 2.4 | 36.03 | 4.19 |
| Total | | | | | 162 | 94,161 | | | |

MDR=male death rate, FDR=female death rate, SR=sex ratio ASFR=Age-specific fertility rate * *taken from Bhat et al.* [7]

Table 2: Data used for estimation of MMR (NDHS 2006)

| Age group (x) | Re-scale x | MDR/ $1000D_m$ | FDR/ $1000D_f$ | SR of $D_f/D_m$ | ASFR $f_x$ | No. of exposure $n_x$ | Relative MMR* $w_x$ | $Y=w_xf_x$ | $Z=Y/D_m$ |
|---|---|---|---|---|---|---|---|---|---|
| 15-19 | 1 | 3.03 | 3.44 | 0.88 | 98 | 22263 | 1.9 | 186.2 | 54.13 |
| 20-24 | 2 | 1.83 | 2.40 | 0.76 | 234 | 23427 | 1.0 | 234 | 97.50 |
| 25-29 | 3 | 3.16 | 2.43 | 1.30 | 144 | 20789 | 1.2 | 172.8 | 71.11 |
| 30-34 | 4 | 2.68 | 2.58 | 1.04 | 84 | 17953 | 1.4 | 117.6 | 45.58 |
| 35-39 | 5 | 2.92 | 2.52 | 1.16 | 48 | 13573 | 1.8 | 86.4 | 34.29 |
| 40-44 | 6 | 3.41 | 5.13 | 0.66 | 16 | 8625 | 2.0 | 32 | 6.24 |
| 45-49 | 7 | 3.90 | 5.70 | 0.68 | 2 | 4751 | 2.4 | 4.8 | 0.84 |
| Total | | | | | | 111382 | | | |

* *taken from Bhat et al.*[7]

The observed values of MMR were 539 in 1996 and 281 deaths per 100000 live births (for 0-6 years before the survey) in 2006 [3,4]. MMR was derived by the maternal death cases from the survey data. The maternal deaths are defined as any death that occurred during pregnancy, childbirth, or within two months after the birth or termination of the pregnancy.

Now we fitted the models (6) and (9) to the data of two surveys of NDHS 1996 and NDHS 2006. First we take G(x) as linear form. Model (6) is fitted to the data of age intervals (15-19) to (45-49), with the sex ratio of mortality, $R_x$, as the dependent variable, and age x and $Z_x$ as the explanatory variables and the fitted model is given below.

Using NFHS 1996 data in model (6), then we get the following estimated equation.

$R_x = -0.334 + 0.188\,x + 0.0112\,Z_x$; ($R^2$=0.89).

The coefficient of Z provides an estimate of MMR. Hence the estimated MMR was found to be 1120 for age interval of 20-24. As using, ω=1120, the overall MMR for women aged 15-49 came out to be 1490 deaths per 100000 live births. Model overestimates the MMR for NFHS 1996 as compared to the observed value of 539 deaths per 100000 live births [3].

Using NDHS 2006 data in model (6), then we get the following estimated equation.

$R_x = 0.738 + 0.013\,x + 0.003\,Z_x$; ($R^2$=0.38).

The coefficient of Z provides an estimate of maternal mortality level. Estimate of maternal mortality ratio was 300 for age interval of 20-24 i.e. assumed standardized age interval. With this estimate (ω = 300), the overall maternal mortality ratio for women aged 15-49 came out to be 389 deaths per 100000 live births for NDHS 2006 data. Model provides slightly overestimates of MMR for Nepal data as compared to the observed value of 281 deaths per 100000 live births [4].

Now, we fitted the model (9) and we get following estimated equation.

Using NFHS 1996 data in model (9), then we get the following estimated equation.

$R_x = 0.960 + 0.00442\,Z_x$; ($R^2$=0.41)

The model provided an estimate of MMR at age interval (20-24) of 442. Finally, an overall estimate of MMR was 588 deaths per 100000 live births for NFHS 1996 data, which is found to be very close to the observed value of MMR of 539 deaths per 100000 live births [3].

Using NDHS 2006 data in model (9), then we get the following estimated equation.

$R_x = 0.805 + 0.002701\,Z_x$; ($R^2$=0.98)

Model provided an estimate of MMR at age interval (20-24) of 270 and an overall estimate of MMR was 351 deaths per 100000 live births for NDHS 2006 data. The estimated value was also slightly over-estimates the MMR as compared to observed value of 281 deaths per 100000 live births [4]. The estimated MMR from different techniques and different data sets was given in Table 3.

**Table 3: Estimated and observed MMR for the NDHS 1996 and 2006 data**

| Used data | Observed MMR* | Estimated MMR/100000 live births | |
|---|---|---|---|
| | | Model: (6) | Model: (9) |
| NDHS 1996 | 539 | 1490 | 588 |
| NDHS 2006 | 281 | 389 | 351 |

*MOH[3,4]

## 4. CONCLUSIONS

This paper discusses the model proposed by Bhat *et al.* [7]. The modification of the model was made by introducing the concept that the sex ratio of mortality rates (excluding the maternal causes of death) specific to women aged between 15 and 49 might be equal to some constant K. The suitability of the models was tested with the Nepal Demographic Surveys data of 1996 and 2006. The models provided an estimate of MMR ranges from 588 to 1490 deaths per 100000 live births for NFHS 1996 data while it ranges from 351 to 389 deaths per 100000 live births for NDHS 2006 data. However, the proposed model provided a very close estimate of MMR for both the data of Nepal. The estimated MMR was found to be 588 in 1996 and 351 deaths per 100000 live births in 2006. These estimates are consistent with the observed MMR of 539 in 1996 and 281 deaths per 100000 live births in 2006. Findings of this paper may help planners and policy-makers to design the policies for reducing maternal mortality as well as fertility in a country where maternal mortality is still a major cause of death.

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