



Using vital registration data to track mortality in
Zimbabwe's metropolitan populations: 2000-2012

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ABSTRACT

The vital registration system in Zimbabwe is incomplete and mortality estimates produced from these data might not give a true representation of mortality in the population. However, it may be assumed that vital registration data for urban areas is more complete than for the country as a whole. This research was, therefore, conducted in an attempt to answer the question of whether vital registration data can be used to track the mortality of Zimbabwe's metropolitan populations. To answer this question, direct and indirect estimates from census and Demographic and Health Survey (DHS) data were used to decide on the viability of using these vital registration data to estimate mortality.

Estimates of under-five mortality between 2001 and 2011 from vital registration data ranged from around 50 to 80 deaths per thousand for Harare while Bulawayo's estimates were generally between 55 and 105 deaths per thousand in the same period. Bulawayo's vital registration data appeared to produce reasonable estimates of under-five mortality, while Harare's vital registration data underestimated both infant and under-five mortality when compared to the other supporting estimates from the alternative data sources.

For adult mortality, ${}_{45}q_{15}$, completeness of vital registration was estimated at 102 and 99 per cent for Harare males and females respectively, and 95 per cent for Bulawayo using the Death Distribution methods. The level of adult mortality from vital registration data in the middle of the period between the 2002 and 2012 census was 48.4 per cent for Harare males, 46.2 per cent for Harare females and 55.2 per cent for Bulawayo (males and females combined). Comparison of the annualised rates and the supporting estimates revealed that Harare's vital registration data produced reasonable estimates of male adult mortality for the population, while the level of female adult mortality was slightly underestimated. For Bulawayo, adult (male and females combined) mortality estimates were found to slightly overestimate the mortality of the population when compared to the estimates from the other data sources. The trend suggested by vital registration estimates, however, was similar to that suggested by the other data sources and methods, implying that vital registration data can be used, at the very least, to follow the trend of infant, under-five and adult mortality in urban areas.

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1 INTRODUCTION

1.1 Background

An accurate and complete vital registration system is the best source of statistical data on the mortality and fertility of a population (Timæus 1991). However, the use of such data to estimate mortality in developing countries cannot be relied upon due to a lack of completeness and uncertainty about the level of completeness in the vital registration systems of most of these countries (Timæus and Jasseh 2004). This incompleteness is a direct result of under-reporting, which stems from non-registration of the births or deaths. Consequently, the estimation of mortality for the aforementioned countries is dependent upon census and survey data, for which direct and indirect techniques can be used to produce estimates.

The estimation of mortality from censuses is primarily dependent on the deaths reported by households and data on the survival of parents and children, while for survey data, estimation depends on sibling and birth history data as well as data on the survival of parents. Dorrington, Timæus and Gregson (2006: 2-3) highlighted some of the problems associated with the deaths reported by households, namely, under-reporting, over-reporting and age misreporting. They also mentioned that “vital registration data, in general, can be expected to be more representative and less biased than data from households with the exception possibly of bias caused by differential coverage of specific populations”. As data on the survival of relatives and children are also subject to more or less the same errors, it is reasonable to expect vital registration data to also be more representative than these different data sources.

Generally, the use of census and survey data is less than ideal as the time frame between consecutive censuses and surveys, provided they even occur, may be long, that is, 10 years for censuses and five years for the DHS. In addition, these data sources have limitations of their own such as changes in mortality between consecutive censuses or surveys that go undetected, and also the fact that these data often provide estimates for a period a few years prior to the survey.

It is therefore important to investigate the extent to which the vital registration data can be used despite its possible incompleteness. If data are representative and completeness does not change substantially over time, vital registration data can give a reliable estimate of mortality or fertility trends regardless of the level of completeness. Also, if the extent of incompleteness can be estimated, then one can adjust the registration

data to produce estimates of the levels of mortality and fertility. Consequently, the use of vital registration data, though the data may be incomplete, may still be able to aid in filling the gaps left by other data sources, that is, census and national survey data, thus giving useful insights into the mortality of a population. Conversely, it may be possible to use the other data sources to improve the estimates from vital registration data through consistency with results from these sources.

As highlighted by Dorrington, Timæus and Gregson (2006), apart from South Africa, Zimbabwe is the only other country in Southern Africa that has vital registration data that are likely to produce meaningful mortality estimates. However, they identify the low level of completeness for adult female data (30-40 per cent) as a reason for the unreliability of the adult female mortality estimates produced. That being said, it is worth mentioning that vital registration data can be expected to be better for metropolitan populations than for rural populations for a variety of reasons including easier access to registrar offices. Thus, while completeness of registration might be low for the country as a whole, it could be sufficiently high in urban areas to allow for reasonable estimates of mortality to be produced.

1.2 Statement of the problem

This research will attempt to investigate the extent to which the vital registration data of Zimbabwe's metropolitan populations (Harare and Bulawayo) can be used to produce plausible estimates of mortality, on the basis of direct and indirect estimates from other sources, for the period 2000-2012.

1.3 Objectives of the study

The specific objectives of the study that will aid in accomplishing the main objective are:

1. To produce indirect estimates of infant, under-five and adult mortality for the populations of Zimbabwe, Harare and Bulawayo from the 2002 and 2012 census data.
2. To produce the direct and indirect estimates of infant, child and adult mortality for the populations of Zimbabwe, Harare and Bulawayo from DHS data available between 2002 and 2012.
3. To derive direct estimates of infant, under-five and adult mortality for the populations of Harare and Bulawayo using vital registration data (adjusted for completeness of reporting where possible) and census population numbers from 2000 to 2012.
4. To assess the reasonableness of mortality estimates derived from vital registration data using the estimates derived from other data sources.

1.4 Structure of the thesis

This study is presented in six chapters. Chapter 2 reviews the direct and indirect infant, under-five and adult mortality estimation methods, and also presents existing research on Zimbabwe's national and sub-national mortality estimates. Chapter 3 provides a description of the data used and assesses these data. The latter parts of this chapter give an outline of the direct and indirect methods used to estimate mortality in this study. The results from census and DHS data obtained from these methods are presented in Chapter 4, while the estimates from vital registration data are given in Chapter 5. A comparison of the vital registration and non-vital registration estimates is presented at the end of Chapter 5, before an assessment of the findings is given in Chapter 6. The conclusion and possible ideas for future research are also presented in the same chapter.

2 LITERATURE REVIEW

This chapter reviews the literature on the estimation methods of infant, under-five and adult mortality. An overview of the methods of estimation, direct or indirect, of adult mortality is given first, then methods of estimating infant and child mortality are considered next. The chapter ends by discussing estimates produced from past studies on Zimbabwe's national and sub-national mortality in the context of the research objectives.

2.1 Methods of estimating adult mortality

If the vital registration system is complete and reliable estimates of the population exposed to risk are available, age-specific estimates of adult mortality can be obtained by dividing the number of deaths in each age group by the population exposed to the risk of dying. Unfortunately for most sub-Saharan African countries, vital registration data are incomplete and hence direct estimates from vital registration data will be unreliable unless the vital registration data are adjusted for incompleteness.

To estimate mortality in these countries, various direct and indirect techniques have been developed. The remainder of this section reviews the estimation of adult mortality using the orphanhood method, sibling histories and the Death Distribution Methods, specifically, the Generalised Growth Balance (GGB) method and the Synthetic Extinct Generations (SEG) method.

2.1.1 Indirect estimation of adult mortality using the orphanhood method

The orphanhood method, whose original formulation was by Brass and Hill (1973), makes use of data on the survival of the respondent's parents and estimates the mortality of adult men and women using these data. Essentially, the method proposes that since the mother must have been alive at the birth of the child, the proportion of respondents whose mother is alive at the time of the survey provides an approximation of the survival probability of women at the mean age at childbearing to the sum of the mean age at childbearing and the respondent's age. The same notion applies for men; however, instead of the mean age at childbearing, the mean age of the father at conception of the child is used, as fathers may die in the period between conception and the birth of the child.

There have been various improvements and adaptations of the orphanhood method (Blacker 1977; Hill and Trussell 1977; Palloni and Heligman 1985; Timæus 1991; Timæus and Nunn 1997), with the main differences being that, the older variants of the method made use of weighting factors to produce life table quantities, while more recent

variants make use of regression-based methods to produce the same indices. The variant described here is similar to the one provided by Timæus (2013b).

The underlying assumptions of the method are that there is no correlation between the survival of parents and their children, selection biases introduced by the over-representation of parents with more than one surviving child can be assumed to be negligible, and that the age pattern of mortality for the population can be represented by a model life table. The method does not require that the population be closed to migration, hence it is applicable for metropolitan populations.

For a cohort aged x at a given time, t , whose mothers were all aged y at the time of their births, conditional survival probabilities are estimated by assuming that the proportion of mothers alive give an approximation of the life table survival probabilities,

$\frac{l_{x+y}}{l_x}$ for those aged y at time $t-x$. To control for the variation in the age range over which

there is exposure to the risk of dying, an estimate of the mean age at childbearing is required. This value is computed using the births in the year preceding the census or survey, and is simply the weighted average of the midpoint of each age-group, with the births used as weights. The same logic can be used for fathers, with the only noteworthy difference being, the calculation of the mean age of childbearing for men. The mean age at childbearing for men is arrived at by adding to the mean age at childbearing of women, an estimate of the age difference between spouses.

Analogous to the approach used to estimate $\frac{l_{x+y}}{l_x}$, the proportion of respondents

with mothers or fathers alive can be used to approximate the conditional survival probabilities, $\frac{l_{M+x}}{l_M}$, where M is the mean age at childbearing of mothers or fathers and

x is the midpoint of each age group. The estimates of survivorship are converted into conditional probabilities of survival using a regression equation, which differs slightly for mothers and fathers.

For mothers, survivorship is estimated between the ages of 25 and $25 + x$ such that the conditional probabilities of survival are given by:

$${}_x p_{25} = a(x) + b(x)M + c(x)S(x - 5, 5)$$

where $S(x-5,5)$ is the proportion of children aged $x-5$ to x whose mother is still alive, M is the mean age at childbearing and $a(x), b(x)$ and $c(x)$ are regression coefficients derived by Timæus (1992). The coefficients, which are sex-specific, were estimated from simulated data where the mortality was represented by relational logit model life-tables based on the Brass (1971) General Standard and fertility was represented by Relational Gompertz models based on the Booth (1984) standard for women, and Paget and Timæus (1994) standard for males.

For fathers, survivorship is estimated from the age of 35 as men are usually older than their spouses. The conditional survivorship probabilities are given by:

$${}_x p_{35} = a(x) + b(x)M + c(x)S(x-5,5) + d(x)S(x,5)$$

where $S(x-5,5)$ is the proportion of children aged $x-5$ to x whose father is still alive, $S(x,5)$ is the proportion of children aged x to $x+5$ whose father is still alive, M is the mean age at childbearing and $a(x), b(x), c(x)$ and $d(x)$ are regression coefficients proposed by Timæus (1992). The conditional survivorship probabilities are then converted into the α -parameter of Brass's 1-parameter relational logit model, which determines the level of mortality in the observed life table relative to the standard. The model life table is assumed to have the same age pattern of mortality in adulthood as the population being studied. The α values obtained and the model life table is then used to obtain indicators of the level of mortality, specifically, ${}_{35}q_{15}$ or ${}_{45}q_{15}$.

The estimates produced by this method provide direct information about cohort mortality but not period mortality. Brass and Bamgboye (1981) argue that if mortality has been changing linearly over time, one can estimate specific points in time or time locations, where the cohort estimates produced from the survivorship probabilities are equal to the period estimates. They postulated that theoretically, the time location for each age group, can be written as:

$$T = \frac{N}{2}(1 - C(N))$$

where N is the midpoint for each age group and $C(N)$ is the correction factor for that age group, which caters for the fact that deaths of mothers during the years prior to the census or survey are disproportionately concentrated in the later portion of the period, and is given by:

$$C(N) = \frac{\ln S(N)}{3} + f(N + M) + 0.0037(27 - M)$$

where $S(N)$ is the proportion of people aged N whose mothers or fathers are alive, $f(N+M)$ is a standard function of age which is derived from interpolation, and M is the mean age at child-bearing. This value of T represents a number of years before the interview, hence it would need to be subtracted from the date of the interview to give the exact point in time at which the cohort estimates are equal to the period estimates.

Brass (1985) modified the estimation of the time location to make use of observed proportions of children whose mother is still alive so that for females, the time location is given as:

$$T = \frac{N}{2} \left(1 - \frac{1}{3} \ln S(x-5,5) + \frac{1}{3} \ln \left(\frac{80-M-N}{80-M} \right) \right)$$

where $S(x-5,5)$ is the proportion of children aged $x-5$ to x whose mother is still alive, M is the mean age at childbearing and N is the number of years that mothers have been exposed to the risk of dying.

For males, the value of T would need to be adjusted to factor in the possibility that fathers may die during the nine months before the respondents were born. The value of T is therefore given by:

$$T = \frac{(N+0.75)}{2} \left(1 - \frac{1}{3} \left(\sqrt{S(x-5,5) * S(x,5)} \right) + \frac{1}{3} \ln \left(\frac{80-M-N}{80-(M-0.75)} \right) \right)$$

where $S(x-5,5)$ is the proportion of children aged $x-5$ to x whose father is still alive, $S(x,5)$ is the proportion of children aged x to $x+5$ whose father is still alive, M is the mean age at men have children and N is the number of years that fathers have been exposed to the risk of dying. Subtracting this value of T from the date of the interview would give the exact point in time to which estimates refer.

One key limitation of the orphanhood method is that it sometimes produces results that suggest rapid mortality declines for some populations. In addition to this, estimates from successive enquiries may be inconsistent. A possible explanation for these inconsistencies is the misreporting of survivorship of parents, due to what is termed, the 'adoption effect'. This phenomenon is common when children are orphaned at a very young age and are raised by someone else as their own child. As a result, they are often enumerated as having living parents when in actual fact, the parents are not alive. Bias introduced by the 'adoption effect' is more pronounced for children under 15 years of age (Preston, Heuveline and Guillot 2001: 237) as the foster parents are more likely to be alive than is the case for older respondents. Other limitations of the method include the

fact that survivorship of parents can be reported only-by children who are alive. Since mortality risks between parents and their children are likely to be correlated, the adult mortality estimates from the method would be biased downwards as a result of this selection effect (Preston, Heuveline and Guillot 2001: 237). This gives rise to a significant source of bias in estimates produced using the orphanhood method in the presence of an HIV/AIDS epidemic.

These biases result from the fact that HIV positive women have lower fertility and to a larger extent that, in the absence of treatment, the elevated mortality risks of infected mothers are transferred to the children through vertical transmission of the virus. This leads to fewer living HIV-positive children from whom data on the survivorship status of parents (expected to be lower than average) can be collected (Timæus and Nunn 1997). Estimates of adult mortality from the orphanhood method are therefore likely to be biased downwards, with this downward bias being more pronounced for women than for men. Timæus and Nunn (1997) identified another source of bias as the regression coefficients used for converting the proportions of respondents with parents alive into estimates of survivorship as the coefficients proposed by Timæus (1992) assumed a different age pattern of mortality from that experienced in populations affected by the HIV epidemic.

2.1.1.1 *Adjusting for HIV/AIDS related bias*

Timæus and Nunn (1997) proposed that biases introduced by mother-to-child transmission and the changes in fertility could be offset by a downward adjustment of the reported proportion of mothers alive. Assuming that individuals who are infected will die within a few years, Timæus and Nunn (1997) derived a correction factor for adjusting the proportion of mothers reported to be alive to give the proportion that would have been reported if HIV-positive women had the same number of living children surviving to the survey date as uninfected women. The relationship between the two proportions for maternal orphanhood is given by:

$$\frac{S(x,5)}{S(x,5)^*} = \frac{1 - hP}{1 + \frac{1 - F}{F} P}$$

where $S(x,5)$ is the proportion of children aged x to $x + 5$, that would have been reported if HIV-positive mothers had as many living children as other women, $S(x,5)^*$ is the proportion of children aged x to $x + 5$ whose mother is still alive, h is the rate of mother-to-child transmission of HIV, P is the HIV prevalence rate among women of

childbearing age and F is a ratio of the level of fertility of HIV-positive women compared to HIV-negative women.

The rationale behind the correction factor is that the ratio of the level of fertility of HIV-positive women compared to HIV-negative women (F) and the vertical transmission rate (h), determine the rate at which bias in the reported proportion of respondents with living mothers increases with HIV prevalence. In addition to the relationship above, Timæus and Nunn (1997) also proposed a new set of regression coefficients, for use in the estimation of conditional probabilities from proportions of respondents whose mother was still alive in populations with high HIV prevalence. These coefficients are to be used on the same regression equation as the conventional method.

Adjusting paternal orphanhood estimates for HIV-related selection bias is a bit more difficult. The task is complicated by the fact that it requires an estimate of the proportion of infected men who have infected partners, which is often unknown. Be that as it may, Timæus (2013b) suggests that for paternal orphanhood, the adjusted proportions is given by:

$$S(x,5) = \left(1 - \left(1 - (1 - h)F(1 - w)P^*\right)\right)S(x,5)^*$$

where P^* is an estimate of HIV prevalence among men, W is the proportion of men with infected partners, F is the ratio of the level of fertility of HIV-positive women compared to HIV-negative women, $S(x,5)$ is the proportion of children aged x to $x + 5$ that would be reported if HIV-positive fathers had as many living children as other men, $S(x,5)^*$ is the proportion of children aged x to $x + 5$ whose father is still alive. Revised regression coefficients to be used when converting the proportions of respondents whose father is still alive into conditional survivorship probabilities for populations with high HIV prevalence are yet to be developed because of the complications arising from a lack of information about the relationship between HIV incidence and fertility among men.

2.1.2 Estimation of adult mortality using sibling histories

The use of sibling histories in estimating adult mortality is generally divided into two approaches, indirect and the direct. The indirect approach is similar to the orphanhood method, but instead of data on the survival of parents, data on the survival of siblings are used to estimate adult mortality. The applicability of using data on siblings for estimating overall adult mortality stems from work by Brass and Coale (1968), though over the years, many other researchers have improved on the use of these data (Hill and Trussell 1977; Graham, Brass and Snow 1989; Bicego 1997; Timæus, Zaba and Ali 2001; Gakidou and

King 2006), with Graham, Brass and Snow's (1989) improvement, aptly called, the 'sisterhood method', owing to its use in the measurement of maternal mortality.

The underlying assumptions of the method are that the mortality risks of siblings are independent, that mortality does not vary by the size of sibships and that the age pattern of mortality can be explained by model life tables. The main limitation of the method is that it underestimates mortality if there is clustering within families and there is multiple reporting by siblings. In addition to this, it has been found that mortality reversals can make the estimation of time locations more difficult. On the upside, a major advantage of the method is that it is free from HIV/AIDS selection bias, hence no adjustments for HIV/AIDS bias are required.

The direct method was developed by Rutenberg and Sullivan (1991) to estimate maternal mortality from sibling history data collected in DHS surveys. Sibling history data make it possible to calculate age- and sex-specific death rates by dividing the number of male or female deaths by the exposure times for certain reference periods. This is possible since births, deaths and exposure times can be allocated time locations in calendar time (Stanton, Abderrahim and Hill 2000). The procedure, as described by Rutstein and Rojas (2006), requires the survival status data for male and female siblings 0-6, 7-13 and 0-13 years before the survey and also the number of years of exposure for male and female siblings 0-6, 7-13 and 0-13 years before the survey. Age-specific death rates are then derived from these data.

The underlying assumptions of the method are essentially the same as those of the indirect method although the age pattern of mortality need not be pre-constrained. The direct approach to estimating adult mortality using sibling histories has essentially the same inherent weaknesses as the indirect approach, while a further complication is the data collection process, which is complex, and as a result, the method is often affected by large sampling errors. The direct approach also shares the advantage of its indirect counterpart in that it is free from HIV/AIDS-related selection bias. The direct approach, however, has an advantage over the indirect approach in that fewer assumptions are required for its application, and as a result, if data are available to produce direct estimates, there may be little purpose to producing indirect estimates using sibling histories.

2.1.2.1 Selection bias in sibling history data

The use of sibling history data to estimate adult mortality, using either the direct or indirect approach, has long been presumed to underestimate mortality if there was clustering of mortality within families (Masquelier 2013). Gakidou and King (2006)

confirmed the presence of this correlation between family size and mortality in DHS data and proposed that this correlation was likely to cause significant bias in the mortality estimates. To reduce the extent of this bias, they derived correction factors based on survey weights, and extrapolation of the number of people who died in families with zero survivors. They found that re-weighting, alone, eliminated the majority of the bias with the corrections for the number who died from families with no survivors reducing the bias even further.

Masquelier (2013), however, suggested that the correction factors proposed by Gakidou and King (2006) tended to overestimate adult mortality if incorrectly applied as the bias corrected by these factors had a relatively modest effect on the adult mortality estimates. They argued that application of the correction factors was based on the assumption of a positive correlation between sibship size and mortality which may have been spurious in nature. They pointed out that not only did past declines in fertility and mortality create these spurious correlations, but also suggested that this did not imply the presence of the selection bias. As a result of these issues, Masquelier (2013) argued that reweighting the data using the correction factors proposed by Gakidou and King (2006) was not very effective. A detailed description of the method is given by Timæus (2013a), and does not allow for the correlation between mortality and sibship size.

2.1.3 Generalised Growth Balance method

The first of the Death Distribution methods to be considered here is the Generalised Growth Balance method. Its conceptualisation revolves around ideas proposed by Brass (1975), who postulated that completeness of reporting of deaths, relative to a population estimate, can be estimated for stable populations that are closed to migration. The major assumptions of Brass's Growth Balance method are that; the population should be stable and closed to migration, that completeness of death reporting is constant above a certain (adult) age, and that census coverage is complete at all ages (Hill 1987).

The rationale of the method follows the idea that in stable, closed populations, the growth rate is equal to the difference between the birth rate and the death rate. Brass (1975) extended this idea and stated that the partial birth rate, defined as the rate at which people turn age x in a population aged x and older ($b(x+)$), is equal to the sum of the rate of growth of a population aged x and older ($r(x+)$), and the partial death rate, which is the rate of mortality in the population aged x and older ($d(x+)$):

$$b(x+) = r(x+) + d(x+)$$

Hill (1987) generalised the idea proposed by Brass (1975) to include non-stable populations. He did this by making use of data from two censuses to estimate the age-specific growth rates, rather than the constant growth rate implied by a single, stable population, proposed in Brass's Growth Balance Method (Dorrington 2013a). This generalisation is known as the Generalised Growth Balance method (GGB). The method provides estimates of the completeness of death reporting relative to an estimate of the population based on the census populations at two points in time. The description of the method given here follows the description given in Hill (1987) and Dorrington (2013a).

Apart from the relaxation of the stability assumption, the underlying assumptions of the method are essentially the same as those of the Brass Growth Balance method. The data required for the method are estimates of the population at two time points and the number of deaths reported to have occurred between those two time points. The procedure revolves around the balancing equation:

$$P_2 - P_1 = B - D$$

where P_1 and P_2 are population enumerations at two successive points in time, B is the number of births and D is the number of deaths that took place in the period between the two successive enumerations. We may define ${}_5P_x(t_i)$ to be the number of people aged between x and $x+5$ for time t_i , where $i = 1, 2$. Aggregating the population estimates and the number of deaths for ages x and older, the balancing equation becomes:

$$P_2(x+) - P_1(x+) = N(x) - D(x+)$$

where $P_2(x+)$ and $P_1(x+)$ are estimates of the populations aged x and older, $D(x+)$ is the cumulative number of deaths for ages x and older and $N(x)$ is the number of people who turned x and older (Dorrington 2013a). $N(x)$ is estimated as follows:

$$N(x) = \left(\frac{t_2 - t_1}{5} \right) \left({}_5P_{x-5}(t_1) \times {}_5P_x(t_2) \right)^{\frac{1}{2}} .$$

The person-years of life lived, $PYL(x+)$, in the inter-censal period is estimated using the formula:

$$PYL(x+) = (t_2 - t_1) \left({}_{\infty}P_x(t_1) \times {}_{\infty}P_x(t_2) \right)^{\frac{1}{2}} .$$

Dividing the balancing equation by the person-years of exposure; yields:

$$n(x+) = b(x+) - d(x+)$$

where the partial birth and death rates are approximated using the formulae:

$$b(x+) = N(x+)/PYL(x+)$$

$$d(x+) = D(x+)/PYL(x+)$$

and the partial growth rate is given by

$$n(x+) = \frac{1}{(t_2 - t_1)} \ln \left(\frac{P_2(x+)}{P_1(x+)} \right).$$

The observed and true deaths, and populations are related as follows:

$$D(x+) = D^o(x+)/c$$

$$P_1(x+) = P_1^o(x+)/k_1$$

$$P_2(x+) = P_2^o(x+)/k_2$$

where the superscript o denotes the observed population, and c, k_1 and k_2 are the completeness of death reporting and the population enumerations, respectively. Re-writing the balancing equation in terms of the observed populations we get:

$$\frac{P_2^o(x+)}{k_2} - \frac{P_1^o(x+)}{k_1} = \frac{N^o(x)}{(k_1 k_2)^{1/2}} - \frac{D^o(x)}{c}$$

while the person-years of life lived in terms of the observed populations is estimated as:

$$PYL(x+) = (t_2 - t_1) \left(\frac{{}_\infty P_x^o(t_1) \times {}_\infty P_x^o(t_2)}{k_1 k_2} \right)^{\frac{1}{2}} = \frac{PYL^o(x+)}{(k_1 k_2)^{1/2}}.$$

Dividing the modified balancing equation by the person-years of exposure yields:

$$n^o(x+) = b^o(x+) - \left(\frac{k_1 k_2}{c} \right) d^o(x+) - \frac{1}{(t_2 - t_1)} \ln \left(\frac{k_1}{k_2} \right)$$

where the partial birth and death rates are approximated using the formulae:

$$b^o(x+) = \frac{N^o(x)}{PYL^o(x+)}$$

$$d^o(x+) = \frac{D^o(x+)}{PYL^o(x+)}$$

and the partial growth rate is given by

$$n^o(x+) = \frac{1}{(t_2 - t_1)} \ln \left(\frac{P_2^o(x+)}{P_1^o(x+)} \right).$$

The graph of $b^o(x+) - n^o(x+)$ against $d^o(x+)$ is plotted over an appropriate range, which is determined by considering factors which include age exaggeration and migration. A straight line is fitted to the points, and estimates of the slope and intercept of the line can be estimated using regression methods. Given that the slope and intercept are a and

b respectively, measures of completeness of the populations relative to each other will be obtained from the following relationships:

$$a = \frac{\ln\left(\frac{k_1}{k_2}\right)}{t_2 - t_1}$$

$$b = \frac{(k_1 k_2)^{1/2}}{c}$$

An estimate of the completeness of death reporting is obtained by setting the larger of k_1 and k_2 to 1. The ratio of $\frac{k_1}{k_2}$ provides an estimate of the relative completeness of the first census to the second. Adjusting the reported deaths and the populations for completeness gives the complete number of deaths relative to the census populations. Mortality rates can then be estimated from these adjusted deaths and the person-years of exposure estimated from the census population adjusted for relative completeness.

2.1.3.1 Allowing for migration

One aspect that may bias the estimates of adult mortality obtained from the GGB approach is migration. It may be necessary to relax the condition of closure to migration when applying the GGB approach to areas where, for example, there is significant net-migration taking place, an example being sub-national populations, where there may be significant urban to rural migration at the older ages. Application of the method without accounting for this may bias completeness and the mortality estimates in the urban areas upwards. Bhat (2002) proposed the use of the GGB approach for populations that are not closed to migration. Other researchers have also adapted the method to allow for migration (Dorrington, Timæus and Moultrie 2008; Hill and Queiroz 2010). Allowance for migration in the GGB approach is done by including an additional term in the balancing equation, that is, the number of migrants aged x and older, such that the balancing equation becomes:

$$P_2(x+) - P_1(x+) = N(x) - D(x+) + NM(x+)$$

where $NM(x+)$ is the net number of in-migrants aged x and older.

2.1.4 Synthetic Extinct Generations method

Preston, Coale, Trussell *et al.* (1980) developed a method for estimating completeness of the reporting of deaths relative to an estimate of the population which assumes that in a stable population, there is a relationship between the numbers of current deaths and the number of people in a population at any given time. The method stems from work by

Vincent (1951) where he proposes that the number of people at a certain age is equal to the total number of deaths in this cohort, till the cohort becomes extinct implying that the current population of age x can be estimated from current deaths of people in that cohort.

This is possible since for a stable, closed population, the number of deaths at a time t years in the future, is equal to the current number of deaths multiplied by a term which represents exponential growth at a constant growth rate r for t years (e^{rt}). The sum of all these deaths will give the population aged x last birthday. The underlying relationship is that in a stable population, closed to migration:

$$N(a) = \int_a^{\infty} D^t(x) \exp(r(x-a)) dx$$

where $D^t(x)$ is the true number of deaths experienced by a population aged x and $N(a)$ is the number of people aged a . If the current deaths are underreported then the extent of underreporting can be estimated using the relationship:

$$D^t(x) = \frac{D(x)}{c}$$

where $D(x)$ is the reported number of deaths and c is an estimate of completeness of the reporting of deaths.

Bennett and Horiuchi (1981;1984) extended this notion by developing a method that is applicable for non-stable populations and this method is now known as the Synthetic Extinct Generations method or SEG. The method makes use of the age-specific growth rates, $r(x, s)$ for a population aged x at time s , instead of the constant growth rate employed in the method by Preston, Coale, Trussell *et al.* (1980), such that:

$$N(x, s) = \int_0^{\infty} D^t(a) \exp\left(\int_a^x r(y, s) dy\right) da$$

where $D^t(x)$ is the true number of deaths experienced by a population aged x at time s and $N(x, s)$ is the number of people aged x at time s .

The underlying assumptions of the method are similar to those of the GGB method, that is, completeness of death reporting is constant for adult ages, census coverage is complete at in the adult ages and the population should be closed to migration, with an additional assumption being that, there is no differential census coverage. Much like for the GGB method, it may be necessary to relax the condition of closure to migration in the SEG method in order to allow for net in-migration. In addition, it is also possible to allow for differential census coverage. A detailed description of the SEG

approach is given in the United Nations manual (United Nations 2002) and in Dorrington (2013b), with the latter giving an approach that allows for migration and differential completeness. The description here is similar to the one in Dorrington (2013b).

The age-specific growth rates are estimated from the numbers at each age in the population at the two time points. The rates are given by:

$${}_5r_x = \frac{\ln({}_5P_x(t_2)/{}_5P_x(t_1))}{t_2 - t_1} - \frac{{}_5NM_x}{(t_2 - t_1)({}_5P_x(t_1) \times {}_5P_x(t_2))^{\frac{1}{2}}} + \delta$$

where ${}_5r_x$ is the growth rate between ages x and $x + 5$, ${}_5P_x(t_i)$ is the number of people aged between x and $x + 5$ for time t_i ($i = 1, 2$), the times of the two censuses, ${}_{NM}(x+)$ is the net number of in-migrants between ages x and $x + 5$, and δ is an estimate which corrects for the relative undercount (or over-count) of one census relative to the other. The delta (δ) adjustment can be obtained either from the slope of GGB or from an iterative procedure (Dorrington 2013b).

Setting the age at the start of the open interval as A , the number of people who turned x between the census at time t_1 and the census at time t_2 are estimated from the reported deaths using the following formula:

$$N_x^* = N_{x+5}^* \exp(5{}_5r_x) + {}_5D_x \exp(2.5{}_5r_x)$$

where ${}_5r_x$ is the growth rate between ages x and $x + 5$, N_x^* the number of people who turned x between the census at time t_1 and the census at time t_2 , and ${}_5D_x$ is the number of reported deaths between ages x and $x + 5$ between the two censuses. For the open-ended age group, the number of people who turned x is given by:

$$N_A^* = {}_\infty D_A \left(\exp({}_\infty r_A \times e_A) - \frac{({}_\infty r_A \times e_A)^2}{6} \right)$$

where ${}_\infty r_x$ is the growth rate for the open interval, N_A^* the number of people who turned A and ${}_\infty D_x$ is the number of reported deaths in the open-ended interval and e_A is the future expectation of life for a person aged A years exactly.

Those aged between x and $x + 5$ in the period where the deaths were recorded are estimated as follows:

$${}_5N_x^* = 2.5(N_x^* + N_{x+5}^*).$$

The number of people aged between x and $x + 5$ in the period in which the deaths were reported is also estimated from the census populations as follows:

$${}_5N_x = (t_2 - t_1) \left({}_5P_x(t_1) \times {}_5P_x(t_2) \right)^{\frac{1}{2}}.$$

The ratio of the number of people aged between x and $x + 5$ during the period in which deaths were reported derived from the deaths reported to the number derived from the census populations gives an estimate of the level of completeness in each age group, that is:

$$c(x) = \frac{{}_5N_x^*}{{}_5N_x}$$

where N_x^* and ${}_5N_x$ are defined above.

2.1.5 Analysis of sensitivity of GGB and SEG methods

The applicability of both the GGB and SEG approaches in instances where the underlying assumptions are violated, is an important facet in the analysis of adult mortality, as both methods can yield misleading results in such circumstances. Hill and Choi (2004) and Hill, You and Choi (2009) argued that the GGB was more sensitive to age misreporting than the SEG, with the SEG (without delta adjustment) being more sensitive to net migration and changes in census coverage. They did this by simulating a non-stable population with known mortality and the data errors.

Dorrington, Timæus and Moultrie (2008) and Hill, You and Choi (2009) agree that both the GGB and SEG work well if the errors for which the methods were developed, were the only ones present in the data. To account for the differential census coverage problems in the SEG (without delta) and the age misreporting problems in the GGB, a combination of the GGB and SEG was proposed by Hill and Choi (2004) where the GGB is used to adjust for relative undercount of the censuses and then the SEG is used to estimate the completeness of reporting of deaths.

Dorrington, Timæus and Moultrie (2008) point out that the version of SEG used by Hill, Choi and Timæus (2005) did not have the adjustment for differential census coverage suggested by Bennett and Horiuchi (1981). Having included this adjustment, Dorrington, Timæus and Moultrie (2008) argued that the SEG with delta performed just as well as the combination of the GGB and SEG and in some cases actually outperformed the combination when applied to the same dataset used by Hill and Choi (2004).

2.2 Methods of estimating infant and under-five mortality

For most sub-Saharan African countries, estimates of infant and child mortality are obtained primarily from census and survey data using direct and indirect methods due to the incompleteness of the vital registration systems. Despite deficiencies in census and general survey data, estimation of infant and child mortality using these data sources can still provide key insights into the mortality of a population. This section will review the direct methods first, then the Brass Children Ever Born/Children Surviving (CEB/CS) method and the Previous Birth Technique.

2.2.1 Direct estimation of child mortality

Direct estimation of infant and child mortality can be done using either vital registration data, household death data or full birth history data, with the latter being; data on the date of birth of each child, survival status of each child and also the date of death for those who die. The use of vital registration data (or household deaths data) to estimate infant and child mortality is fairly straight forward. For infant mortality, the number of deaths of children under 12 months in a particular period is divided by the number of births in the same period (Rutstein and Rojas 2006). Estimation of child mortality requires further data, that is, an estimate of the population exposed to the risk of dying, which will be drawn from a population register or censuses. The method is effective if the vital registration systems are complete and the estimates of population exposure are accurate. This is not the case for most sub-Saharan African countries, particularly with respect to the deaths and births, and as such, the method is not normally used in sub-Saharan African countries.

The variants that make use of full birth histories are the true cohort life table approach and the synthetic cohort life table approach (Rutstein and Rojas 2006). For the true cohort life table approach, the number of deaths of children under 12 months of age of a specific cohort is divided by the number born to that cohort. For the under-five mortality rate, the number of deaths of children under the age of five is divided by the number of children born to that cohort. The method has two main drawbacks, that is, it excludes the most recent births and also relates the true cohort rates to the date of birth of the cohort and not a particular period at death.

The synthetic cohort life table approach, which is usually used to produce estimates from DHS surveys, accounts for the weaknesses of the true cohort life table approach. It ensures that the most recent data are used and that rates are specific for time periods. In the DHS, children are classified into the following age segments: less than 1 month, 1-2 months, 3-5 months, 6-11 months, 12-23 months, 24-35 months, 36-47 months and 48-

59 months (Rutstein and Rojas 2006). To calculate the age-specific probabilities of death, the number of deaths in a specific age group is divided by the sum of the person-years lived in that age group over a specified time period. To find the infant and under-five mortality rates, we make use of the age-specific probabilities of survival. To get the probability of surviving from birth to age 1, p_0 , we can find the product of these age specific probabilities of survival up to age 12 months. The probability of not surviving would be:

$$q_0 = 1 - p_0.$$

Another way of approximating this probability is the infant mortality rate which is obtained by dividing the number of deaths less than one year of age in a specific period by the number of births in that period. For under-five mortality, we again make use of the age-specific probabilities of survival. To get the probability of surviving to age five, we find the product of the age-specific survival probabilities up to the 48-59 months age segment. Defining the probability of surviving from age x to $x+1$ as p_x , the probability of surviving from birth to age 5, ${}_5p_0$, is given by the expression:

$${}_5p_0 = p_0 \times p_1 \times p_2 \times p_3 \times p_4,$$

with the probability of dying between age 0 and 5, ${}_5q_0$, being:

$${}_5q_0 = 1 - {}_5p_0.$$

2.2.1.1 *The effect of HIV/AIDS on direct estimates.*

One of the assumptions in estimating survival probabilities from the survival status of children reported by mothers is that, there is no correlation between the mortality of the mothers and the mortality risks of the children. The existence of a correlation between these mortality risks could lead to an underestimation of under-five mortality as there will be no information about survival of children of dead mothers. This scenario is particularly evident in populations affected by the HIV/AIDS epidemic. It is therefore important to account for this HIV-related selection bias in direct estimates. The United Nations Inter-agency Group for Child Mortality Estimation, UN IGME, accounted for this bias in full birth history data and provided an adjustment for countries whose prevalence exceeded 5 per cent in the adult population (aged 15 to 49 last birthday). They argued that the extent of the bias depended on background mortality, the period before the survey and also the dynamics of the epidemic in the population.

The method proposed by Walker, Hill and Zhao (2012) makes use of data on HIV prevalence to produce estimates of annual births, the number of HIV-positive infants and

the number of women needing services to prevent mother-to-child transmission (PMTCT), all obtainable from the Spectrum population projection software as output, and then used as input data in the UN IGME model. In essence, the method entails estimating the number of births and under-five deaths reported, and then comparing these with the true births and deaths to produce an estimate of the bias; the ratio of the proportion reported dead to the true proportion dead, which is given for the periods 0-4, 5-9 and 10-14 years before the survey, and also 1-5, 6-10 and 11-15 years before the survey, which are employed to try and reduce transference errors, which are common in DHS datasets. Once this bias is obtained, the survey estimates of under-five mortality can be adjusted by dividing the observed values by the difference between one and this ratio.

To establish the true annual number of births and deaths, the births among adult women (from Spectrum) are divided into three categories: those born to HIV-negative mothers and not infected, those born to HIV-positive mothers and not infected and those born to HIV-positive mothers and are infected. For each stream of births, corresponding deaths in the ensuing five years are estimated. Assuming that the mortality risks of HIV-negative children born to HIV-negative and HIV-positive mothers are the same, these children were assumed to experience only background mortality from the Coale and Demeny 'West' family of model life tables. Assuming that the effect of antiretroviral treatment was negligible before 2007, the probability of dying from birth to age five for HIV-positive births in each year is estimated using a mortality schedule derived from cohort studies. In the schedule, the probability of dying by age five is assumed to be 0.625 for HIV-positive births.

To determine the annual number of unreported births and under-five deaths as a result of the death of the mother, it is assumed that HIV-negative mothers have zero risk of dying in a short time period. A direct implication of this assumption is that all births and deaths to HIV-negative women are reported. As births to HIV-positive women are more likely to occur soon after infection rather than later, the probabilities of surviving from any year prior to the given survey year, to the survey year are estimated from survival curves derived from various cohort studies. The first survival curve, with a median survival time of 9.5 years, is created from point of infection whereas the other curve, derived from the first survival curve, is for four years after infection. The proportion of unreported births and deaths from HIV-positive women, under the assumption that they all survived to the year of the survey, are obtained from these curves.

2.2.2 Indirect estimation of child mortality: Brass Children Ever Born Children Surviving (CEB/CS) method

The method was originally formulated by Brass and Coale (1968), but has undergone several changes over the years, with variants of the method being developed by other researchers (United Nations 1990). The major differences between the variants concern the models used to simulate the quantities of interest. In the basic variant, as formulated by Brass, estimates of the probability of dying between birth and exact age x , ${}_xq_0$ are derived from the proportions of dead children among those who were ever born by women in different age groups, with allowance being made for the duration of exposure to the risk of dying and also the pattern of fertility. The method allows for a population's fertility pattern by considering the average parity.

The assumptions underlying the method are that the mortality of the children does not vary by five-year age group of their mother, that there is no correlation between the mortality risks of the mother and those of her children, that childhood mortality and fertility patterns have been fairly constant for some time and that a model life table that adequately represents the mortality of the population is available.

There are two prominent variants of the CEB/CS method in use today: the Trussell variant (Trussell 1975) and the Palloni and Heligman variant (Palloni and Heligman 1985). The main differences between the two variants are that the former uses the Coale-Demeny regional model life tables, while the latter uses the United Nations model life tables (United Nations 1990). In addition to this difference, the Palloni and Heligman variant uses additional information on births in the year before the survey (United Nations 1990). The procedures for the two versions are similar. For both variants, one first calculates the average parities of the women in each five-year age group, indexed by i , where $i = 1, 2, \dots, 7$ represents ages 15-19 to 45-49, as:

$$P(i) = \frac{CEB(i)}{FP(i)}$$

where $P(i)$ is the average parity of women in age group i , $CEB(i)$ is the number of children ever born to women in age group i and $FP(i)$ is the female population in each five-year age group i .

Next, one calculates the proportion dead which is given by the ratio of the total number of dead children to the number of the children ever born:

$$D(i) = \frac{CD(i)}{CEB(i)}$$

where $D(i)$ is the proportion of children who are dead for women in age group i , $CD(i)$ is the number of dead children reported by these women. One then calculates the multipliers or correction factors using the average parities of consecutive age groups:

$$\frac{P(i)}{P(i+1)}.$$

The age groups used in the calculation of the multipliers for both variants are 15-19, 20-24 and 25-29 as these are more likely to represent the fertility experience of a population. For the Trussell variant, the multipliers are given as:

$$k(i) = a(i) + b(i) \frac{P(1)}{P(2)} + c(i) \frac{P(2)}{P(3)}$$

where the coefficients $a(i), b(i), c(i)$ were determined by Trussell using regression analysis and simulation for each age group and each family of the Coale-Demeny regional model life tables.

For the Palloni and Heligman variant, the correction factors differ slightly as they included an extra term, the mean age at child-bearing, M :

$$k(i) = a(i) + b(i) \frac{P(1)}{P(2)} + c(i) \frac{P(2)}{P(3)} + d(i)M$$

where coefficients $a(i), b(i), c(i), d(i)$ were determined by Palloni and Heligman using regression analysis and simulation for each age group and each family of the United Nations model life tables for developing countries. M , the age at maternity, is given by:

$$M = \frac{\sum_{i=1}^7 B(i)mp(i)}{\sum_{i=1}^7 B(i)}$$

where $B(i)$ is the number of births to women in five-year age group i and $mp(i)$ is the midpoint of age group i . Next, one uses the multipliers and the proportion of children dead to find the probability of dying between birth and age x :

$${}_xq_0 = k(i)D(i)$$

The same formula is used for both the Trussell and Palloni and Heligman variants of the Brass CEB/CS method. It is important to mention that the mortality rates obtained are not for the time of the survey but for some years before the survey. To obtain an estimate of the time location of these estimates for both variants, we can find the number of years before the time of the survey using:

$$t(i) = e(i) + f(i) \frac{P(1)}{P(2)} + g(i) \frac{P(2)}{P(3)}$$

where the coefficients $e(i)$, $f(i)$, $g(i)$ are again determined using regression analysis and simulation for each age group and each family of the Coale-Demeny regional model life tables for the Trussell variant and each family of the United Nations model life tables for developing countries for the Palloni and Heligman variant.

With most indirect methods relying on assumptions, there are circumstances when these assumptions may not hold (Rutstein and Rojas 2006). The CEB/CS method is no different in this regard, as the assumption that the mortality of children does not vary by the five-year age group of the mother is often violated as children born to younger mothers are known to experience higher mortality than those born to women over 25 (Ewbank 1982). Assuming that fertility and mortality patterns have remained constant for more than 15 to 20 years may not be practical, especially for regions still undergoing a demographic transition. The effect of changes in fertility has, however, been found to be negligible if the changes were gradual and unidirectional (Brass, Coale, Demeny *et al.* 1968).

Finding a model life table that adequately represents the mortality of the respective population is very important as an incorrect choice of table may lead to unreliable estimates of child mortality. The emergence of HIV has made this task harder as the existing tables, the Coale-Demeny model life tables and the United Nations model life tables, do not account for the bias introduced by the epidemic.

2.2.2.1 *Impact of a generalised HIV/AIDS epidemic*

Assuming that the survival of mothers and the survival of their children is independent is somewhat unreasonable for populations experiencing the HIV epidemic. The chance of transmission of HIV from mother to child has been estimated to be as high as 35 per cent in the absence of antiretroviral therapy (Hill 2013b). The elevated mortality risks experienced by HIV-positive mothers are therefore transferred to the HIV-positive children meaning that both the HIV-positive children and mothers have higher mortality than the rest of the uninfected population. As HIV-positive mothers are less likely to survive, there will be no one to report the higher mortality of the HIV-positive children, leading to an underestimation of mortality (Mahy 2003).

In addition to this, as HIV prevalence is associated with the mother's age, the assumption of independence between the mother's age and the mortality of the child is also violated (Mahy 2003; Ward and Zaba 2008). Thus, the HIV epidemic has had an adverse effect on the suitability of the Brass CEB/CS method for estimating child mortality. Ward and Zaba (2008) examined the appropriateness of using the CEB/CS

method in populations with a generalised HIV epidemic. To do this, they estimated the potential bias of using this method by simulating its application to stable populations with known mortality and fertility, and with different prevalence levels (assumed to remain constant over time).

The main assumptions they made were that, there were no changes in mortality and that prevalence was also constant over time. They showed that the HIV prevalence could be used to determine the size of the error which also depended on the background mortality and that significant bias in the child mortality estimates were obtainable even for HIV prevalence levels as low as 3 per cent for the 40-44 and the 45-49 age groups. In general, they concluded that higher prevalence translated into higher error, as the bias would become more pronounced at higher prevalence levels. They produced correction factors that could be used to adjust for the bias and also to determine the prevalence level that will produce an error that is significant (greater than 5 per cent) for each age group. They suggested that the true mortality of a population will be given by $q(z)^t$ where:

$$q(z)^t = q(z)^e + n(z)$$

where $q(z)^e$ is the estimate calculated without accounting for HIV and $n(z)$ is the correction factor.

The correction factors were estimated using either a basic model or an extended model. Both are regression models fitted to the HIV prevalence in women of childbearing age, but the difference is that the extended model improves on the basic model for the 15-19 age group. The basic model was given by:

$$n(z) = aPREV + b(PREV)^2$$

while the extended model was given by:

$$n(z) = aPREV + b(PREV)^2 + cPREV(15)$$

where $PREV$ is the prevalence among women of childbearing age and $PREV(15)$ is the prevalence in women aged 15-19. The coefficients a, b and c were all estimated using regression. At the 5 per cent level of significance, the authors found that for a prevalence rate as high as 45 per cent on basic model, the corrected estimates of child mortality for the age group 30-34 had an error that was not significantly different from zero, while for the 25-29 and the 35-39 age groups, the maximum prevalence at which the error is not significant is 30 per cent. In addition to this, a maximum prevalence of 12 per cent was found to produce insignificant errors for the 15-19, 20-24 and the 40-44 age groups. Application of the extended model, increases the maximum prevalence at which estimates

produce an error that is not significant at the 5 per cent level. In general, errors in the corrected estimates fell within 5 per cent of the true value for each age group after the corrections were applied.

The underlying assumptions of the model mentioned above do not hold for most southern African countries as neither HIV incidence nor child mortality are constant in these countries. For example, after the onset of the epidemic, child mortality in South Africa and Zimbabwe increased steadily until it peaked in the early 2000s. The introduction of ARVs and PMTCT programmes then caused a decline in the level of child mortality. This poses a problem when attempting to use the correction factors suggested by Ward and Zaba (2008).

Darikwa and Dorrington (2011) suggested an approach for adjusting Ward and Zaba's correction factors to allow, to some extent, for changing HIV prevalence. For this, it is necessary to estimate some time location to which the estimates from Ward and Zaba would apply if mortality has been changing and HIV prevalence has been increasing. As the Ward and Zaba correction factors are a function of the HIV prevalence at the time of the survey, if prevalence has been increasing prior to the survey, this implies that at a time where there was no HIV, the correction factors should be zero. Assuming that HIV had no impact on the time location, Darikwa and Dorrington (2011) therefore replaced the HIV prevalence at the time of the survey, with weighted average prevalence taking into account the different prevalence levels for each group of women over time. The adjustment requires an estimate of the average prevalence at the time of childbearing. This was estimated as the weighted average of the prevalence at the time of birth for all births to women in each age group with the weights being the number of births to women in each age group.

Defining C_y^{z-x} as the number of births per woman x years before the survey, with z being the year of the survey, for women aged y years at the time of the survey, the weighted average of the HIV prevalence at childbirth would be given by:

$$PREV = \frac{\sum_{x=0}^{y-15} w_y^{z-x} * PREV(z-x)}{\sum_{x=0}^{y-15} w_y^{z-x}}$$

where $w_y^{z-x} = \frac{C_y^{z-x}}{\sum_{x=0}^{y-15} C_y^{z-x}}$ is the weight and $PREV(z-x)$ is the prevalence of women of

childbearing age exactly x years before the time of the survey. The HIV prevalence of

the median age in each age group is then used to represent the prevalence at the time of birth for each group. These estimates of HIV prevalence are then used to adjust Ward and Zaba's correction factors. Darikwa and Dorrington (2011) also noted that the use of model life tables which did not account for the effects of HIV to calculate mortality rates using Brass' CEB/CS method adjusted for HIV-related bias would be inappropriate. To cater for this, they used model life tables from the ASSA2003 AIDS and Demographic projection model which incorporated the effects of HIV on mortality.

2.2.3 Indirect estimation of child mortality: Previous Birth Technique

The method was first proposed by Brass and Macrae (1984) and was initially intended for use in health facilities, where birth registration occurs but death registration is not complete. In the original formulation, the probability of dying between birth and the age of $2, {}_2q_0$, can be estimated using information on the survival of any previous births. Taking the mean birth interval for countries where there is virtually no contraception as 30 months, Brass and Macrae (1984) proposed that the proportion of children born prior to the current birth who died, is a function of the distribution of recent births over time and the cumulative probability of dying. This proportion was considered as a good approximation of ${}_2q_0$. Over the years, various extensions of the Previous Birth Technique have been developed by many researchers (Brass and Macrae 1985; David, Bisharat and Hill 1990; Aguirre 1994; Bairagi, Shuaib and Hill 1997) including its adaptation for use in censuses and large-scale surveys by David, Bisharat and Hill (1990) (Hill 1991).

2.2.3.1 Blacker and Brass variant of the Previous Birth Technique

To obtain recent estimates of infant and child mortality, data on the previous births are obtained from questions on either the date of a woman's most recent birth or whether a woman had a live birth in a specified period and the survival status of that child. One of the extensions that makes use of the date of a woman's most recent birth was developed by Blacker and Brass to estimate infant mortality from information on the survival of the births that took place 24 months prior to a census or survey. Conventionally, the infant mortality rate can be estimated from information on the proportion of births in the last 12 months that died before reaching age 1. Blacker and Brass (2005), however, noted certain inconsistencies that resulted from the use of these data, which include heaping of births 12 months before the inquiry is made. To avoid this heaping and other irregularities, the use of births in a period 24 months before the survey was proposed.

Blacker and Brass (2005) argued that the use of a 24-month period not only eliminated the effect of heaping, but also reduced sampling errors due to a bigger sample size of births. They then proposed that the proportion dead among children born in the 24 months prior to the survey or census be used to approximate infant mortality if multiplied by a factor of 1.09. Given that the number of survivors in the life table, l_x , in the first few years of life resembles the shape of a hyperbola,)proposed that in infancy and early childhood, the life table of survivors is given by:

$$l_x = (1 + \alpha x)^{-\beta}$$

where x is the age in months or years, α is a shape parameter and β gives the level of mortality. The proportion dead among the children born in the last 24 months, D , can also be represented in terms of life table survivorship functions as:

$$D = 1 - \frac{\int_0^2 l_x dx}{2}.$$

To convert this proportion, D , into the probability, q_0 , which in terms of the life table survival function is:

$$q_0 = 1 - l_1 = 1 - (1 + \alpha)^{-\beta},$$

an adjustment or correction factor equivalent to q_0/D is required. This correction factor will, however, depend on the values of α and β , which are determined by simulation. The correction factors obtained from the simulations were within the range of 1.04 to 1.1, depending on the level of mortality. They suggest the use of a ‘default’ correction factor of 1.09 for areas whose age pattern of mortality is unknown (Blacker and Brass 2005: 32).

Apart from the method providing up to date estimates of infant mortality and its simplicity, the previous birth technique, as given by Blacker and Brass, is very robust when applied to populations with high HIV prevalence. The drawbacks of the method include its sensitivity to reporting errors and non-response, and to a lesser extent, the bias introduced by choosing wrong correction factors. Hill (2013a) points out that there are a few biases related to its use on health facility data. He identifies that the focus on recent births leads to an underestimate if there are short birth intervals after the death of a child, since only the death of the first of the two births will be missed. In addition, there is selection bias introduced by the fact the population attending these health facilities is not randomly selected, thereby leading to estimates of infant and child mortality that are not necessarily representative of the population as a whole. Moreover, he adds that bias

introduced by using the most recent births in populations with low fertility rates, translates to the use of first births which usually have higher than average mortality.

2.3 Mortality estimates in Zimbabwe

This section reviews the estimates of Zimbabwe's national and sub-national mortality produced by previous research.

2.3.1 Estimates of adult mortality for Zimbabwe's national and sub-national populations

Due to the incompleteness of the vital registration system in Zimbabwe (estimated at approximately 44 per cent for females and 63 per cent for males between 1982 and 1992 by Feeney (2001)), much of the research on adult mortality in Zimbabwe is based on indirect estimates derived from census and survey data. Moreover, most of the research concentrates on the mortality at a national level with very little research done at subnational levels. While there is a consensus among researchers that adult mortality in Zimbabwe rose considerably in the early 1990s, with much of this rise being attributed to the HIV/AIDS epidemic, the levels of adult mortality suggested by researchers, however, differ significantly.

Adult mortality estimates are generally represented by indices ${}_{35}q_{15}$, ${}_{35}q_{30}$ or the more common ${}_{45}q_{15}$. However, early work on adult mortality estimation in Zimbabwe made use of crude mortality rates to obtain national and sub-national estimates of adult mortality. Bicego (1997) made use of the 1994 Zimbabwe DHS data to estimate adult mortality using sibling histories, and found that for Harare and Bulawayo separately, the crude adult mortality rate for individuals aged 15-49 was 4.1 per thousand with the national estimate being slightly higher than for either Harare or Bulawayo, at 4.5 deaths per thousand for the same ages.

The work done by Feeney (2001) on estimating adult mortality using the indices mentioned above for post-independence Zimbabwe, provided a starting point for most of the subsequent research on Zimbabwe's adult mortality. Using vital registration data and deaths reported by households, together with orphanhood and sibling history data, he found that adult mortality had increased sharply between the mid-1980s and the mid-1990s. Specifically, he found that using vital registration data, the male ${}_{35}q_{30}$ had increased from approximately 0.40 in 1982 to about 0.60 in 1995, with that of females having risen from 0.25 to around 0.42 in the same period. These estimates, and those derived from other data sources are given in Figure 2.1.

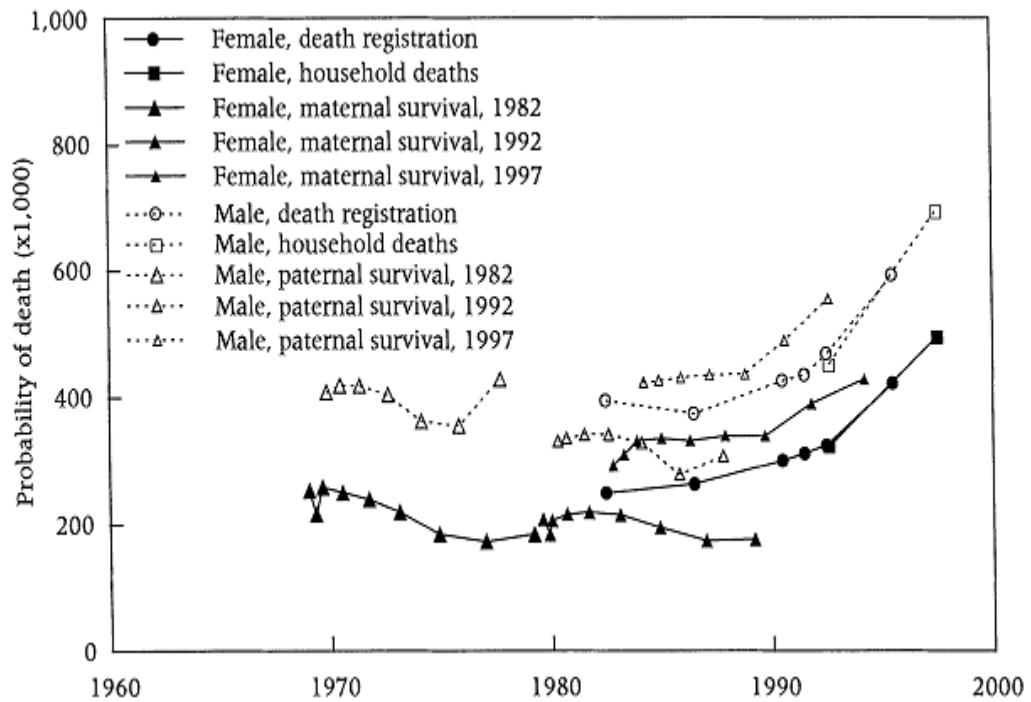


Figure 2.1 Probability of a 30 year old dying before reaching the age of 65

Source: Feeney (2001: Figure 3)

The fact that the completeness of the vital registration data used to produce the estimates was estimated to be significantly lower than 60 per cent is a limitation of the research, as it increases the degree of uncertainty surrounding the estimates produced. As was mentioned earlier, the levels suggested by various researchers differ, as shown by the contrast in estimates of Feeney (2001) and those of Timæus and Jasseh (2004). Timæus and Jasseh (2004) produced estimates of adult mortality (${}_{45}Q_{15}$) using sibling histories from DHS data on 23 sub-Saharan African countries which included Zimbabwe, which were about 30 per cent and 10 per cent lower than those produced by Feeney (2001) for 1990 and 1997, respectively. Dorrington, Timæus and Gregson (2006) applied a combination of the Generalised Growth Balance (GGB) method and the Synthetic Extinct Generations (SEG) method to the 1992 and 2002 census data and found that the trend of adult mortality estimates from household deaths were consistent with the other data sources. However, they found that the level of the estimates was more consistent with the estimates produced by Timæus and Jasseh (2004), than those produced by Feeney (2001). These findings are illustrated in Figure 2.2.

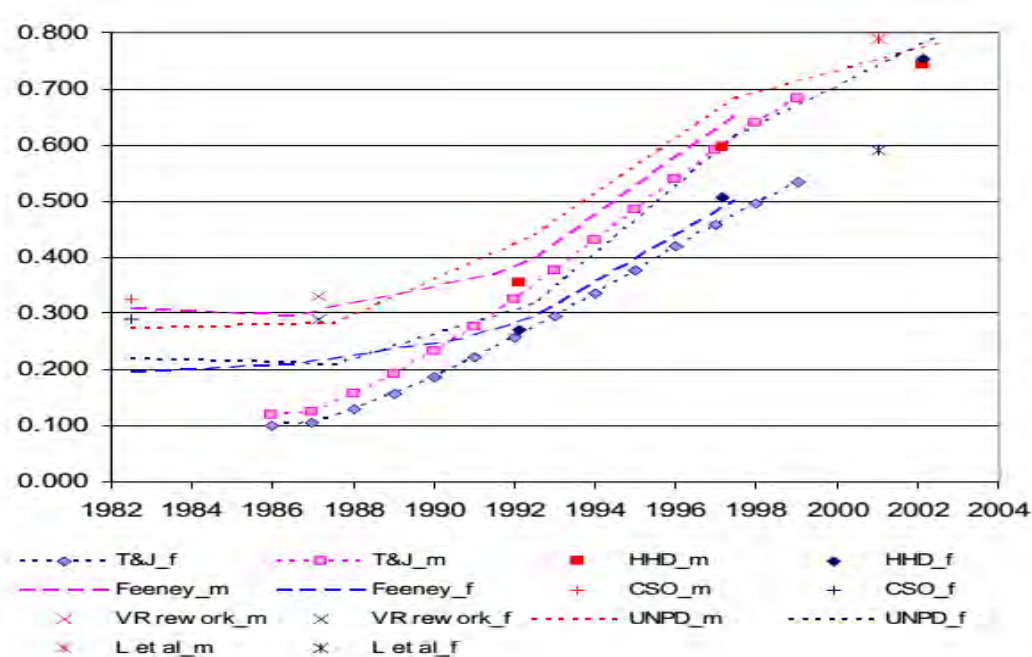


Figure 2.2 Probability of an individual aged 15 dying before the age of 60, $45q_{15}$
 Source: Dorrington, Timæus and Gregson (2006: Figure 4)

Gregson, Gonese, Hallett *et al.* (2010) compared national estimates of adult mortality derived from the 1982, 1992 and 2002 censuses using the deaths reported by households, with estimates from sibling survival histories derived from DHS data. They found that estimates derived from census data were generally higher than those derived from DHS data. For sub-national estimates, they calculated the crude death rates from vital registration data for Harare and Bulawayo and compared the levels in the mortality rates with those derived for these cities from census data, that is, the deaths reported by households. They found that the levels of mortality from vital registration were more or less consistent with those derived from census data, a result with which Dorrington, Timæus and Gregson (2006) concurred.

More recent research on Zimbabwe's adult mortality by Marera (2011), also used the combination of the Generalised Growth Balance and Synthetic Extinct Generation methods, and the orphanhood method (adjusted for HIV-related selection bias) on the available census data for the former, and both census and DHS data for the latter. From the death distribution methods, he found that the probability of those aged 15, dying before they reach age 60 was 0.36 for males, and 0.32 for females for the period between 1982 and 1992, while between 1992 and 2002 it was 0.62 for males and 0.59 for females. Estimates from the orphanhood method and direct sibling histories for the 1988, 1994,

1999 and 2005 DHS and depicted an increasing trend in adult mortality from 1985 for both sexes.

For subnational estimates of adult mortality, the most recent work is by Dlodlo, Fujiwara, Hwalima *et al.* (2011), who estimated overall age and sex-specific crude mortality in Harare and Bulawayo from 1979 to 2008, using data on registered deaths, obtained from the health service departments of both cities. They also sought to find out if anti-retroviral therapy had caused any mortality reductions since its introduction around 2004. Among their findings, they indicated that Bulawayo's sex-specific and overall adult mortality was higher than that of Harare. In addition to this, they also found that the rates were higher for males than for females, as expected for the period.

Overall, there was an initial drop in crude mortality rates followed by an increase in the early 1990s. This rapid increase reached its peak in 2003 with overall crude mortality rates of 12.2 deaths per thousand and 15.5 deaths per thousand for Harare and Bulawayo respectively. The lowest rates were recorded in the late 1980s where they were 2.3 deaths per thousand and 2.5 deaths per thousand for females and males respectively in Harare. The highest rates were recorded in the early 2000's at 11.1 deaths per thousand for Harare females and 13.3 deaths per thousand for the corresponding males. Interestingly, Dlodlo, Fujiwara, Hwalima *et al.* (2011) also found that there had been a slight reduction in adult mortality since the roll-out of anti-retroviral therapy in Zimbabwe. With reference to the cause specific death rates, they found that deaths due to HIV/AIDS had increased significantly in the period. The registered deaths were, however, not corrected for incompleteness, nor were they assessed to see if they were consistent with data from other sources (or indeed, whether cause was accurately recorded).

2.3.2 Estimates of infant and under-five mortality for Zimbabwe's national and sub-national populations

Similar to adult mortality, shortcomings in Zimbabwe's vital registration system, have prompted reliance on direct estimates from full birth histories and indirect methods for the estimation of infant and under-five mortality. Marindo and Hill (1997) highlighted that infant and child mortality in Zimbabwe was on a downward trend from around 1980 until 1988 after which there was a reversal of this decline due to the effects of HIV/AIDS. They also found that in the period (1980-1988), infant mortality risks were lower for children born in the metropolitan areas of Harare and Bulawayo, than for children born in other areas.

Direct estimates of infant mortality and under-five mortality are normally given in the census reports and the DHS reports for the years in which the censuses and surveys

took place. The infant mortality rate for the 2010-11 DHS, 0-4 years before the survey was estimated to be 57 deaths per thousand births, whereas the estimate for the 2005-06 DHS, in the same period before the survey, was 60 deaths per thousand births, which is a decrease in infant mortality between the two successive DHS surveys (2007; 2012).

In the DHS reports (2007; 2012), sub-national rates were estimated for the period 0-9 years before the survey to reduce the sampling errors that are associated with small populations. The infant mortality rates for Harare were found to be slightly higher than those of Bulawayo. Estimates from both the 2002 and 2012 censuses (Zimbabwe National Statistics Agency (ZIMSTAT) 2002, 2012), given in Table 2.1, reveal that the infant mortality rate for the population of Bulawayo was lower than that of Harare, with both being lower than the national rate.

Table 2.1 Infant mortality rates by population and sex (per thousand)

| Population | 2002 Census | | | 2012 Census | | |
|------------|-------------|--------|----------|-------------|--------|----------|
| | Bulawayo | Harare | Zimbabwe | Bulawayo | Harare | Zimbabwe |
| Males | 53.8 | 47.6 | 72.5 | 48.0 | 58.0 | 70.0 |
| Females | 44.2 | 41.3 | 62.1 | 43.0 | 48.0 | 57.0 |

Marera (2011) produced indirect estimates of infant and under-five mortality from the 1982, 1992 and 2002 censuses and also the 2005-06, 1999, 1994 and 1988 DHS's, using a variant of the Brass children ever born, children surviving method (CEB/CS) that adjusts for HIV/AIDS-related bias to estimate infant and under-five mortality. While the trend was seen to be similar to that of estimates from full birth history, the levels of the indirect estimates are a bit higher than for the full birth histories for both measures. The difference between the direct and indirect estimates can be attributed, at least in part, to the adjustments made for HIV/AIDS-related bias on one and not the other.

A plot of the infant mortality rates from the DHS surveys, censuses, the Inter-Agency Group for Mortality Estimation (IGME) and the UN Population Division (UN Pop Div) in Figure 2.3, show inconsistencies between the various estimates. The trend and level of infant mortality suggested by the rates are quite different for the different data sources and studies. Both the 2002 and 2012 censuses appear to be slightly higher than those from other sources. However, the major inconsistency is seen when comparing estimates whose reference date is similar but whose data source differs. An example of this is the mortality estimate 5-9 years before the 2010-11 DHS. This estimate is much lower than another estimate at the same time point, but representing mortality 0-4 years before the 2005-06 DHS. The fact that these DHS estimates were not adjusted for

HIV/AIDS-related bias probably explains some of the differences. The IGME estimates however, were adjusted for HIV/AIDS-related bias and are thus likely to be more reliable than the other estimates.

Masquelier, Reniers and Pison (2014) adjusted the direct estimates of under-five mortality for HIV/AIDS-related selection bias from the available DHS surveys for Zimbabwe using the method proposed by the IGME in Walker, Hill and Zhao (2012), and reported that for Zimbabwe the under-five mortality rate for the year 2000 had been underestimated by almost 28 per cent. In addition to this, estimates of under-five mortality from this study showed that under-five mortality had been increasing, but then it levelled off between 2000 and 2005.

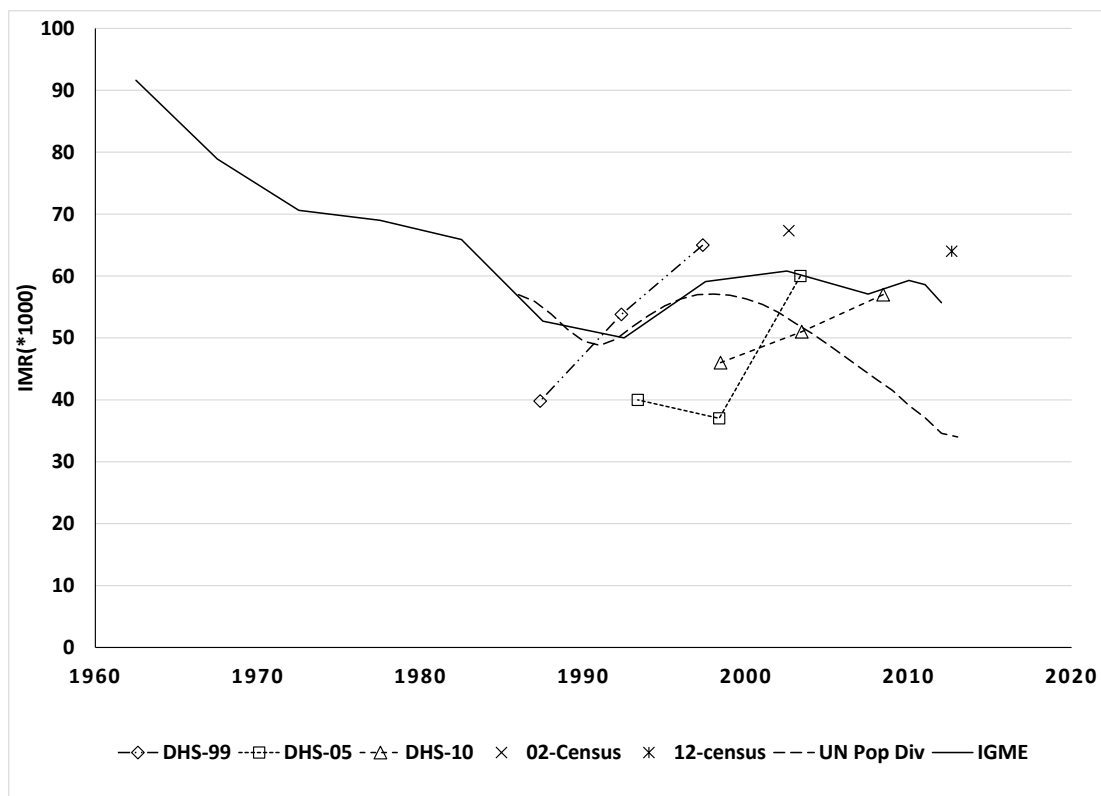


Figure 2.3 Infant mortality rates (per thousand) by source

A comparison of the direct estimates from full birth histories adjusted for HIV/AIDS by Masquelier, Reniers and Pison (2014), the indirect estimates produced by Marera (2011), and estimates produced by the Inter-Agency Group for Mortality Estimation (IGME) and the Institute of Health Metrics (IHME), is given in Figure 2.4. As children with younger mothers have significantly higher mortality, the most recent estimate for the indirect method is normally excluded as it overestimates the mortality of the population. The level of the adjusted estimates differs significantly for the three data sources. The census

estimates are significantly higher than the estimates from other sources, with another interesting feature being the closeness of the adjusted direct and indirect DHS estimates after 1995. There is also significant similarity between the IGME estimates and the estimates produced by Masquelier, Reniers and Pison (2014).

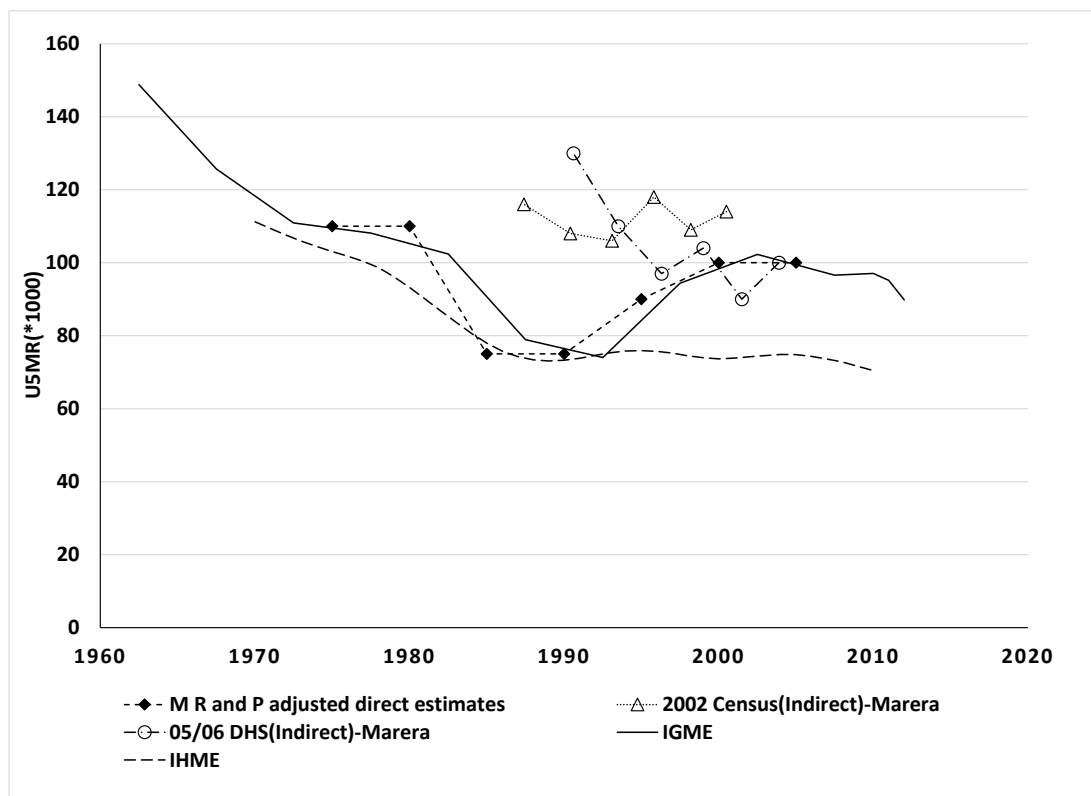


Figure 2.4 Under-five mortality rates (per thousand) by source and author

2.4 Conclusions

Evidently, there is very little research on the use of vital registration data for estimating both national and subnational mortality. Moreover, most of the research on Zimbabwe's mortality is at a national level, with very little research on sub-national estimates of mortality. The use of crude rates for most of the available research provides a weak comparison of national and sub-national adult mortality, which does not account for the age structure of mortality or the population. For infant and child mortality, there is even less that is known at the sub-national level than adult mortality, with most of the estimates being what is provided in the census and DHS reports. From the available research, however, mortality in the metropolitan areas of Harare and Bulawayo is slightly lower than that of the country as a whole, with mortality in Bulawayo being lower than that of Harare. It is the purpose of this research, not only to assess the usability of vital registration data in tracking mortality of Harare and Bulawayo, but also to provide updated estimates of infant, under-five and adult mortality from DHS and census data.

3 DATA AND METHODS

The purpose of this chapter is to provide a detailed description of the data and the methods used in the study. Section 3.1 gives a description and assesses the quality of these data, before an outline of the methods employed to estimate adult mortality is given in Section 3.2. Infant and under-five mortality estimation is described in Section 3.3.

3.1 Data sources and quality assessment

3.1.1 Vital registration data

Vital registration data for both the urban populations of Harare and Bulawayo in the period of interest, were obtained in tabular form from the health services departments of each respective city. The data from Harare were disaggregated by age and sex, while the data from Bulawayo were disaggregated only by age. Data from both cities were extracted from death certificates captured in vital registration records except for the data for Bulawayo for 2004 which were extracted from burial records rather than vital registration records. The numbers of deaths given represent all the deaths that took place in the urban populations of Harare and Bulawayo, that is, all the deaths of residents and non-residents of Harare and Bulawayo (Bulawayo City Health Department 2012; Harare City Health Department 2012).

3.1.1.1 *Distribution of deaths over time*

The plot of registered deaths per year for Harare and Bulawayo is given in Figure 3.1. For both cities there is a slight increase in the number of registered deaths between 2000 and 2002 with the trend continuing for Harare until 2003. The actual reason for this increase is unclear, but possible reasons include a high proportion of HIV/AIDS-related deaths, changes in the levels of completeness of death registration or changes in the population of Harare itself. There is a slight decrease for Harare thereafter, while for Bulawayo there is a significant decrease from 2003 to 2004 which stems from the fact that deaths were obtained from burial records rather than vital registration records. There are, however indications of a general decline in the number of registered deaths for both populations from 2006. Registered deaths in Harare from 2009, however, exhibit a rather inconsistent trend the cause of which is unknown.

The deaths reported by households in the census, also given in Figure 3.1, suggest a general decrease in the number of deaths from 2002/2003 to 2012/2013 for both cities. Comparing the deaths reported by households with the registered deaths reveals that the

numbers of deaths from both sources are more in line with each other in 2012 than in 2002. This can be attributed to a number of reasons which include the emigration of the working age population to neighbouring South Africa within the period, and improvements in medical facilities in other parts of the country, such that individuals need not come to either of the cities for medical attention.

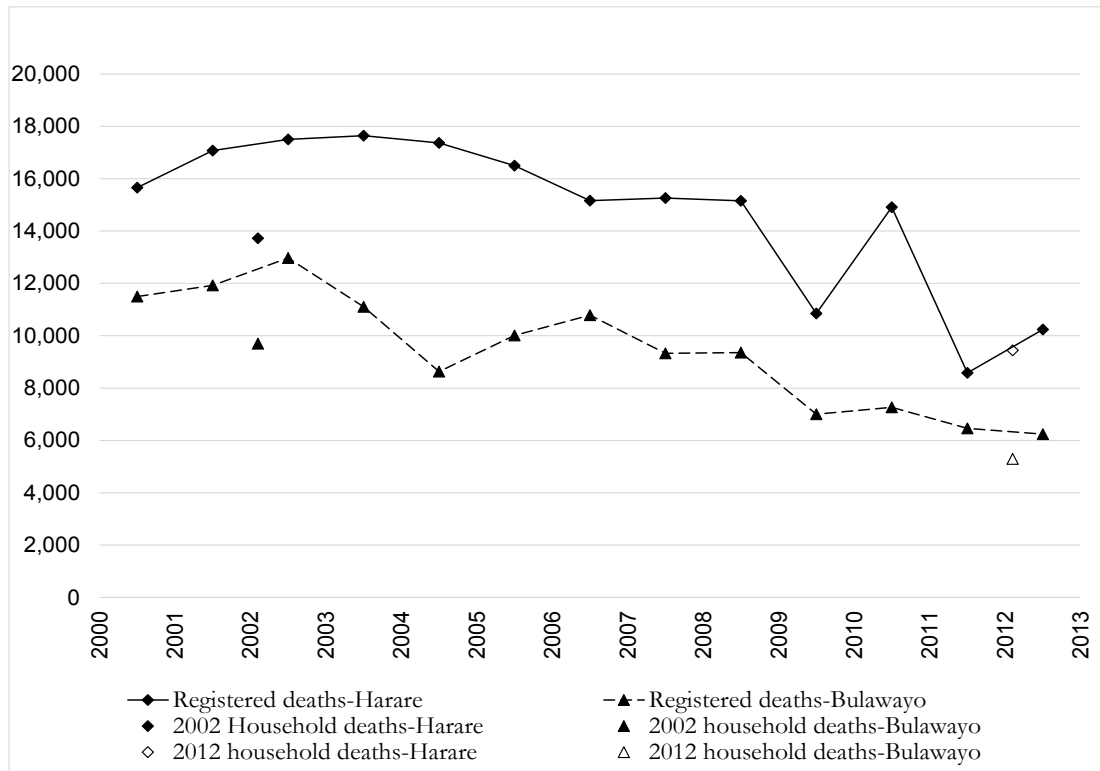


Figure 3.1 Registered deaths by year

3.1.1.2 Distribution of deaths by age

The age-distribution of deaths for both cities, shown in Figure 3.2 and Figure 3.3 reveal that the majority of deaths were observed to be infant deaths for the period, with a distinct hump from around the early adult ages to around 55 years. This is to be expected as the majority of individuals in metropolitan populations are likely to be aged between 20 and 60 and with the associated high mortality rates in developing countries, a high percentage of deaths is to be expected for that age range. Barring the bizarre shape of the deaths in Harare in 2010, there is a significant decrease in the number of deaths after the year 2008 in Harare, which can be attributed to the significant out-migration that took place as a result of Zimbabwe's economic crisis reaching its peak in that period. Other noteworthy features include the large number of infant deaths that were unregistered in Bulawayo for 2009 and the striking similarity of the number of deaths by age in Harare in 2006 and 2007. Reasons for these anomalies could however, not be ascertained.

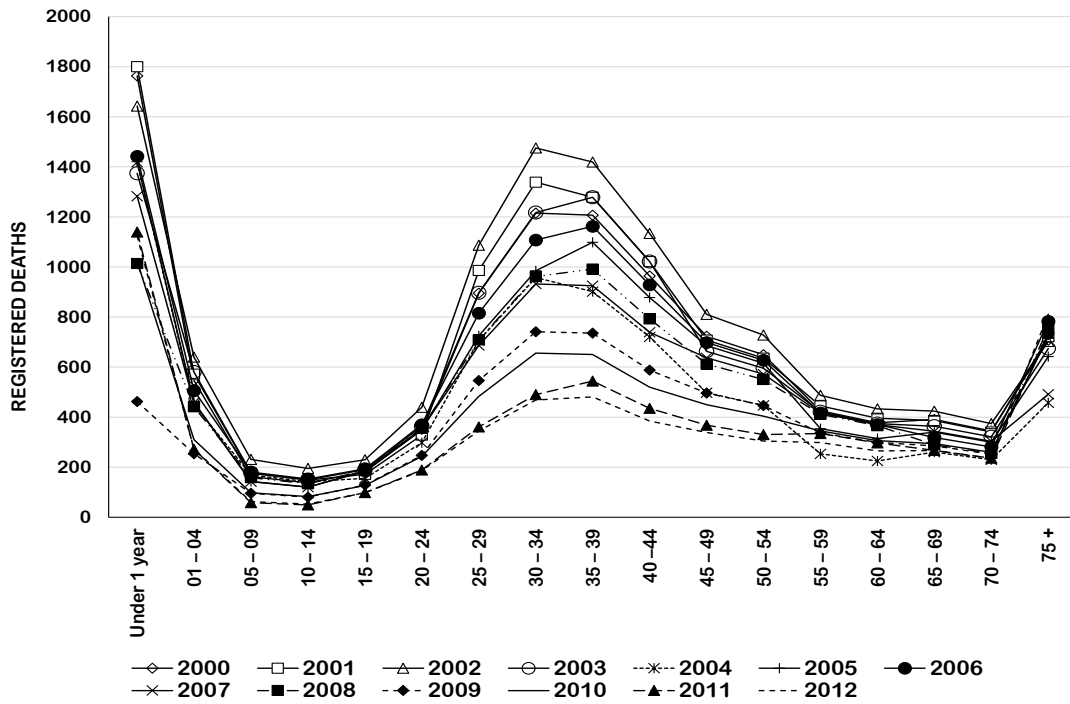


Figure 3.2 Age distribution of deaths by age, Bulawayo

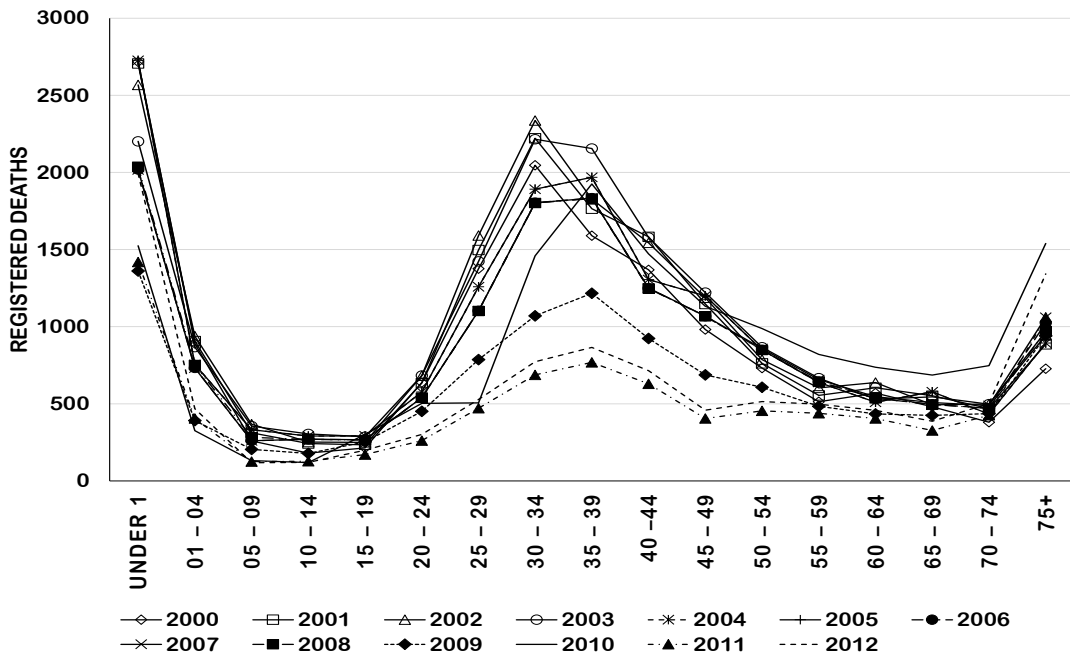


Figure 3.3 Age distribution of deaths by year, Harare

3.1.1.3 Births

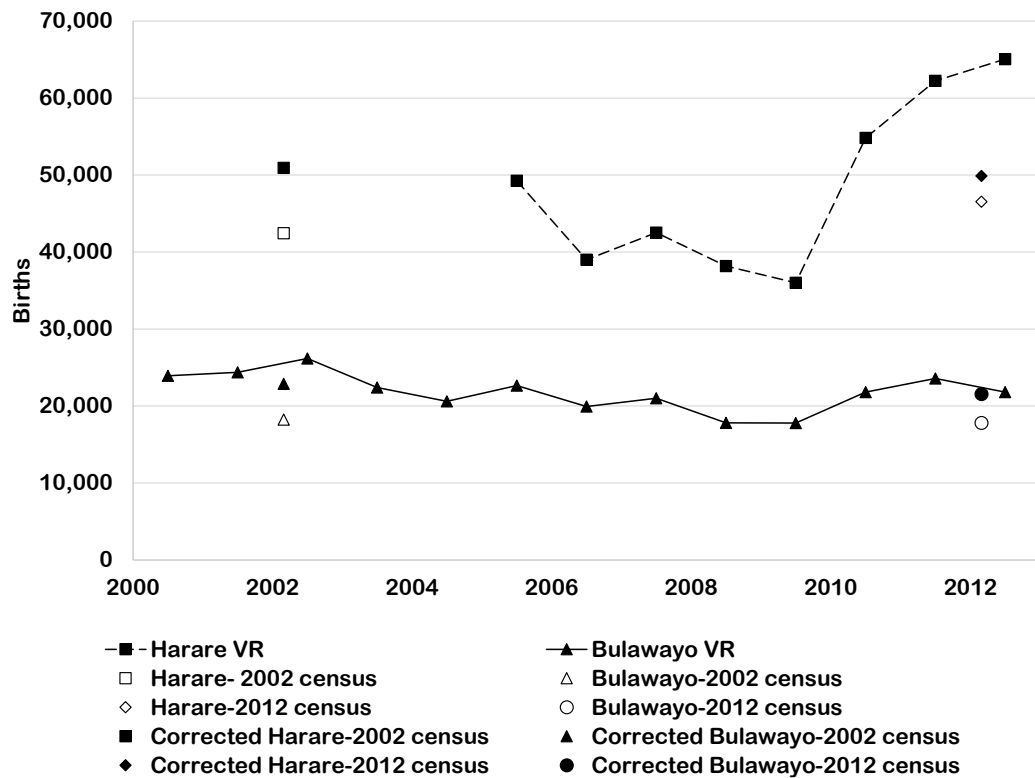


Figure 3.4 Vital registration births, 2002 to 2012

From the plot of births given in Figure 3.4, available registered births are higher than those from the censuses for both cities implying that either some of the registered births were for individuals from other parts of the country, or that the census births were heavily underreported. Correcting the age-specific fertility rates of both censuses using the Relational Gompertz model from a spreadsheet which accompanies Moultrie (2013) reveals that the reason is more likely to be the former as registered births are still higher than the corrected births.

Bulawayo's registered births appear to have a more discernible trend than Harare's registered births and are closer to the corrected census births hence they are likely to be more usable than the available registered births for Harare, which appear not have any consistent trend and are vastly different from the births from the 2012 census.

3.1.2 Census data

Zimbabwe has held four post-independence censuses, that is, in 1982, 1992, 2002 and 2012, with the censuses taking place in August of the stated year. Of these censuses, only the 2002 and 2012 censuses fall in the period under consideration and as such, the data required for this study are extracted from these censuses. The majority of the data required

are obtainable from the national and provincial reports of both the 2002 and 2012 censuses, with the remainder being obtained upon request from the ZIMSTATS Census Office.

3.1.2.1 Population age distributions

Estimates of the urban populations of Harare and Bulawayo, and that of Zimbabwe as a whole by age and sex, are presented in the census reports. The percentage composition of the Zimbabwe population by age and sex is given Figure 3.5. The proportion aged between 0 and 4 years increased from the 2002 to 2012 census. This suggests under-enumeration in this age group for the 2002 census as fertility actually fell in the period and there has also been significant out-migration of women of child-bearing age, as evidenced by the two percentage point reduction in the proportions aged between 15 and 49 for both sexes.

Projecting the actual 2002 population figures forward, ignoring migration, to 2012 using survival ratios obtained from the life tables in the World Population Prospects (United Nations 2013) and comparing this to the 2012 census, reveals a reduction of the expected population aged between 15 and 35 years possibly due to net out-migration during Zimbabwe's economic crisis, as seen in Figure 3.6. The proportions in the censuses at the latter years are fairly similar for both sexes.

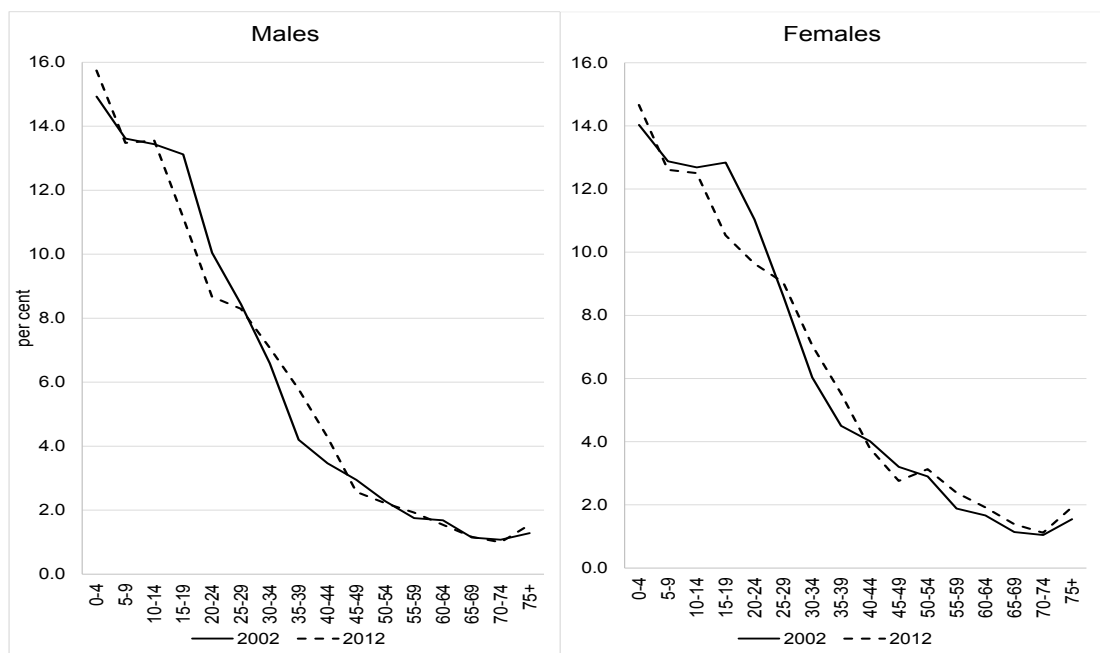


Figure 3.5 Composition of the Zimbabwe population by age and sex (per cent)

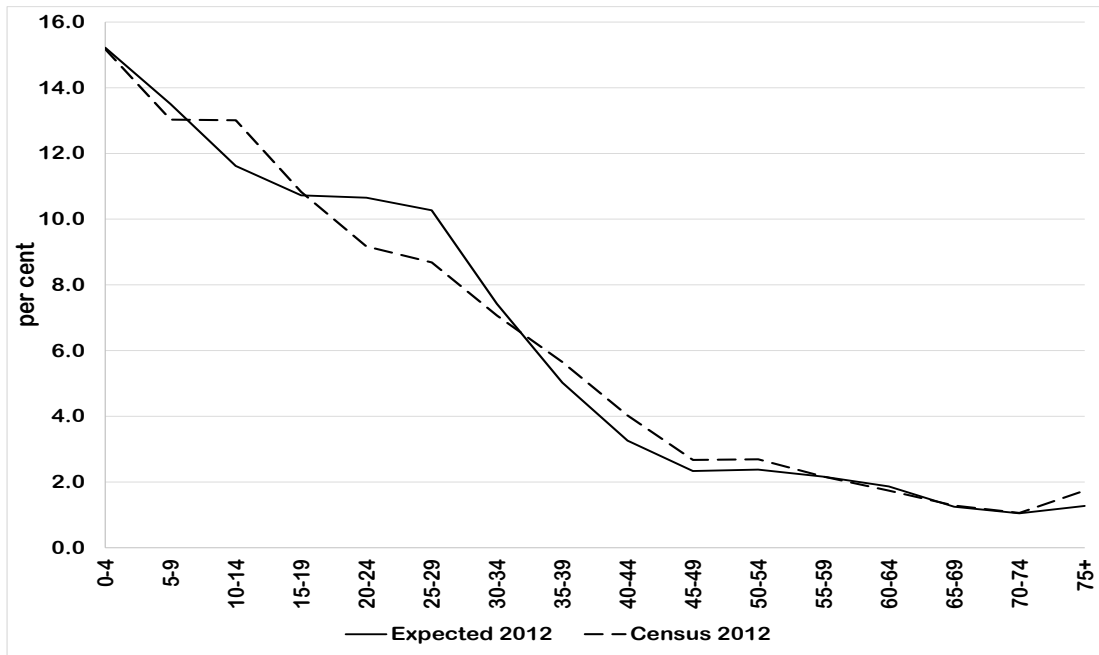


Figure 3.6 2012 Census population vs 2012 Expected population (per cent)

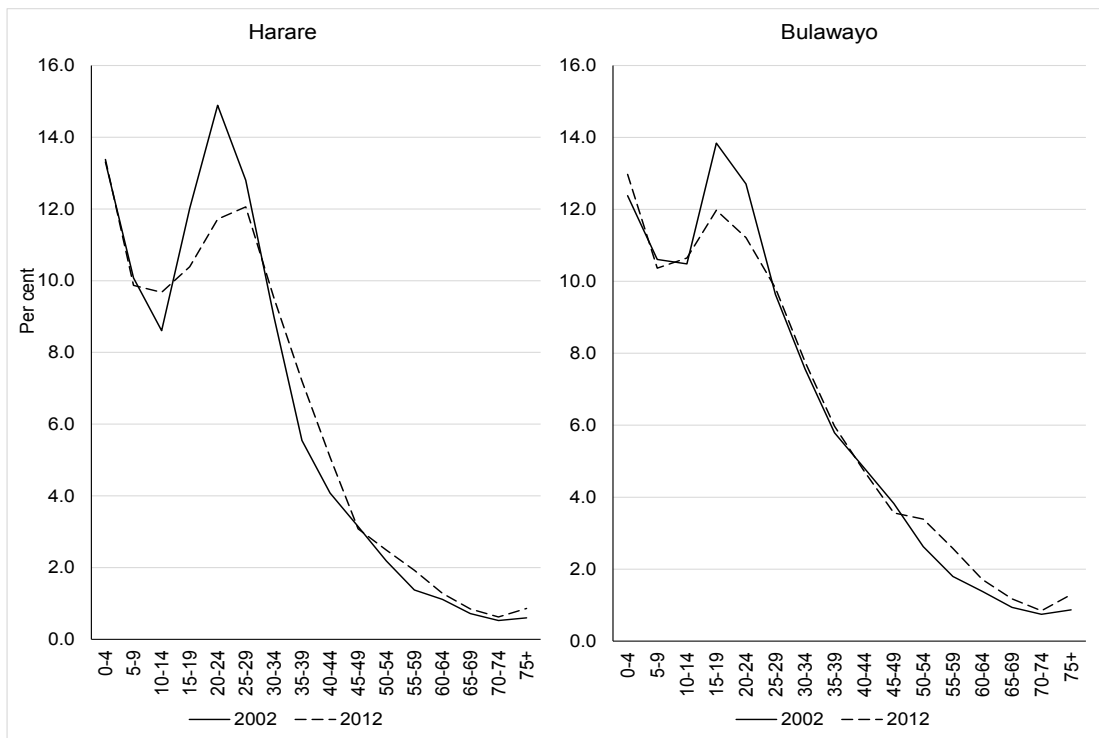


Figure 3.7 Population composition by age group (per cent)

The populations of both Harare and Bulawayo are characterised by a fairly conspicuous net in-migration shape. This is due to a significant amount of rural to urban migration that takes place as people of working age move to the metropolitan areas in search of better opportunities. As this population is also highly sexually active, the proportion aged between 0 and 4 years is also expected to be high, as seen in Figure 3.7. For both cities,

there was a significant reduction in the population aged between 15 and 29 in successive censuses which, while it might be ascribed to a reduction in rural to urban migration, is more likely a consequence of the emigration of individuals to neighbouring South Africa. The dip in Harare's 5-9 age group for the 2002 census is evidence of undercount of that age group.

3.1.2.2 Age ratios

The age ratios were calculated for the populations in question using the formula;

$${}_nA_x = \frac{3 \cdot {}_n P_x}{{}_n P_{x-5} + {}_n P_x + {}_n P_{x+5}}$$

where ${}_n P_x$ is the population aged between x and $x + n$. The age ratios for Harare and Bulawayo (Figure 3.8 and Figure 3.9) are generally close to 100 except the ratios for the youngest and oldest ages in the both censuses. For the oldest ages, this is due to the fact that accurate reporting of age is generally poor owing to the rapid increase in mortality. For the youngest ages, this is possibly to the high levels of in-migration experienced by both cities. In addition to this, an inspection of sex-specific age ratios between the censuses for this particular age group suggests that there was under-enumeration in the 2002 census when compared to the 2012 census for the city of Harare. A visual inspection of the age ratios however suggests that age reporting in Bulawayo was better than in Harare in both censuses. There appears to be an aberration in the age ratios for Bulawayo males aged 30-39 in 2002 and 40-49 in the next census. This appears to be some sort of cohort effect for these ages. The exact cause of this pattern, however, is unknown.

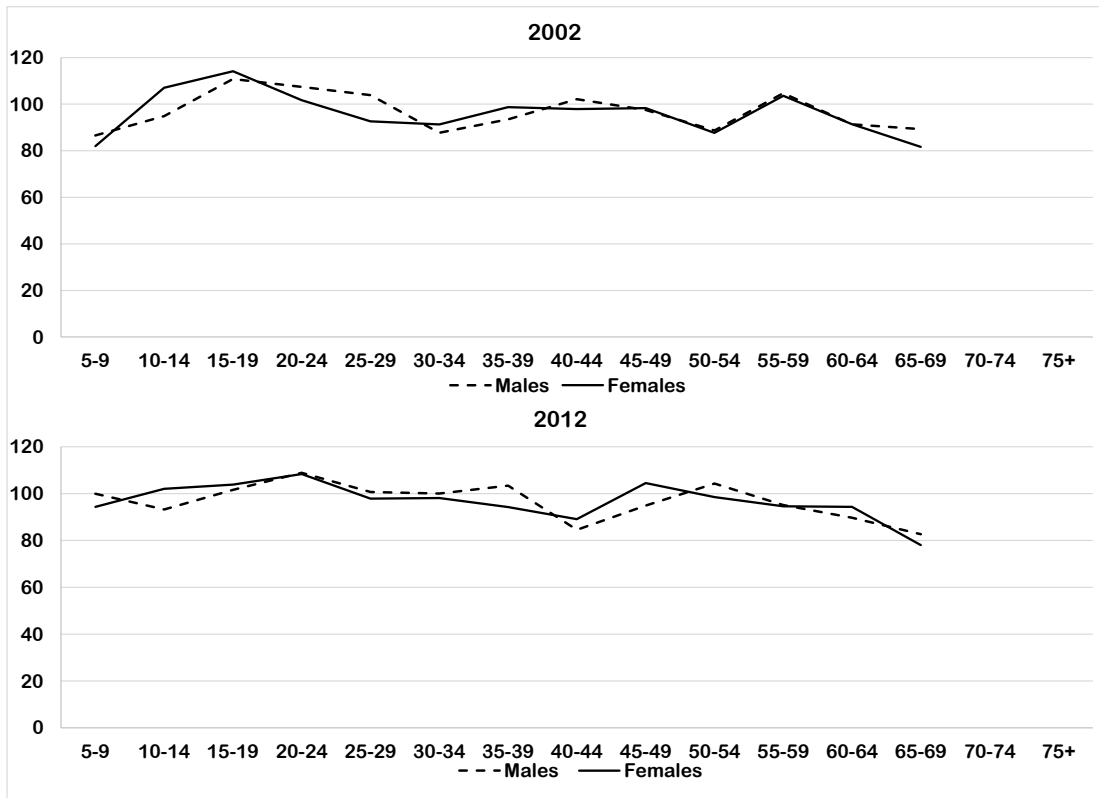


Figure 3.8 Age ratios by age group-Harare

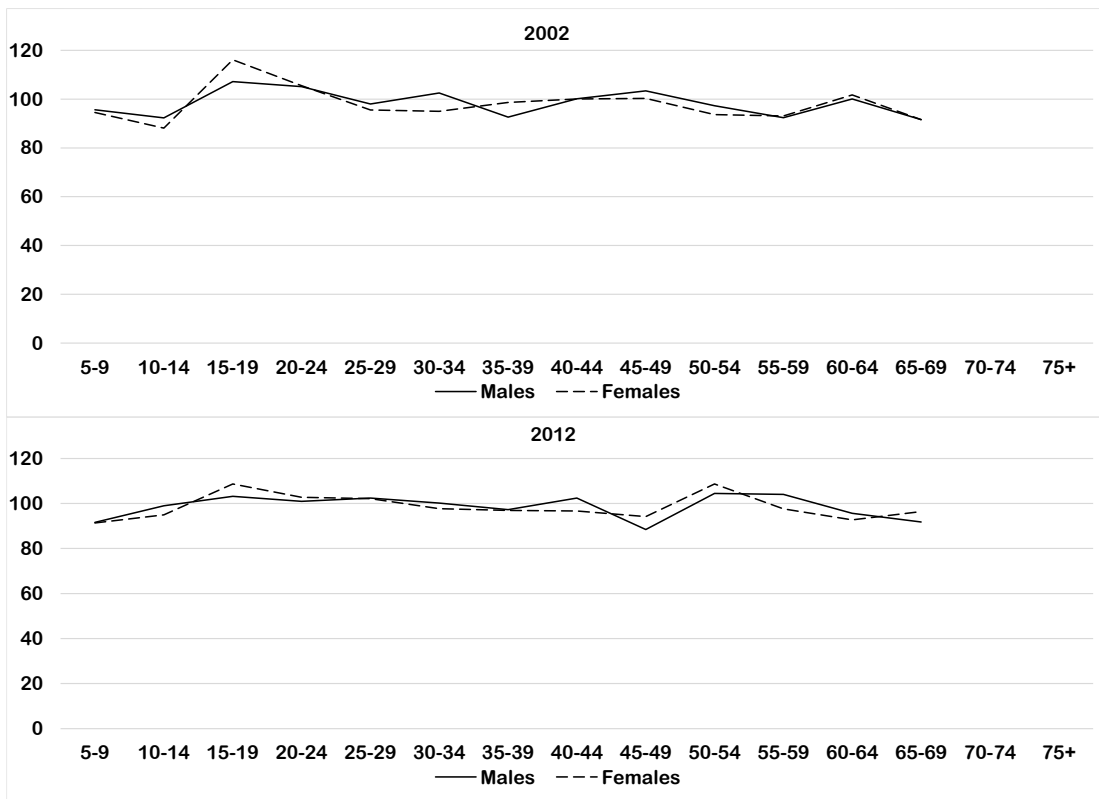


Figure 3.9 Age ratios by age group-Bulawayo

3.1.2.3 Sex ratios

The sex ratios for Harare and Bulawayo for the two censuses are given in Figure 3.10. The ratios are consistent for the two censuses up to around age 20. After age 20, the ratios for 2012 in both cities appear to be lower than those of 2002. The ratios for those aged between 20 and 40 for Bulawayo, and those aged between 20 and 30 for Harare are less than 100 suggesting undercount of young adult men or possibly, male labour out-migration experienced between 2002 and 2012 to neighbouring South Africa. The effects of male rural to urban migration, as characterised by sex ratios greater than 1, are clearly visible in both censuses for Harare between 30 and 44. For the 2002 census, there is an anomaly where the ratio of males to females at the older ages in both cities is above 100. This feature which is indicative of the age reporting errors or under-enumeration of females in the populations. There is also some indication of a cohort effect for ages 30-34 in 2002 and 40-44 in 2012 for Harare. This is possibly a result of in-migration of young adult males taking place prior to the 2002 census.

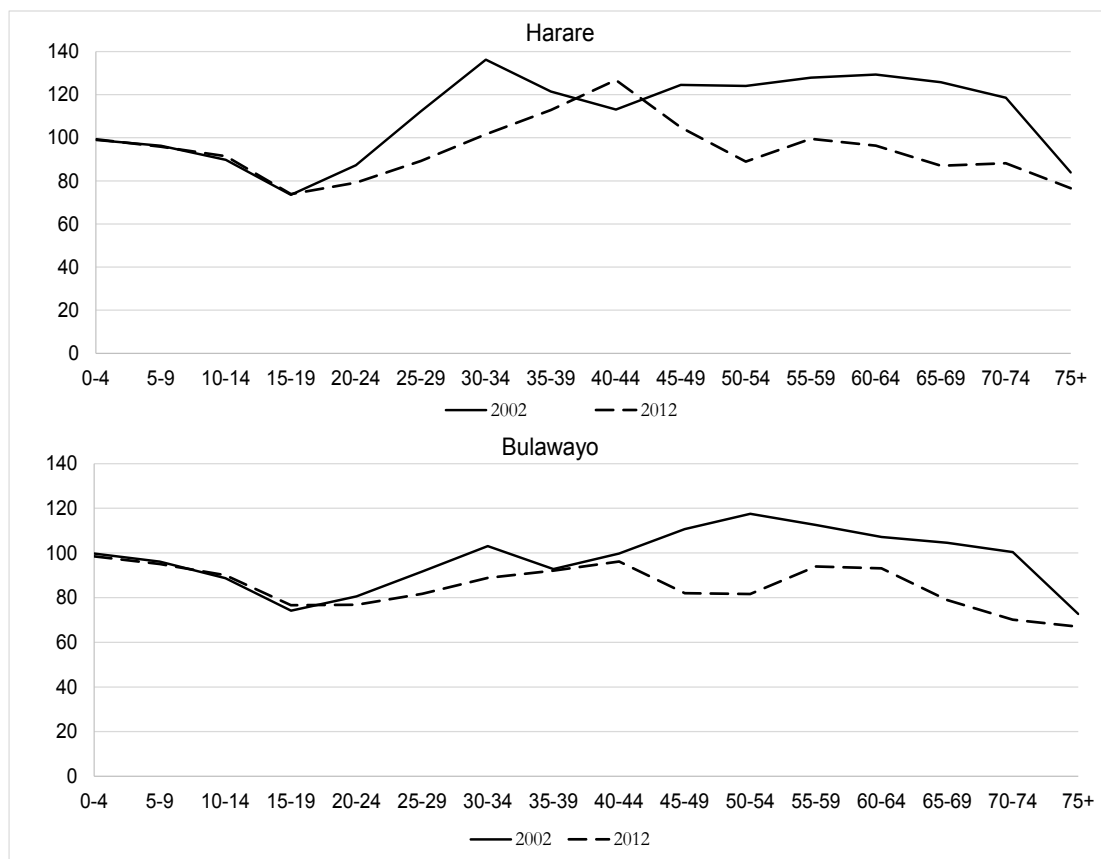


Figure 3.10 Sex ratios by age group

3.1.3 DHS data

There are two Demographic and Health Surveys undertaken in Zimbabwe during the period of interest for this particular research, specifically, the 2005/06 and the 2010/11 DHS with the reference date of each survey being taken as the midpoint of the survey period, which is 01 November 2005 for the 2005-06 DHS and 01 December 2010 for the 2010-11 DHS. For both surveys, only a sample of the population was taken and assumed to be nationally representative of the population at the time of the survey with the sampling frame being determined from the 2002 census for both surveys. The number of households, men and women captured for each survey is given in Appendix A. As a check on the consistency of consecutive surveys, a comparison of the age distributions of the cohorts of men and women interviewed in each survey was made (see Appendix A).

The female age distributions for Zimbabwe, Harare and Bulawayo were all reasonably consistent for the consecutive surveys. The male age distributions for Zimbabwe and Harare also exhibited the same consistency, however, Bulawayo's distributions were less consistent for the surveys. An assessment of the age-ratios for Harare and Bulawayo in both surveys (Figure 3.11) reveals significant deviation from 100 for the male age ratios which is likely to indicate significant in-migration to these areas.

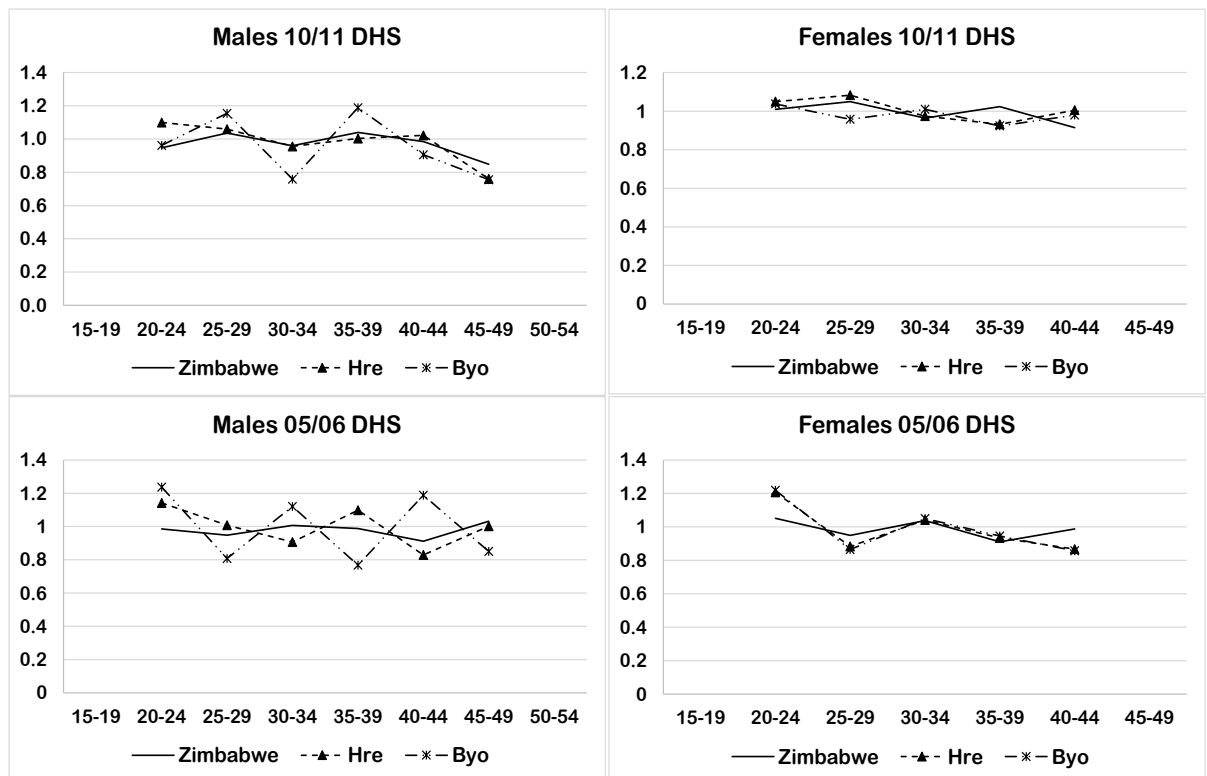


Figure 3.11 Age ratios by sex and age group, DHS data

3.1.3.1 Birth history data

For full birth history data, there is the issue of transference, which results from births being incorrectly reported as occurring in the year prior to the year of birth to, presumably, reduce workload by avoiding having to answer extra questions on younger births. This is common for the calendar year about five years before a survey is conducted. To detect transference, the numbers of births in each year prior to the survey were obtained from the 2005/06 and 2010/11 datasets, and birth ratios were calculated using the formula:

$$\frac{2B_t}{B_{t+1} + B_{t-1}}$$

where B_t represents the number of births reported in year t . Deviation from unity can be seen as an indicator of birth transference.

Plots of birth ratios against the number of years before the survey (Figure 3.12 for surviving children and dead children) show that for the 2005/06 DHS, there is possible transference of births in the Bulawayo and Harare data, owing to the significant difference between the birth ratios of the surviving and dead children, while there is no evidence of such transference for the whole of Zimbabwe. It is, however, possible that the irregular birth ratios could be indicative of poor data. The 2010/11 DHS displays no evidence of transference for any of the three populations.

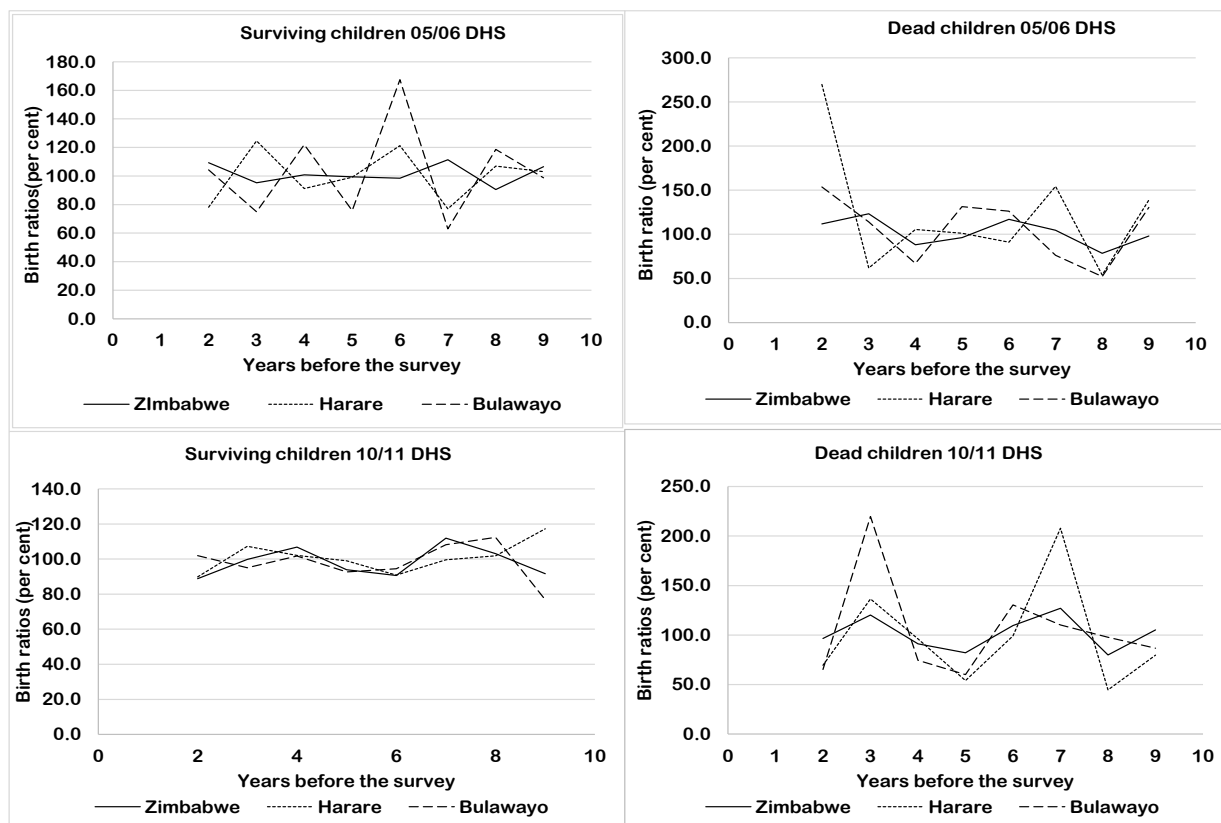


Figure 3.12 Birth ratios (per cent) by year before the survey

3.2 Methods: Adult mortality estimation

This section describes the direct and indirect methods used to estimate adult mortality for the populations of Zimbabwe, Harare and Bulawayo. It considers the direct estimation of adult mortality from sibling histories, the indirect estimation using the orphanhood method and the application of the GGB and SEG methods on deaths reported by households and vital registration data.

3.2.1 Direct estimation from sibling histories

Following the procedure outlined in the literature review, direct adult mortality estimates for the 2005/06 DHS and the 2010/11 DHS were obtained from sibling histories using data files provided on the DHS website, upon request, and Stata version 12 software. Estimates were produced for each of the populations of Zimbabwe, Harare and Bulawayo, for a period 0-6 years before each respective survey. Direct adult mortality estimates, in the form of sex-specific mortality rates for each five-year age group between 15 and 49 years are also given in the DHS reports by the Zimbabwe National Statistics Agency (ZIMSTAT) and ICF International (2007; 2012). As a check on the code, the results presented in both reports for Zimbabwe were reproduced exactly for the period

0-6 years before each survey (see Appendix A), while the code used is given by Marera (2011).

As the more reliable age-specific mortality rates obtained from sibling histories are between the ages of 15 and 49, the age-specific mortality rates are then converted to an index of mortality, ${}_{35}q_{15}$, using the formula;

$${}_{35}q_{15} = 1 - \exp\left(-5 * \sum_{i=1}^7 M_i\right)$$

where M_i is the age-specific mortality rate for five-year age group i , where i ranges from 1 to 7 representing age groups 15-19 to 45-49. This assumes the force of mortality is constant by age in each five-year age group. To convert the index ${}_{35}q_{15}$ to the more common ${}_{45}q_{15}$, the ‘AIDS standard’, devised for countries with moderately severe HIV epidemics was used (Timæus 2013b: 237).

3.2.2 Orphanhood method

The variant of the orphanhood method employed in this research is the one that incorporates the HIV/AIDS epidemic (Timæus and Nunn 1997) and is described in the literature review. The method was applied to each of the 2005-06 DHS, 2010-11 DHS, 2002 and 2012 census datasets, using a spreadsheet that accompanies Timæus (2013b). Estimates of antenatal HIV prevalence (for maternal orphanhood) and HIV prevalence among men (for paternal orphanhood), required as input for the method, were obtained from the AIDS Impact Model (AIM) module of the Spectrum population projection software, version 5.03. The same assumptions and ‘AIDS’ standard used by Timæus (2013b) were also used in this research.

3.2.3 Death distribution methods

This section describes the application of the death distribution methods to estimate adult mortality for the populations of Zimbabwe, Harare and Bulawayo based on the nature of the data available and the how estimates of migration and completeness were obtained.

3.2.3.1 Deaths reported by households

Death distribution methods, specifically the GGB and SEG methods were used in this research to estimate completeness of reporting of adult deaths and hence, to estimate adult mortality using data on deaths reported by households. There were two approaches used. The first is similar to the one in Dorrington (2013b) where the SEG plus an estimate of the differential census coverage, delta, were applied to the data, while the other is

similar to that suggested by Hill, Choi and Timæus (2005) where, the GGB method was used to correct for relative undercount of the 2002 and 2012 censuses. The adjusted distributions were then used as input for the SEG method (without the delta adjustment for differential census coverage), which is used to estimate completeness and hence adult mortality. The total number of inter-censal deaths were interpolated from the deaths in the year before each of the 2002 and 2012 censuses using a spreadsheet which accompanies Dorrington (2013b).

3.2.3.2 Vital registration data

For vital registration data, the procedure adopted mirrors the one employed for the deaths reported by households in every aspect, except the approximation of the inter-censal deaths. The numbers of deaths in the inter-censal period for the populations of Harare and Bulawayo were obtained by summing the annual deaths between 2003 and 2011 and increasing this number by the number of deaths corresponding to the ratio of the length of the full period for 2002 and 2012. This was thought to be more accurate than apportioning the registered deaths in 2002 and 2012. These deaths were given in five-year age groups.

3.2.3.3 Estimating net migration

Net migration needs to be properly accounted for in both Harare and Bulawayo as there is likely to be a significant amount of rural-to-urban, urban-to-rural and urban-to-urban migration taking place. In addition to this, there is the issue of international migration which was quite substantial for the period in question, with a significant proportion of the young working-age population emigrating to neighbouring South-Africa. However, as reliable net-migration figures are not readily available, it was necessary to derive rough estimates by trial and error to be used as input in the SEG method.

The method employed to estimate net migration in this research is similar to that suggested by Dorrington, Timæus and Gregson (2006) where the overall number of migrants were set to minimise deviation from the fitted line in the GGB method. These estimates of net migration for the populations in question were obtained as follows: an initial estimate of migration, which provides the age profile of migration, is obtained by averaging the forward and reverse survival methods for estimating migration using survival ratios obtained from life tables for Zimbabwe covering the inter-censal period from the World Population Prospects (United Nations 2013).

Taking any excess in or out-migration in age groups that are unlikely to experience significant migration (for example, ages 5-9 for the national population, and ages 70-74

for the populations of Harare and Bulawayo) as an indication of the level of relative over-count or under-count between the censuses, new migration estimates are obtained by assuming this level is applicable for all ages, then correcting for this in the census population figures and repeating the forward and reverse survival methods to estimating migration. The estimate obtained is a closer depiction of the actual age profile of migration. As no significant in or out-migration is expected for the older age groups (70+), any excess or deficit migration in these age groups can be taken to be the result of age exaggeration and therefore be redistributed to the other younger age groups.

As net-migration flows are predominantly age-specific, this age profile is then split into separate age bands to represent the different migration flows. These profiles are then multiplied by non-negative scalars and used as input in the GGB. The level that produces the best fit, that is, one that minimises the deviations from the fitted line, is then taken as the migration estimate. The line of best fit was plotted by setting the lower age as 5 and the upper age as 74, representing the ages for which completeness is assumed to be constant. This was done under the premise that differential completeness for ages 5-14 is unlikely to distort the completeness at older ages due to the relatively small numbers of deaths for these groups, hence the choice of age 5 and not 15. Where both vital registration data and deaths reported by households are available, the procedure described here is performed on both sets of data to get separate migration estimates and an average of the two separate estimates is taken as the overall migration estimate.

3.2.3.4 *Estimating completeness*

For the deaths reported by households, the levels of completeness obtained from each of the methods outlined in section 3.2.3 are then used to determine the final estimate of completeness. This final estimate of completeness was decided on by comparing estimates of implied adult mortality (${}_{45}q_{15}$), before and after adjusting for incompleteness, with those from other sources. Estimates from the orphanhood method and direct sibling histories were employed to adjust upwards (or downwards) the levels of completeness to ensure reasonable estimates of adult mortality. Estimates from the World Population Prospects (United Nations 2013), and the IHME are then used to ascertain the reasonableness of the estimate adopted for the national estimates.

For vital registration data, implied adult mortality estimates from the GGB, SEG and GGB+SEG were compared to those from the deaths reported by households, the orphanhood method and direct sibling histories. The level of completeness corresponding to the median estimate of adult mortality for the different methods was taken as a

reasonable estimate of completeness, and used to adjust the annual vital registration deaths under the assumption that completeness was constant in the inter-censal period. For consistency, the years outside the inter-censal period (2000 and 2001) were also adjusted using this same estimate.

3.2.4 Direct estimation from vital registration data

The number of vital registration deaths for Harare and Bulawayo's are then adjusted for incompleteness using the estimates of completeness obtained from the death distribution methods, for the ages where completeness is assumed to be constant. The adjusted annual deaths and the mid-year population estimates, obtained by interpolating the census population estimates, are then used to calculate age-specific mortality rates, which are in turn, converted into an index of mortality, ${}_{45}q_{15}$, using the formula:

$${}_{45}q_{15} = 1 - \exp\left(-5 * \sum_{i=1}^9 M_i\right)$$

where M_i is the age-specific mortality rate for five-year age group i , with i representing age-groups from 15-19 to 55-59.

3.3 Methods: Infant and under-five mortality estimation

This section describes the direct and indirect methods used to estimate infant and under-five mortality for the populations of Zimbabwe, Harare and Bulawayo in the period 2000-2012 using DHS, census and vital registration data.

3.3.1 Direct estimation from full birth histories

Full birth history data, as collected in most DHS surveys are considered to be one of the more credible sources of infant and under-five mortality estimates in countries with poor vital registration systems. Information from full birth history data provides the basis from which the direct estimates of infant and under-five mortality can be extracted directly. The Zimbabwe National Statistics Agency (ZIMSTAT) and ICF International provide reports on the DHS surveys conducted (2007; 2012) from which the mortality estimates in question may be obtained with estimates being given for periods 0-4, 5-9 and 10-14 years before the survey

The synthetic cohort approach was employed, where children are classified into the following age segments: less than 1 month, 1-2 months, 3-5 months, 6-11 months, 12-23 months, 24-35 months, 36-47 months and 48-59 months (Rutstein and Rojas 2006). Deaths falling in each of these age ranges are divided by the exposure to the risk of dying in that age range over a specified time period. Assuming that deaths are uniformly

distributed in any age interval, age-specific death rates are then converted to survival probabilities using the relationship;

$${}_nq_x = \frac{{}_nM_x}{\left(1 + \frac{{}_nM_x}{2}\right)}$$

where ${}_nM_x$ is the age-specific death rate and ${}_nq_x$ is the probability of dying between age x and $x+n$.

In an attempt to corroborate the estimates published in the reports for each of the time periods, the data files provided on the DHS website and a STATA version 12 program were used to estimate the age-specific death rates and the survival probabilities. The estimates for each of the time periods in the published reports were reproduced exactly using this procedure. It was also necessary to produce estimates that were corrected for possible transference of births. As such, estimates for the periods 1-5, 6-10, and 11-15 years before the survey were also produced using the STATA code given in Appendix D.

3.3.1.1 *Adjusting for the effect of HIV/AIDS on direct estimates.*

Due to the existence of a correlation between the mortality risks of a mother and her child, accentuated by high levels of HIV prevalence, the estimate of under-five mortality is likely to be biased downwards, hence the need to account for this bias in direct estimates. The method developed by Walker, Hill and Zhao (2012) to adjust under-five mortality for the effect of HIV was employed in this research.

The input data required for the procedure were obtained from Spectrum population projection software, version 5.03. A national projection was performed for the Zimbabwe population, while subnational projections were performed for Harare and Bulawayo by assuming that Harare and Bulawayo make up 16.3 per cent, and 5 per cent of the national population respectively, which is in line with the relative proportions of these populations in the 1992, 2002 and 2012 censuses. Births were obtained from the Demproj module, whereas the number of women in need of Prevention of Mother to Child Transmission (PMTCT) treatment and the newly infected infants were obtained from the AIM module. The level of pre-AIDS mortality chosen for Zimbabwe and Harare was 75 deaths per thousand births. This level determines the under-five mortality of HIV-negative births and is essentially the background mortality.

3.3.2 Indirect estimation: Brass CEB/CS method

Seeing as breastfeeding is still prevalent, and children are generally weaned at a later age (greater than 1 year) in Zimbabwe, it can be assumed that the 'Princeton North' standard life table is the closest to resembling Zimbabwe's childhood mortality pattern. The Trussell coefficients for the Princeton North model life table were used to convert the proportions of deceased children into life-table probabilities of dying from birth to exact age x , ${}_xq_0$, and also to provide an appropriate time location, $t(i)$, to which the probabilities apply. The procedure was applied on children ever born, children surviving data from the 2002 census, the 2005-06 and 2010-11 DHS, and the 2012 census for the populations of Zimbabwe, Harare and Bulawayo.

Due to the effects of HIV/AIDS, the estimates provided by the Trussell variant of the CEB/CS method are likely to underestimate the true mortality of the population. To factor in the impact of HIV/AIDS-related selection bias, the procedure proposed by Ward and Zaba (2008) was applied. Although Ward and Zaba (2008) proposed two models, the basic model, which only requires the HIV-prevalence of women of child-bearing age, was used to allow for the effects of HIV/AIDS in this study, rather than the extended model, which requires additional information on the HIV-prevalence of women aged 15-19 which was not readily available.

One of the underlying assumptions of the model is that HIV prevalence among adult females of child-bearing age should be constant over time. This however, is not the case with Zimbabwe as HIV prevalence has been far from stable. Various methods, which make use of the prevalence at the time of child-bearing, can be applied to factor in the changing HIV prevalence. The method used for this particular study is the one used by Darikwa and Dorrington (2011), and makes use of the HIV prevalence at the date of the time location $t(i)$. Estimates of annual HIV prevalence for women of child-bearing age were obtained from the AIM module of the Spectrum population projection software (v5.03).

3.3.3 Previous Birth Technique

The technique was applied to the 2005-06 DHS and the 2010-11 DHS. Data on the most recent births to women aged between 15 and 49 years in the period 24 months before the survey, were extracted for each of the populations of Zimbabwe, Harare and Bulawayo. The proportion dead among these recent births was then multiplied by a conversion factor of 1.09 to get the infant mortality rate which can be assumed to correspond to the time location exactly one year before each respective survey.

3.3.4 Direct estimation from vital registration data and deaths reported by households

As mentioned in the literature review, infant and under-five mortality can be estimated directly from vital registration data and deaths reported by households. The procedures for the two data sources are the same and both require extra data on the number of births in the same period that the deaths are experienced. The infant mortality rate, which approximates q_0 , is obtained by dividing the number of infant deaths (those aged less than one year) by the number of births for the same period. Under-five mortality, as measured by ${}_5q_0$, is estimated from the infant mortality rate and the child mortality rate, ${}_4q_1$, using the formula:

$${}_5q_0 = 1 - [(1 - q_0) * (1 - {}_4q_1)]$$

The child mortality rate, ${}_4q_1$, was obtained by dividing the deaths to those aged between 1 and 5 years by the corresponding population estimates (mid-year population estimates for vital registration data) to get the age-specific death rate, ${}_4M_1$, which is then converted into ${}_4q_1$, on the assumption that the force of mortality is constant for all ages 1-5, using the formula:

$${}_4q_1 = 1 - \exp(-4 * {}_4M_1)$$

The erratic nature of the vital registration data on births for Bulawayo and more so Harare, makes it rather difficult to use these births solely to estimate infant mortality. It is therefore necessary to incorporate census data in an attempt to obtain reasonable estimates of births.

3.3.4.1 Estimating births

Rough estimates of births from 2000 to 2012 are obtainable from census data by interpolating the age-specific fertility rates and female population estimates for the period 1992, 2002 and 2012 censuses to give annual age-specific fertility rates, and use them, after shifting them to the middle of the year, to obtain the births. More specifically, rough estimates of births for each year in the period, can be obtained using the formula;

$$\sum_{i=1}^7 f_i * FP_i$$

where f_i is the age-specific fertility rate for five-year age group i , and FP_i represents the interpolated mid-year female population in the same age group, where i represents ages 15-19 to 45-49.

Age-specific fertility rates for Harare and Bulawayo from the 1992, 2002 and 2012 censuses were corrected using the Relational Gompertz Model before being used in the

estimation procedure. This was done in an attempt to reduce the extent of under/over reporting of births, age-reporting errors and discrepancies in average parity data (Moultrie 2013), and this correction was done using a spreadsheet that accompanies Moultrie (2013).

4 RESULTS: ESTIMATES FROM CENSUS AND DHS DATA

This chapter describes the application of the methods used to estimate mortality for the populations of Zimbabwe, Harare and Bulawayo, based on DHS and census data. In the first section, estimates of adult mortality from the two data sources are given, while the second section concentrates on infant and under-five mortality estimates.

4.1 Adult mortality

4.1.1 Direct estimation using sibling histories

The direct estimates of adult mortality produced from sibling histories are given in Table 4.1. These estimates apply for a period about three and a half years before the survey which coincides with time locations of approximately 2002.3 and 2007.4 for the 2005/06 and the 2010/11 DHS's, respectively.

Table 4.1 Probability of an individual aged 15 dying by age 60-Direct sibling histories

| Survey | Males | | | Females | | |
|---------|----------|--------|----------|----------|--------|----------|
| | Zimbabwe | Harare | Bulawayo | Zimbabwe | Harare | Bulawayo |
| 2005/06 | 0.677 | 0.783 | 0.702 | 0.644 | 0.680 | 0.642 |
| 2010/11 | 0.587 | 0.454 | 0.608 | 0.575 | 0.553 | 0.493 |

From these estimates, there is evidence of a decline in mortality for all three populations with the level of Bulawayo's estimates being similar to those of Zimbabwe for the males in both surveys and females in the 2005-06 DHS. In both surveys, male adult mortality is higher than female adult mortality, as might be expected.

4.1.2 Orphanhood method

Estimates of adult mortality derived from the survival status of parents of children aged 5 to 14 are presented here as these estimates are based on the most recent deaths and the complete five-year age groups, which are more reliable than deaths for the 15-19 age group. This is due, in part, to the fact that as respondents get older, the length of the interval between birth and the interview also increases which is likely to reduce the precision of the mortality estimates.

4.1.2.1 Female adult mortality.

The estimates of female adult mortality from the orphanhood method for the populations of Zimbabwe, Harare and Bulawayo are plotted in Figure 4.1. The general trend of female adult mortality for the three populations is that mortality was increasing from the early

1990s and reached its peak between 2002 and 2005, after which it started decreasing. Zimbabwe's mortality appears to be generally higher than that of Harare and Bulawayo except for a few points, prior to 1995, and time location 2001.9 in the 2010-11 DHS.

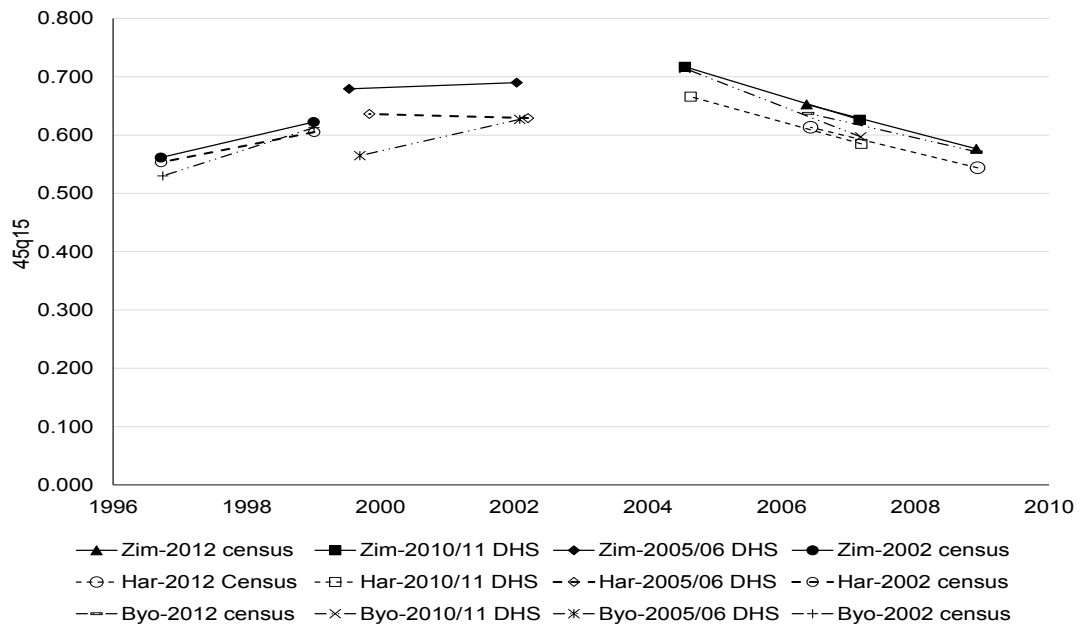


Figure 4.1 Probability of a 15 year old female dying before reaching age 60-Maternal orphanhood

4.1.2.2 Male adult mortality

The estimates of male adult mortality for the populations of Zimbabwe, Harare and Bulawayo are plotted in Figure 4.2. There was an increase in mortality for all the three populations from the mid-1990s till around 2003, followed by a decline for all three populations thereafter. The ranking of adult mortality estimates for the three populations is the same for the four data sources with Zimbabwe having the highest estimates, then Bulawayo and Harare except for the 2005/06 DHS, where Harare has higher estimates than Bulawayo. It is important to note that the estimates of male adult mortality are lower than those of female adult mortality which is inconsistent with the results of siblinghood data, suggesting there may be issues with the quality of the orphanhood data.

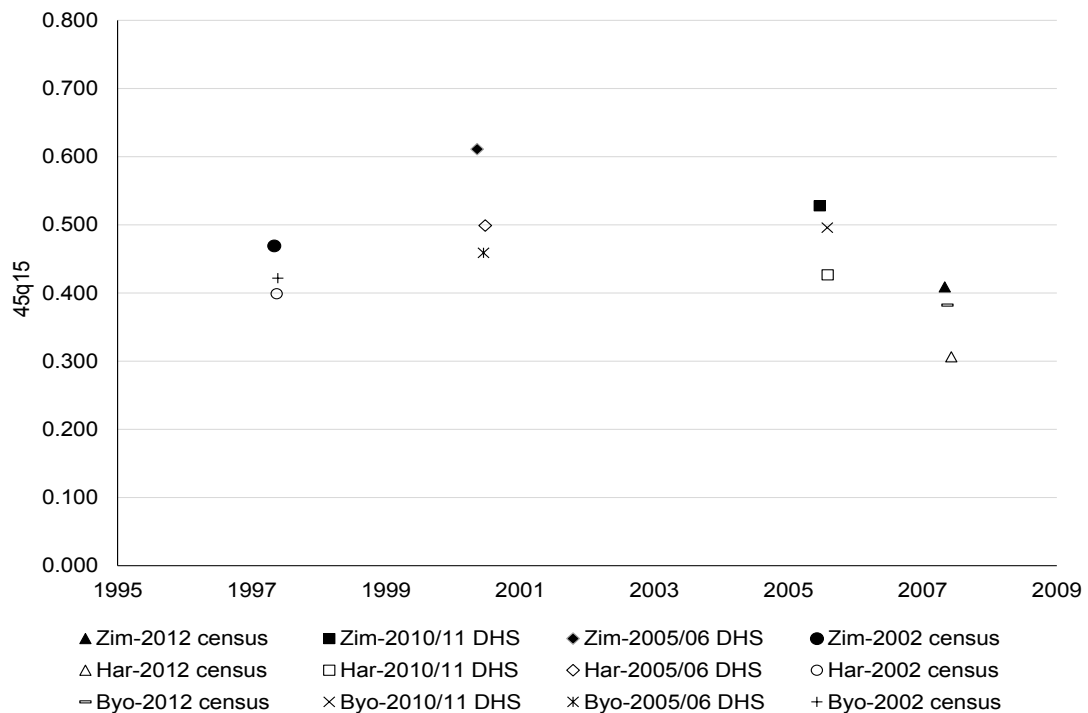


Figure 4.2 Probability of a 15 year old male dying before reaching age 60-paternal orphanhood

4.1.3 Deaths reported by households

4.1.3.1 Zimbabwe

Results obtained from the GGB fitting process are given in the form of fitted plots. The plots for Zimbabwe males and females are given in Figure 4.3. Ideally the points should lie on the straight line. The fit for male data appears to be satisfactory as most data points lie close to the fitted straight line. The female data, however, do not fit well specifically for ages between 25 and 49. This is probably a consequence of poor quality data.

As shown in the plots of completeness from the SEG method (Figure 4.4), both male and female completeness is largely constant over the age range, with a slight drop in completeness in the older ages for both sexes, which is consistent with bias introduced by the disintegration of households upon the death of a key member. The level of completeness obtained from the methods outlined earlier in the section are given in Table 4.2. Male completeness appears to be higher than female completeness suggesting that since wives are likely to survive their husbands, they will report their husbands' deaths while there will be no one to report their deaths. Adjusting for incompleteness using these estimates of completeness, male estimates of adult mortality (${}_{45}q_{15}$) for each of the GGB, GGB+SEG and SEG methods, with an approximate time location of 2007.6, are 58.5,

59.6 and 59.2 per cent, respectively, while the female estimates are 52.4, 56.0 and 55.5 per cent, respectively, as shown in Table 4.2

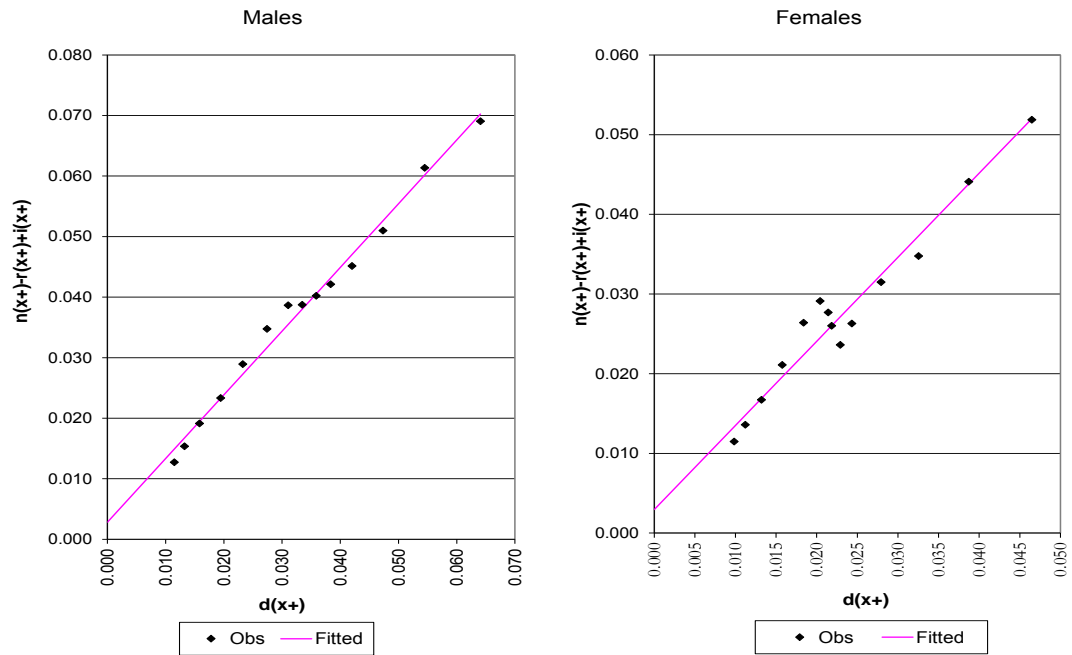


Figure 4.3 Partial birth rate minus partial growth rate against partial death rate: Zimbabwe deaths reported by households (2002-2012).

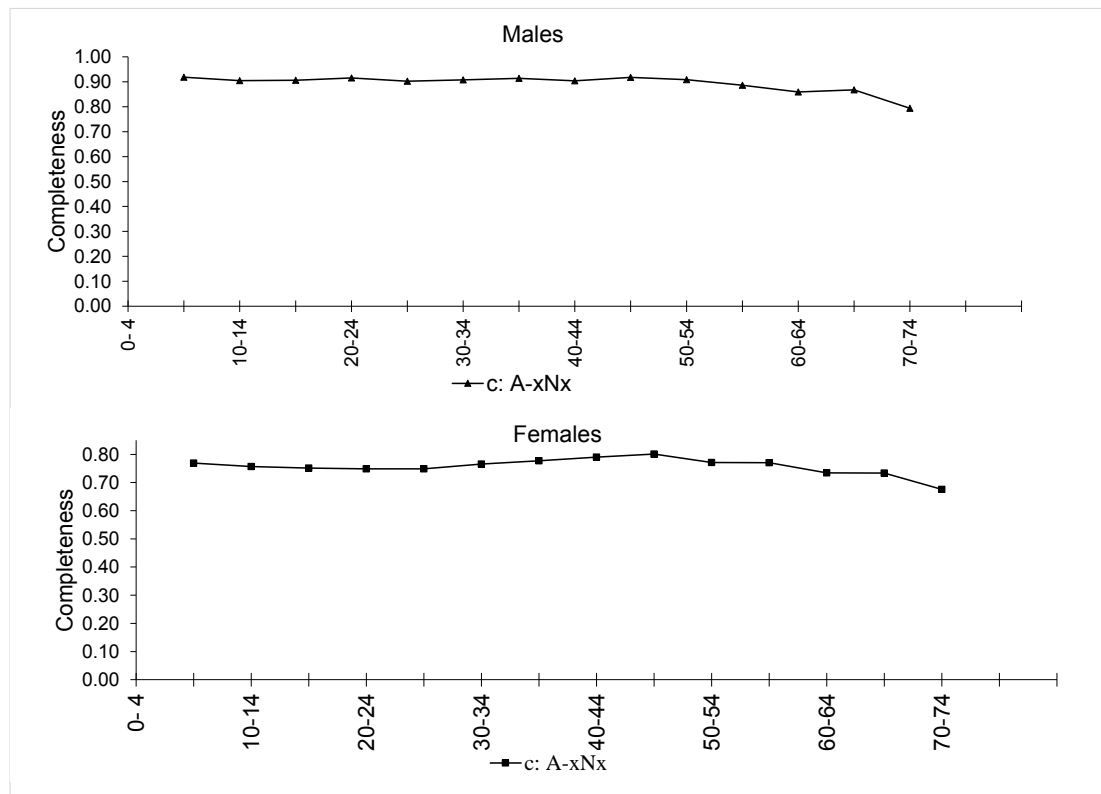


Figure 4.4 Completeness of reporting -Zimbabwe (2002-2012)

Estimates from direct sibling histories with a corresponding time location (2007.4) are 57.5 per cent for females, and 58.7 per cent for males. The only estimate close enough to the time location in question (2007.6) for the orphanhood method, is the female estimate from the 2010/11 DHS which is 62.6 per cent for a time location of 2007.2. Comparing these estimates with those from the death distribution methods given above, suggests a completeness of 93 per cent for males and 76 per cent for females, corresponding to adult mortality estimates of 59.2 per cent for males, and 55.5 per cent for females. Male estimates of completeness were consistent with those obtained by Dorrington, Timæus and Gregson (2006) for the period 1992 to 2002 while female estimates appear to be slightly lower.

Table 4.2 Completeness of reporting and 45q15 estimates by sex and method-Zimbabwe (2002-2012)

| | Males | | Females | |
|---------|----------------------------|-------------------------|----------------------------|-------------------------|
| | Completeness (per cent) | 45q15 (per thousand) | Completeness (per cent) | 45q15 (per thousand) |
| GGB | 95 | 58.5 | 83 | 52.4 |
| GGB+SEG | 92 | 59.6 | 75 | 56.0 |
| SEG | 93 | 55.5 | 76 | 55.5 |

Figure 4.5 compares these estimates along with those from the World Population Prospects (United Nations 2013), and the Institute of Health Metrics (IHME) (Wang, Dwyer-Lindgren, Lofgren *et al.* 2012). Estimates that are close to 60.0 per cent for both males and females appear to be reasonable implying that estimate adopted for Zimbabwean males is consistent with the WPP and IHME estimates, while the female estimate is slightly lower.

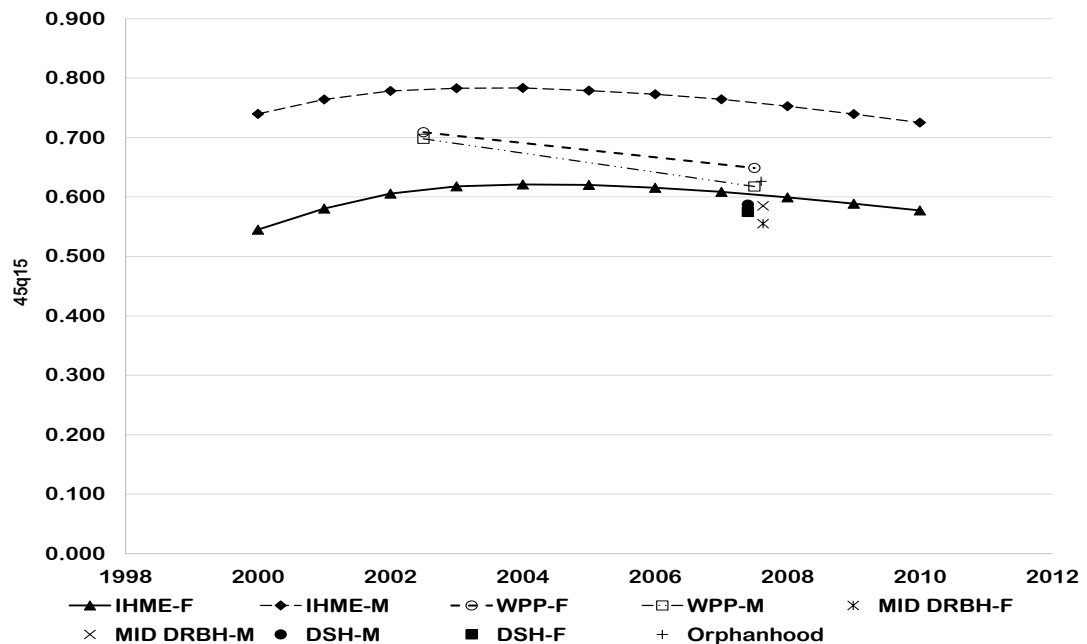


Figure 4.5 Comparison of adult mortality estimates, 2002-2012

4.1.3.2 Harare and Bulawayo

The fitted plots for both cities are given in Figure 4.6 and Figure 4.7. Male data for both cities fit well as opposed to female data, where the greatest deviations are for ages between 25 and 49, much like female data for Zimbabwe as a whole. For Bulawayo, data points seem to fall below the fitted straight line for the older ages indicating age exaggeration, which is common for household death data. Completeness estimates for both cities, obtained from the methods are given in Table 4.3. Proceeding in the same manner as for Zimbabwe, adult mortality estimates, adjusted using estimates from direct sibling histories and the orphanhood method, were found to be 44.4 and 45.0 per cent for Harare males and females, while for Bulawayo estimates were 46.5 per cent for males and 45.9 per cent for females (Table 4.4). The corresponding completeness estimates were 76 and 70 per cent for Harare males and females, respectively, 99 per cent for Bulawayo males, and 90 per cent for Bulawayo females.

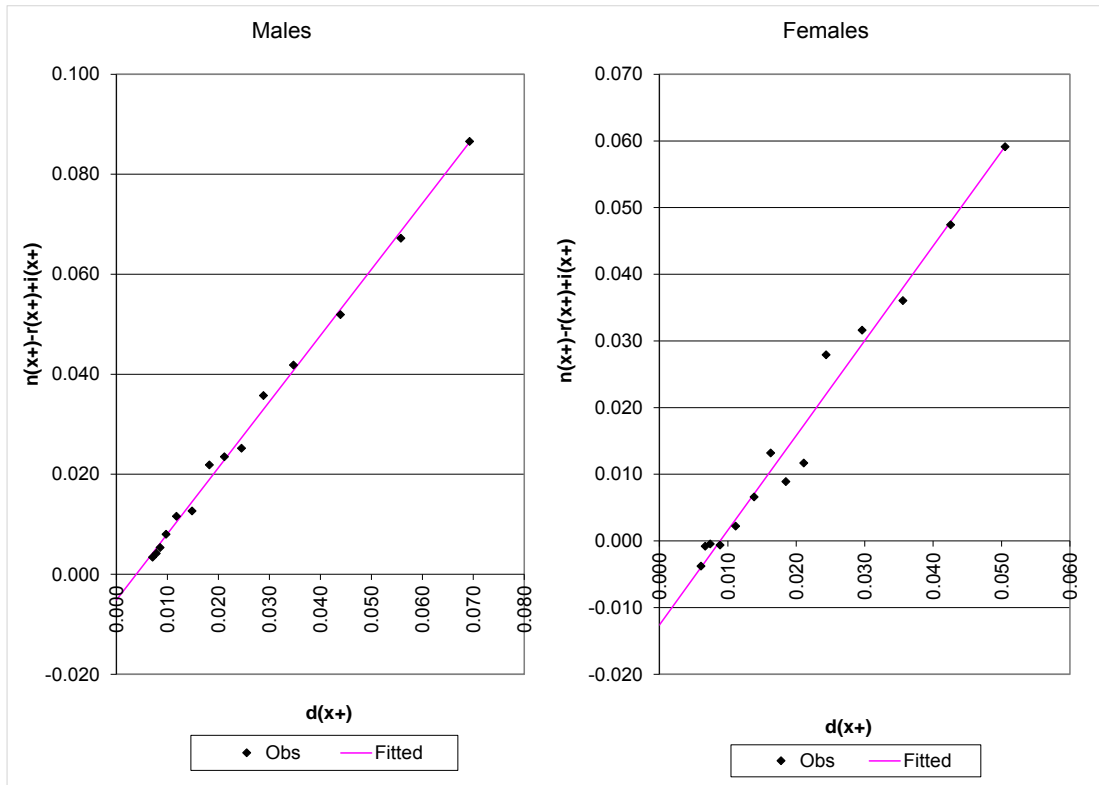


Figure 4.6 Partial birth rate minus partial growth rate against partial death rate: Harare deaths reported by households (2002-2012)

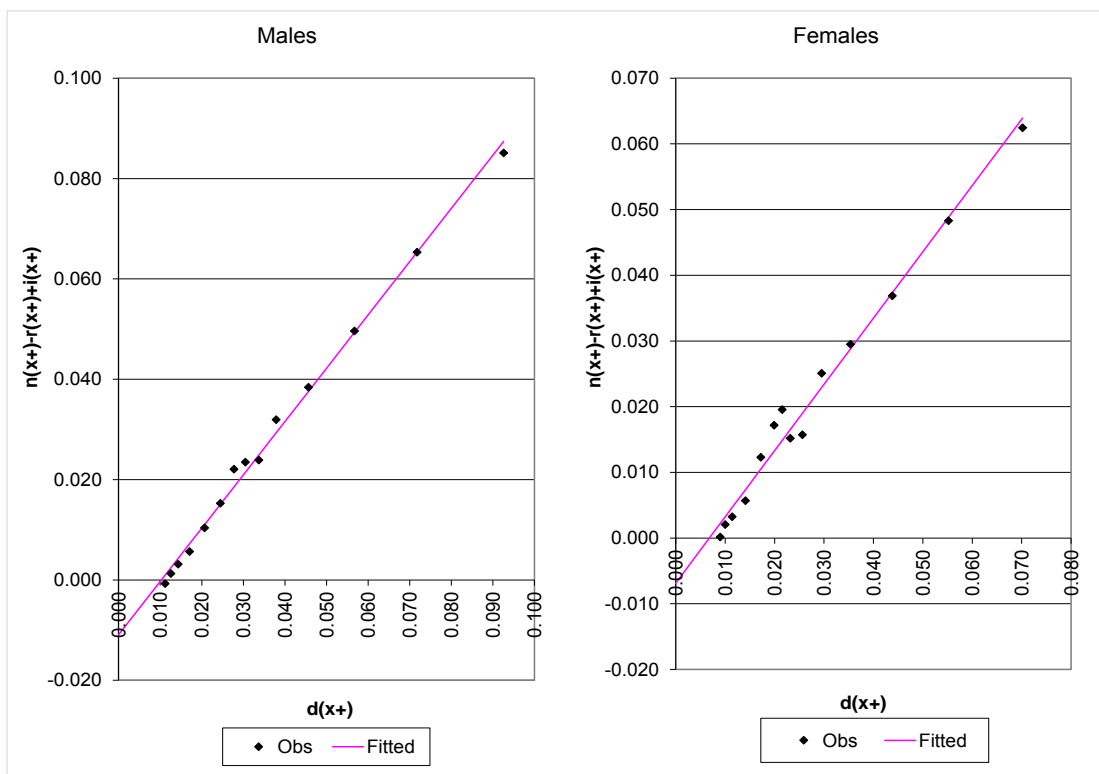


Figure 4.7 Partial birth rate minus partial growth rate against partial death rate: Bulawayo deaths reported by households (2002-2012)

Table 4.3 Completeness for Harare and Bulawayo (per cent)-deaths reported by households

| Method | Harare | | Bulawayo | |
|----------|--------|------|----------|------|
| | Female | Male | Female | Male |
| GGB | 70 | 76 | 99 | 94 |
| SEG | 71 | 77 | 94 | 99 |
| GGB +SEG | 72 | 73 | 90 | 85 |

Table 4.4 Probability of an individual aged 15 dying by age 60, Harare and Bulawayo - deaths reported by households

| Method | Harare | | Bulawayo | |
|-------------------|--------|-------|----------|-------|
| | Female | Male | Female | Male |
| GGB | 0.450 | 0.444 | 0.428 | 0.465 |
| SEG | 0.445 | 0.440 | 0.444 | 0.465 |
| GGB+SEG | 0.441 | 0.457 | 0.459 | 0.493 |
| Sibling histories | 0.553 | 0.454 | 0.493 | 0.608 |
| Orphanhood | 0.585 | 0.306 | 0.597 | 0.382 |
| Median 45q15 | 0.450 | 0.444 | 0.459 | 0.465 |
| Completeness (%) | 70 | 76 | 90 | 99 |

4.2 Infant and under-five mortality

4.2.1 Direct estimation deaths reported by households

Comparing estimates of infant and under-five mortality for the deaths reported by households for the consecutive censuses (Table 4.5) indicates a decline in both measures of mortality. There is however a possibility that the reduction of infant and under-five mortality is spurious, specifically for Harare and Zimbabwe, as the number of births for these two populations generally increased between the two censuses (Table 4.6). As such, one cannot say with confidence that for deaths reported by households, infant and under-five mortality have fallen in the inter-censal period.

Table 4.5 Infant and under-five mortality rates (per thousand) - deaths reported by households

| | Infant mortality rate | | Under-five mortality rate | |
|----------|-----------------------|------|---------------------------|------|
| | 2002 | 2012 | 2002 | 2012 |
| Harare | 46 | 45 | 70 | 58 |
| Bulawayo | 46 | 44 | 72 | 59 |
| Zimbabwe | 67 | 62 | 111 | 84 |

Table 4.6 Births and deaths- deaths reported by households

| | Harare | | Bulawayo | | Zimbabwe | |
|-------------|--------|--------|----------|--------|----------|---------|
| | 2002 | 2012 | 2002 | 2012 | 2002 | 2012 |
| <1(Deaths) | 1 953 | 2 104 | 837 | 775 | 23 672 | 25 236 |
| 0-4(Deaths) | 2 900 | 2 632 | 1 287 | 1 040 | 39 903 | 34 550 |
| Births | 42 445 | 46 532 | 18 249 | 17 811 | 351 635 | 408 819 |

4.2.2 Direct estimates from full birth histories

The infant and under-five mortality rates produced using the synthetic cohort life table approach described above, matched those published for Zimbabwe in both DHS reports and are given in Appendix B for the periods 0-4, 5-9 and 10-14 years before the survey. Due to the sampling errors that are likely to be present for relatively smaller samples, estimates for Harare and Bulawayo are presented for the period 10 years before the survey, as is done in the reports. As highlighted earlier, estimates that correct for birth transference were also produced and it is those estimates that are presented here. The under-five mortality rates produced after correcting for HIV-related bias for periods 1-5, 6-10 and 11-15 years before the survey are presented in Table 4.7 and plotted in Figure 4.8, while corrected estimates corresponding to the periods 0-4, 5-9 and 10-14 years before the survey are given in Appendix B.

The general trend in under-five mortality is that there was an increase in Zimbabwe and Harare's under-five mortality between 1992 and 2007. In both DHS surveys, Harare's estimates are slightly lower than those of Zimbabwe. There is a lack of consistency between estimates with similar time locations but from different surveys, a case in point being the Harare estimates with a time location of 2002 and Zimbabwe's estimates whose time location is 1997. Notably, the estimates for the 2005-06 DHS, for Zimbabwe are significantly lower than those of the 2010-11 DHS.

Bulawayo's estimates exhibit a rather peculiar trend owing to its relatively smaller sample size (Table A.1). The estimates 6-10 and 11-15 years before the 2005/06 DHS were unreasonably low and were not included in the plot. The increase in mortality between 1997 and 2002, and the ensuing decrease appears to be exaggerated when compared to the levels for Zimbabwe and Harare. This again can be attributed to random sampling errors that arise due to the relatively small sample size of the Bulawayo population.

Table 4.7 Adjusted direct under-five mortality rates corrected for transference of births/deaths (per thousand)

| | 2005/06 DHS | | | 2010/11 DHS | | |
|----------------------|-------------|--------|--------|-------------|--------|--------|
| | 1-5 | 6-10 | 11-15 | 1-5 | 6-10 | 11-15 |
| Zimbabwe | 89.9 | 71.9 | 66.9 | 94.4 | 91.7 | 90.7 |
| Harare | 87.6 | 55.8 | 50.3 | 89.6 | 85.0 | 55.2 |
| Bulawayo | 65.3 | 15.5 | 11.2 | 61.2 | 103.7 | 60.1 |
| Time location | 2002.3 | 1997.3 | 1992.3 | 2007.4 | 2002.4 | 1997.4 |

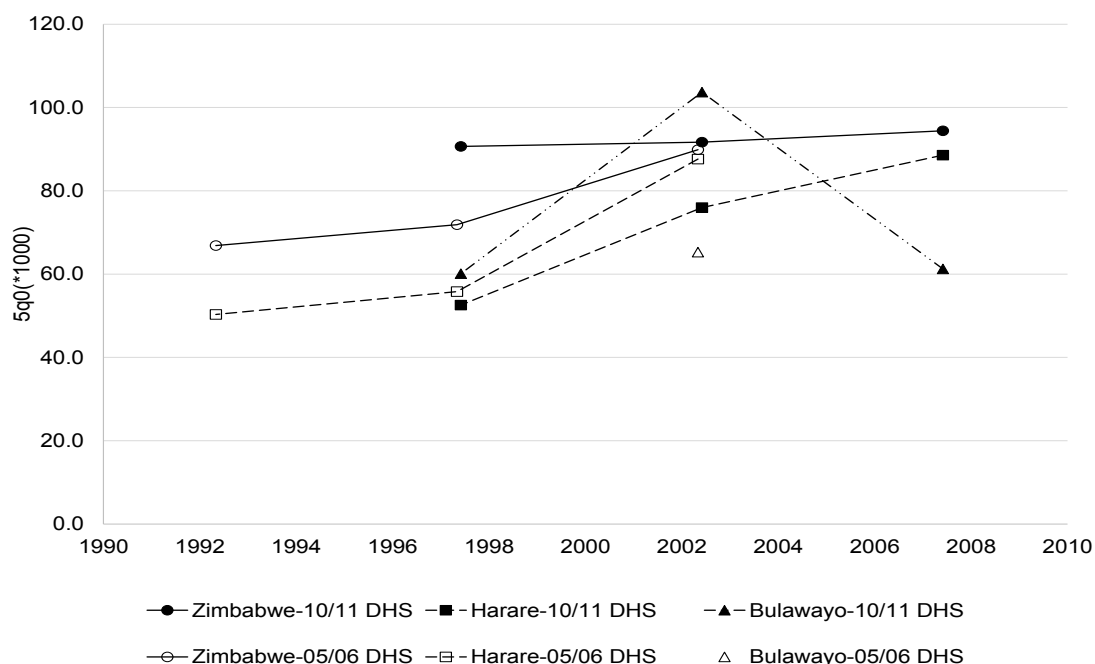


Figure 4.8 Direct estimates of under-five mortality (per thousand)-full birth histories

4.2.3 Brass CEB/CS method

Estimates of under-five mortality for Zimbabwe, and Harare and Bulawayo, are plotted in Figure 4.9 and Figure 4.10, respectively, while the plots of infant mortality are given in Appendix B. The trend for under-five mortality for the three populations is similar, with Zimbabwe's under-five mortality being relatively constant at around 100 deaths per thousand in the period. For Harare and Bulawayo, there is a rise in under-five mortality in the early 1990s, peaking in the period between 1997 and 2002 possibly due to the HIV/AIDS epidemic. There, however, appears to be a reduction in under-five mortality in recent years for both Harare and Bulawayo. For infant mortality, the trend is the same with signs of a decline in infant mortality after 2000 for the three populations, though this decline is more pronounced for Zimbabwe.

For the populations of Harare and Bulawayo, the estimates from the different data sources do not necessarily tell the same story, as was the case for the country as a whole. While each data source suggests a decline in mortality after 2000, albeit slight, the levels suggested by each of the data sources vary greatly for these two populations. In particular, estimates of infant and under-five mortality derived from the 2005/06 DHS for the three populations are not consistent with estimates from the other sources at approximately the same time location. In addition to this, the 2012 census data exhibit an unusual shape

which suggests irregularities in the CEB/CS data for both the 2005/06 DHS, and the 2012 census.

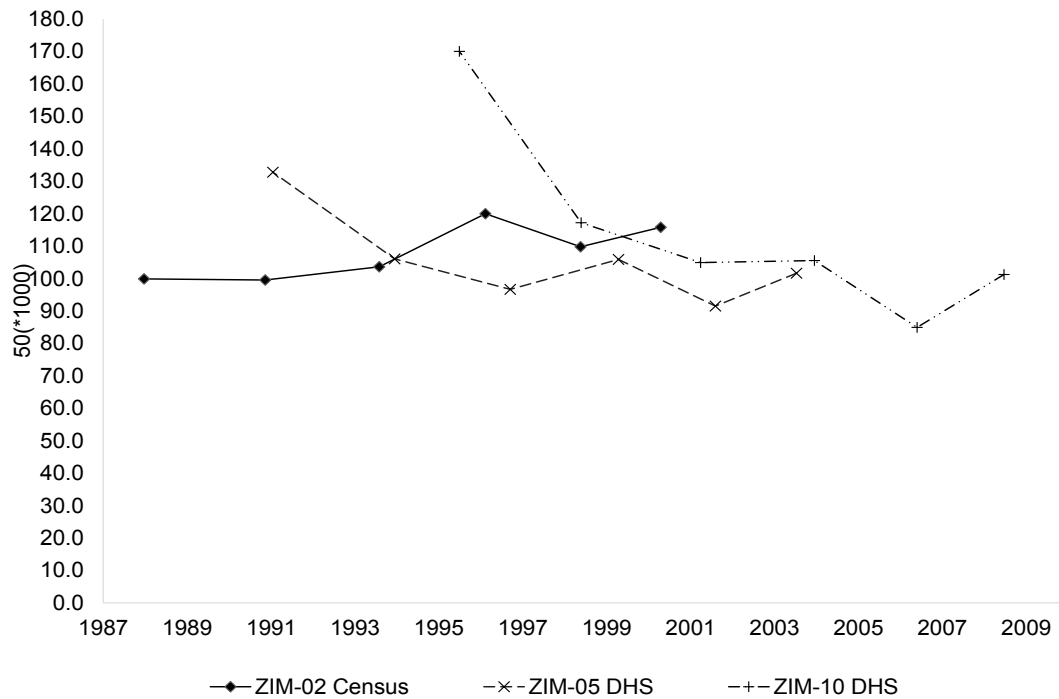


Figure 4.9 CEB/CS under-five mortality rates-Zimbabwe

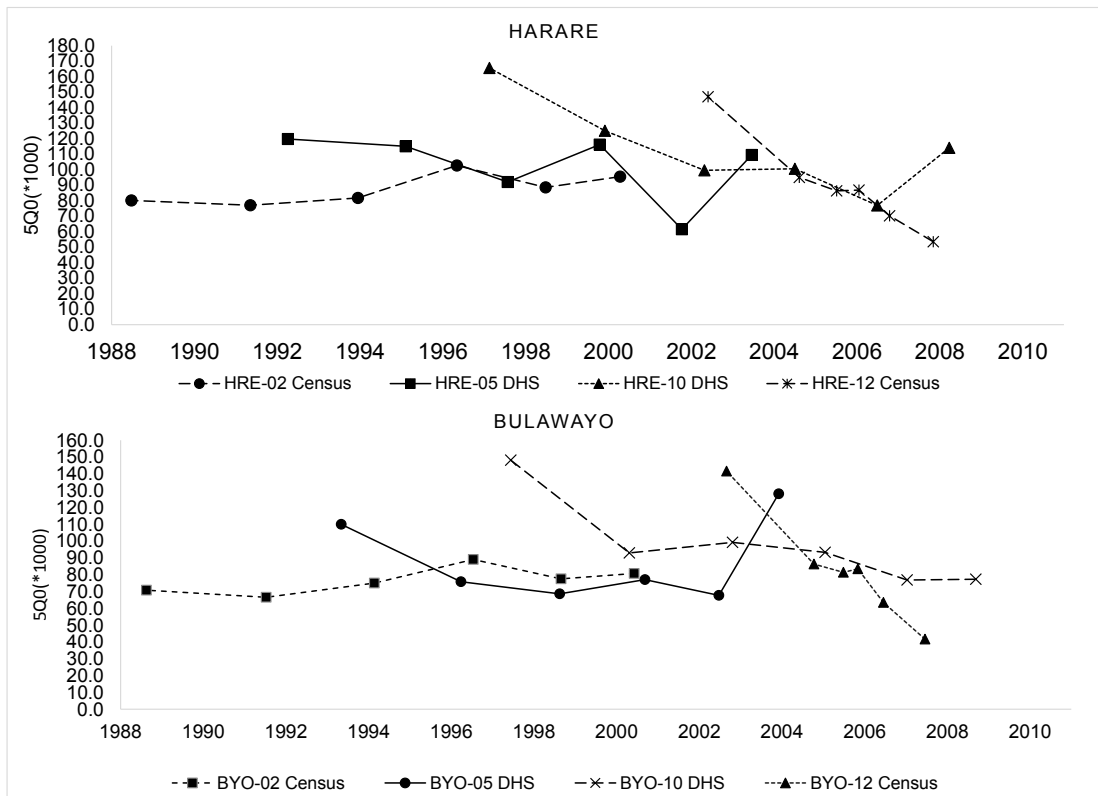


Figure 4.10 CEB/CS under-five mortality rates-Harare and Bulawayo

4.2.4 Previous Birth Technique

The estimates derived from the previous birth technique for the populations of Zimbabwe, Bulawayo and Harare are given in Table 4.8. For the population of Zimbabwe, infant mortality seems to have fallen from 2004 to 2009. In both DHS's, estimates of infant mortality were higher for Harare than for the whole of Zimbabwe which is unexpected. The reason for this could not be ascertained, however, it is likely to be just a random sampling error considering the relatively small sample size for Harare in comparison to that of Zimbabwe which undermines the reliability of these estimates. As a result, one cannot say with much confidence that, for the 2005-06 DHS, infant mortality in Bulawayo is lower than for Harare and Zimbabwe as a whole, due to these random fluctuations.

Table 4.8 Previous birth technique

| | 2005-06 DHS | | | 2010-11 DHS | | |
|---------------------------|-------------|--------|----------|-------------|--------|----------|
| | Zimbabwe | Harare | Bulawayo | Zimbabwe | Harare | Bulawayo |
| Dead | 116 | 20 | 4 | 115 | 27 | 2 |
| Living | 2 028 | 239 | 104 | 2 333 | 325 | 109 |
| Total Births | 2 144 | 259 | 108 | 2 448 | 352 | 111 |
| Proportion Dead | 0.054 | 0.079 | 0.041 | 0.047 | 0.077 | 0.017 |
| 1q0 (per thousand) | 59 | 86 | 45 | 51 | 84 | 19 |
| Time Location | 2004.8 | 2004.8 | 2004.8 | 2009.9 | 2009.9 | 2009.9 |

This chapter is divided into three main sections. The first two sections concentrate on presenting the adult, infant and under-five mortality estimates obtained from vital registration data, respectively. The third section then presents comparisons of mortality estimates obtained from vital registration data with those of non-vital registration data, in a bid to ascertain the reasonableness of vital registration mortality estimates.

5.1 Adult mortality

5.1.1 Death distribution methods

Proceeding in the manner described in section 3.2.3 for vital registration data, the fitted plots from the GGB fitting process for Harare (Figure 5.1), are similar to those from the deaths reported by households, where male data fit reasonably well throughout the age range and female data have significant deviations between ages 35 and 55. The reason for the female plots not fitting well is also likely to be due to data quality. Bulawayo data, which are not sex-specific, are depicted in Figure 5.2. These data fit relatively well throughout the age range except for a few deviations, also between 35 and 55. Points rising above the fitted line at the older ages indicate a fall in completeness in this age range due to urban to rural (retirement) migration.

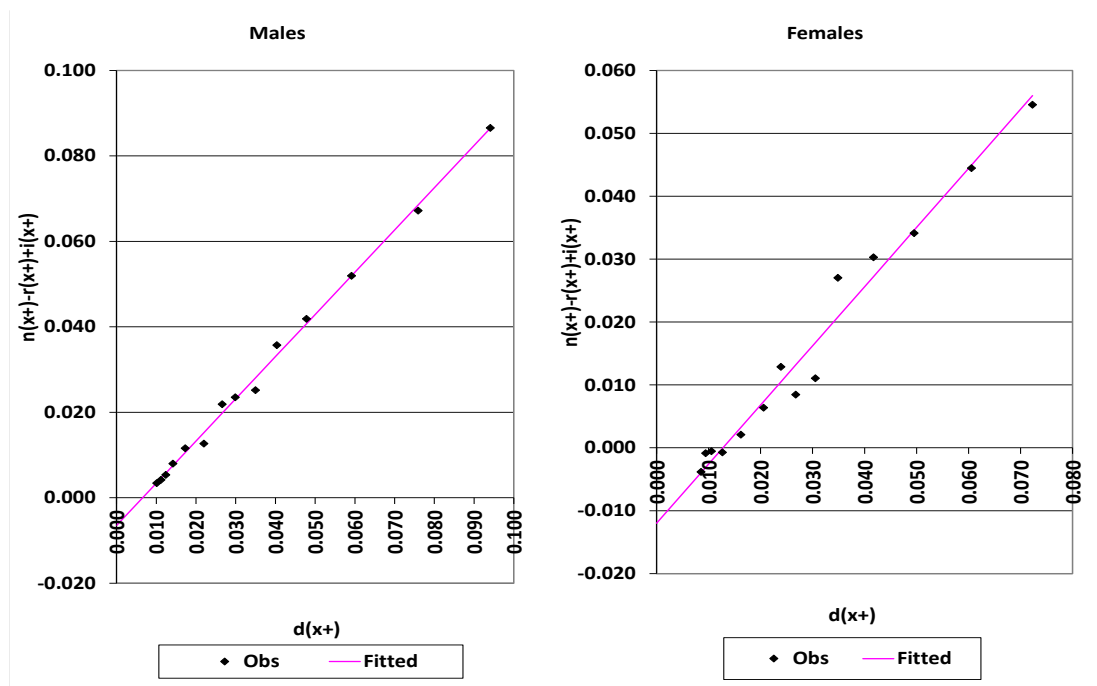


Figure 5.1 Partial birth rate minus partial growth rate against partial death rate: Harare vital registration data (2002-2012)

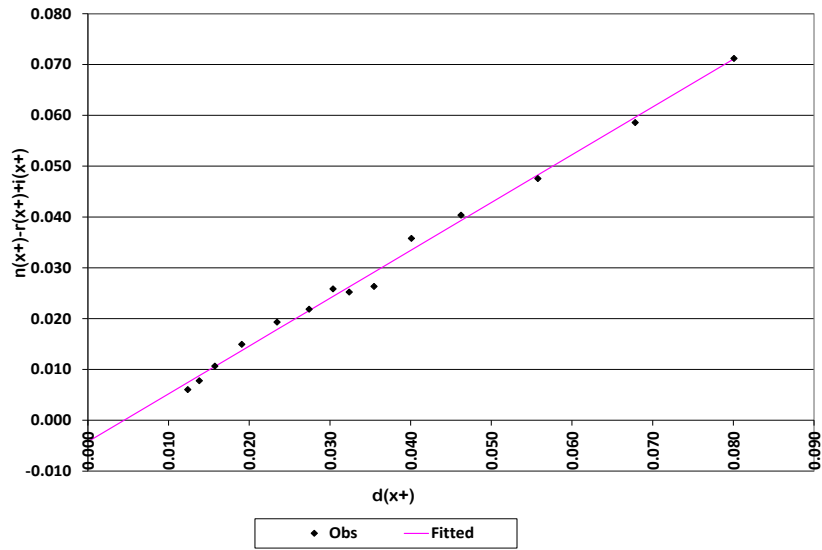


Figure 5.2 Partial birth rate minus partial growth rate vs partial death rate: Bulawayo vital registration data (2002-2012)

Graphs of completeness, given in Figure 5.3 and Figure 5.4, respectively, depict constant completeness of Harare males, with a rise in completeness at the older ages for males, indicative of age exaggeration, possibly in the population as individuals tend to exaggerate their ages in order to be eligible for state pensions, and in the deaths as relatives may be the ones reporting the individual's age at death. Harare female and Bulawayo data, however, depict a significant drop in completeness at the older ages, consistent with bias introduced by urban to rural (retirement) migration. Harare male completeness estimates are above 100 per cent suggesting that some of the deaths registered as Harare deaths were in actual fact from elsewhere or that the censuses underestimated the population.

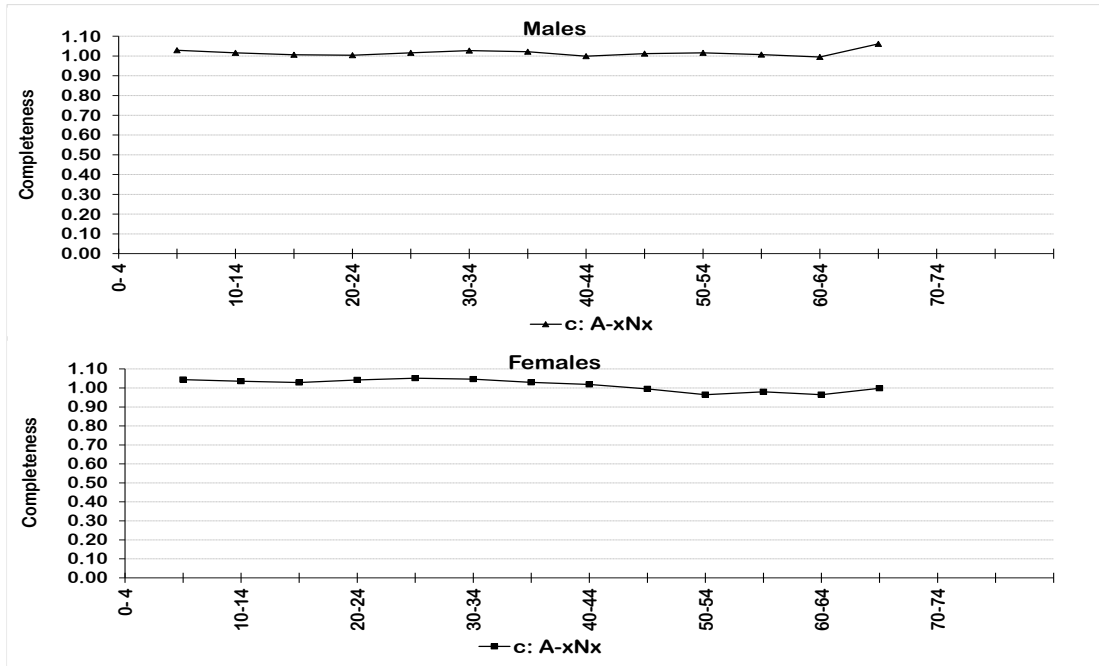


Figure 5.3 Completeness of vital registration (per cent)-Harare

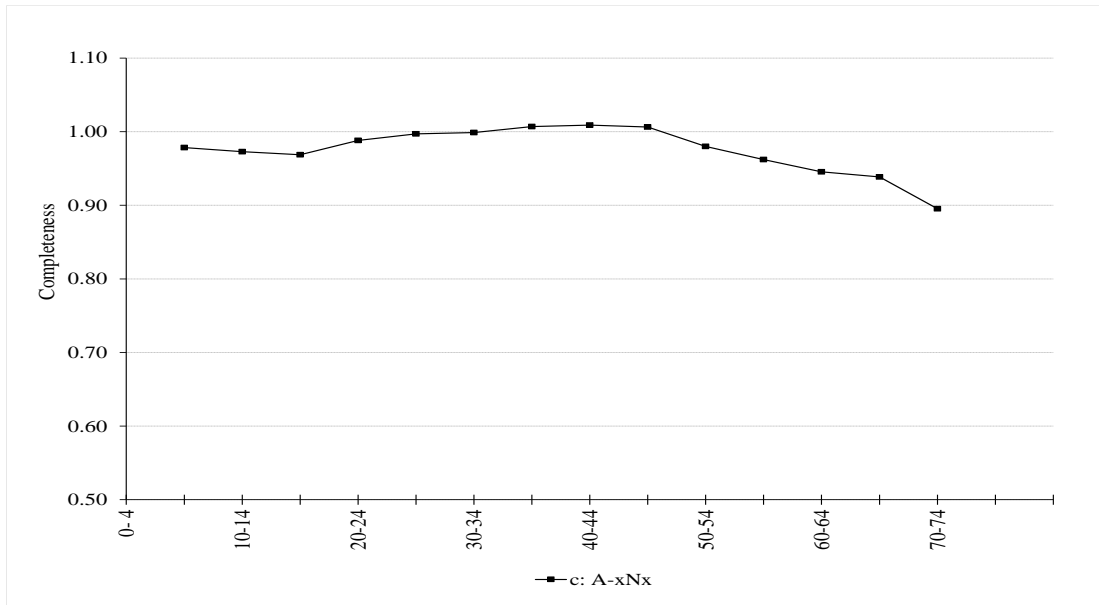


Figure 5.4 Completeness of vital registration (per cent) – Bulawayo

Table 5.1 Completeness of vital registration (per cent) - 2002 to 2012

| Method | Harare | | Bulawayo Combined |
|----------|--------|------|----------------------|
| | Female | Male | |
| GGB | 106 | 101 | 95 |
| SEG | 103 | 102 | 109 |
| GGB +SEG | 96 | 96 | 88 |

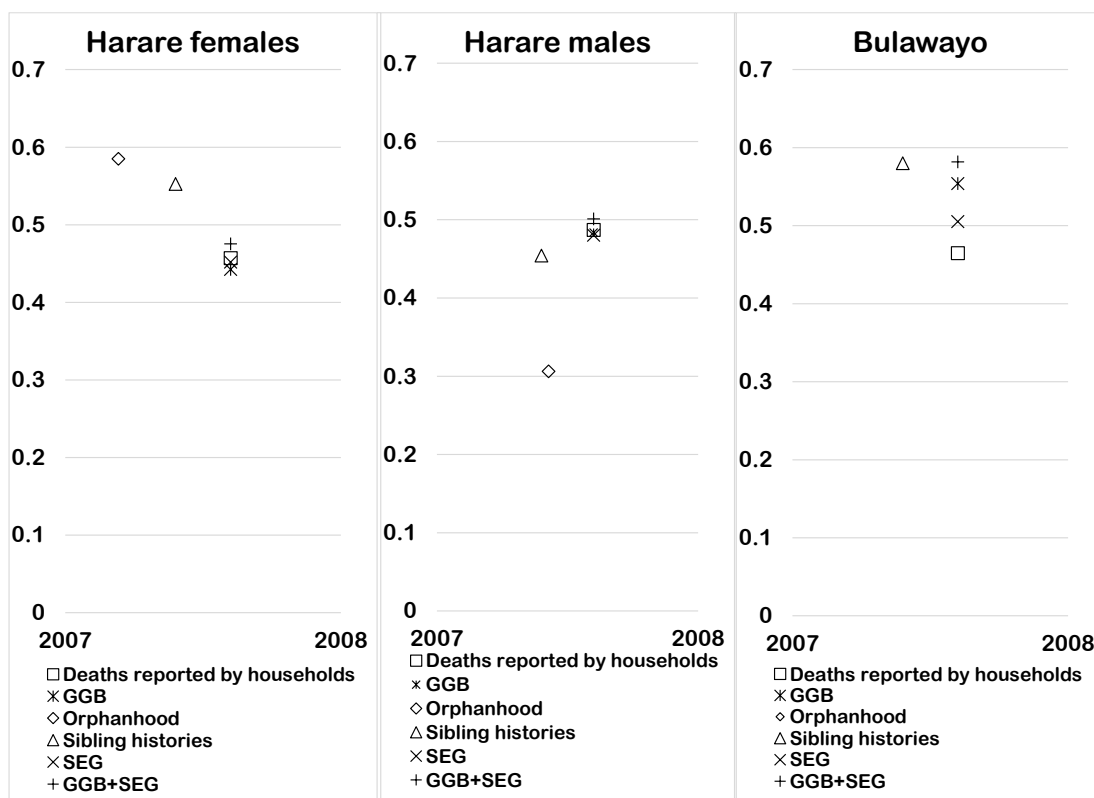


Figure 5.5 Comparison of adult mortality estimates by source and method

Adult mortality estimates derived from the completeness estimates given in Table 5.1 were then compared with estimates from sibling histories, the orphanhood method and deaths reported by households (Table 5.2 and Figure 5.5). Using the median estimate of ${}_{45}q_{15}$ to determine the level of completeness for both cities in the inter-censal period, the completeness of Harare vital registration data was estimated at 102 and 99 per cent for males and females respectively, while for Bulawayo, the estimate was 95 per cent.

Table 5.2 Probability of an individual aged 15 dying before reaching the age of 60 by method and time location

| Method | Harare Females | | Harare Males | | Bulawayo | |
|-------------------|----------------|--------------|--------------|--------------|----------|--------------|
| | Time | Estimate | Time | Estimate | Time | Estimate |
| Orphanhood | 2007.2 | 0.585 | 2007.4 | 0.306 | 2007.2 | - |
| Sibling histories | 2007.4 | 0.553 | 2007.4 | 0.454 | 2007.4 | 0.580 |
| GGB | 2007.6 | 0.443 | 2007.6 | 0.484 | 2007.6 | 0.554 |
| SEG | 2007.6 | 0.452 | 2007.6 | 0.480 | 2007.6 | 0.505 |
| GGB+SEG | 2007.6 | 0.475 | 2007.6 | 0.501 | 2007.6 | 0.582 |
| Household deaths | 2007.6 | 0.450 | 2007.6 | 0.444 | 2007.6 | 0.465 |
| Median | | 0.464 | | 0.484 | | 0.554 |

5.1.2 Adjusted annual vital registration data

The estimates of completeness adopted from the death distribution methods are 102 and 99 per cent for Harare males and females respectively, while for Bulawayo males and females combined, the estimate is 95 per cent. Proceeding in the manner described in section 3.2.4, the implied estimates of ${}_{45}q_{15}$, for each of the years in the period 2000 to 2012, were obtained.

Due to the irregularities in the death data for certain periods, these estimates of adult mortality might present a distorted picture of the trend in adult mortality in those periods. In an attempt to smooth these irregularities in the rates, a simple moving average of the rates was calculated, in addition, using the formula;

$${}_{45}\bar{q}_{15} = \frac{{}_{45}q_{15}^{n-1} + {}_{45}q_{15}^n + {}_{45}q_{15}^{n+1}}{3}$$

where ${}_{45}q_{15}^n$ represents the probability of an individual aged 15 dying before reaching the age of 60 in year n , and ${}_{45}\bar{q}_{15}$ is the average estimate corresponding to time n .

Plots of the probabilities obtained, are given in Figure 5.6, Figure 5.7 and Figure 5.8 for Harare males, Harare females and Bulawayo males and females combined, respectively. They reveal that there was a general decrease in adult mortality, from around 2003 for both Harare and Bulawayo, barring the spike in 2010 for Harare and the dip in 2003 for Bulawayo. As expected, male adult mortality is higher than female adult mortality for most of the years in Harare's time series. The smoothed estimates depict the same trend, with the main differences being observed after 2009 for Harare and around 2004 for Bulawayo where the spikes and troughs have been smoothed.

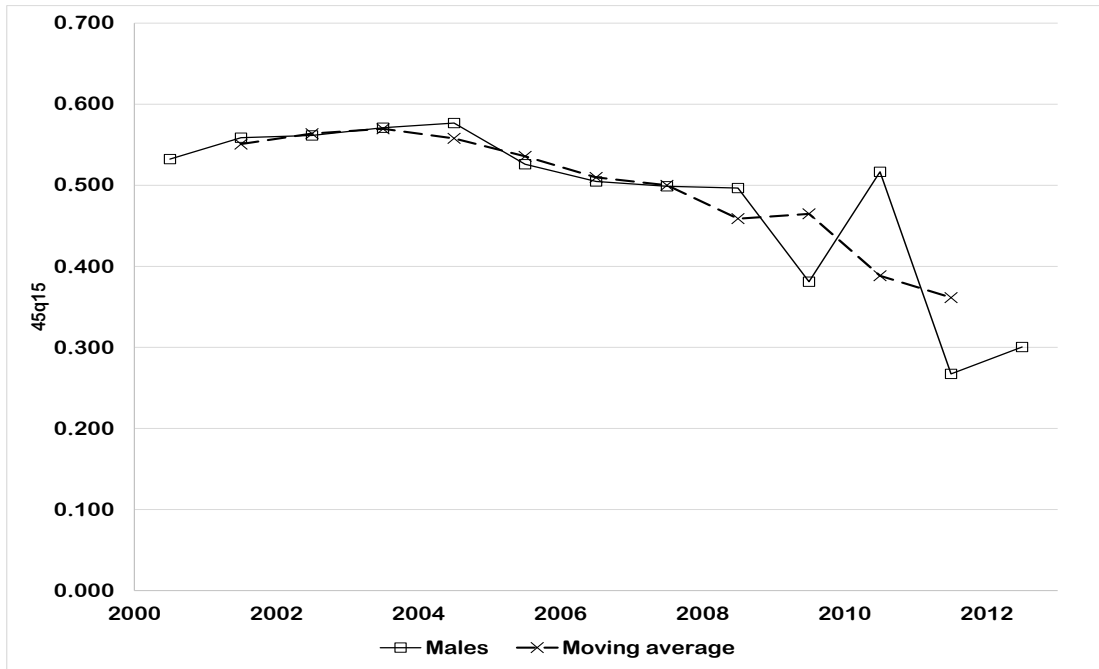


Figure 5.6 Probability of a male aged 15 dying before reaching the age of 60 in Harare, 2002-2012

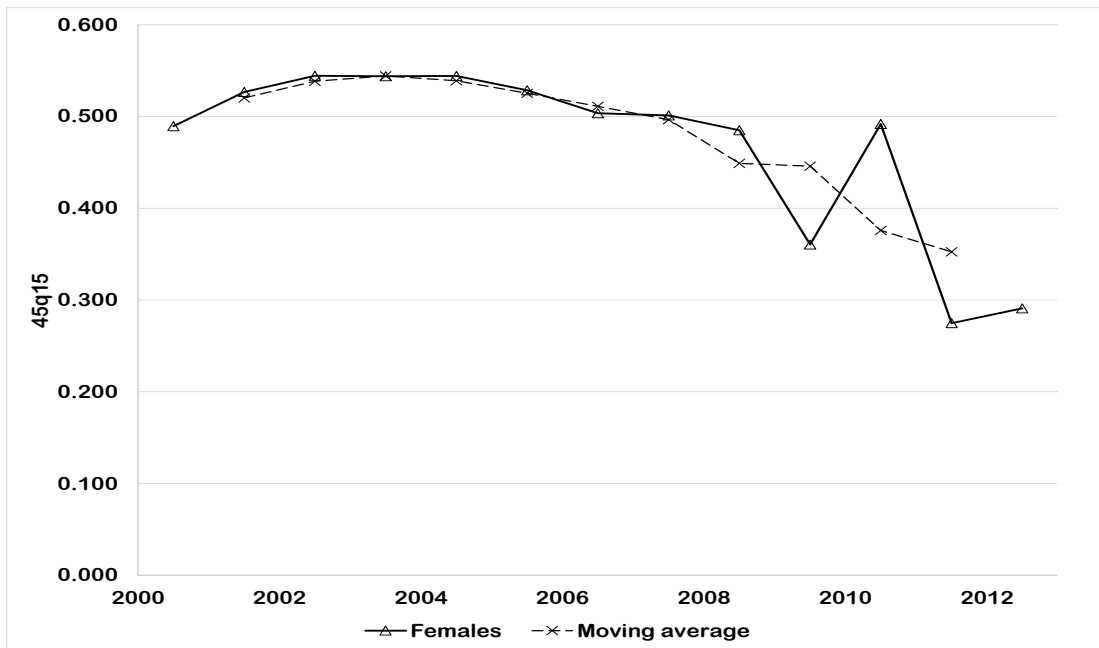


Figure 5.7 Probability of a female aged 15 dying before reaching the age of 60 in Harare, 2000-2012

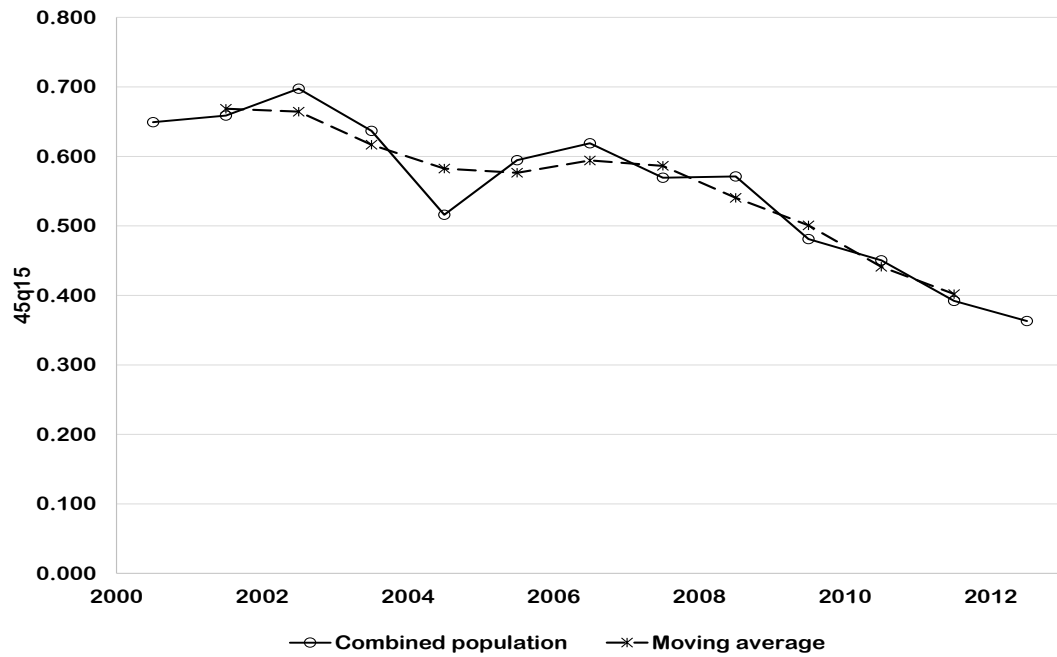


Figure 5.8 Probability of an individual aged 15 dying by the age of 60 in Bulawayo, 2000-2012

5.2 Infant and under-five mortality

5.2.1 Estimated births

A plot of the estimated births is given in Figure 5.9. The births from the interpolation procedure are higher than those reported in either census for both Harare and Bulawayo. While available registered births for Harare appear to be quite different in both level and trend from the births obtained from the interpolation procedure, Bulawayo's registered births were closer to the estimated births.

There is therefore reason to believe that Harare's registered births are not a close representation of the true births that took place in the city, while Bulawayo's registered births are more reliable and usable. As a result of the relative similarity between the interpolated births and registered births, Bulawayo's true births for the period were obtained by averaging the vital registration births and interpolated births. On the other hand, due to the significant difference between the registered births and the corrected census births for Harare, the true births were taken as the annual births obtained using the afore-mentioned interpolation procedure.

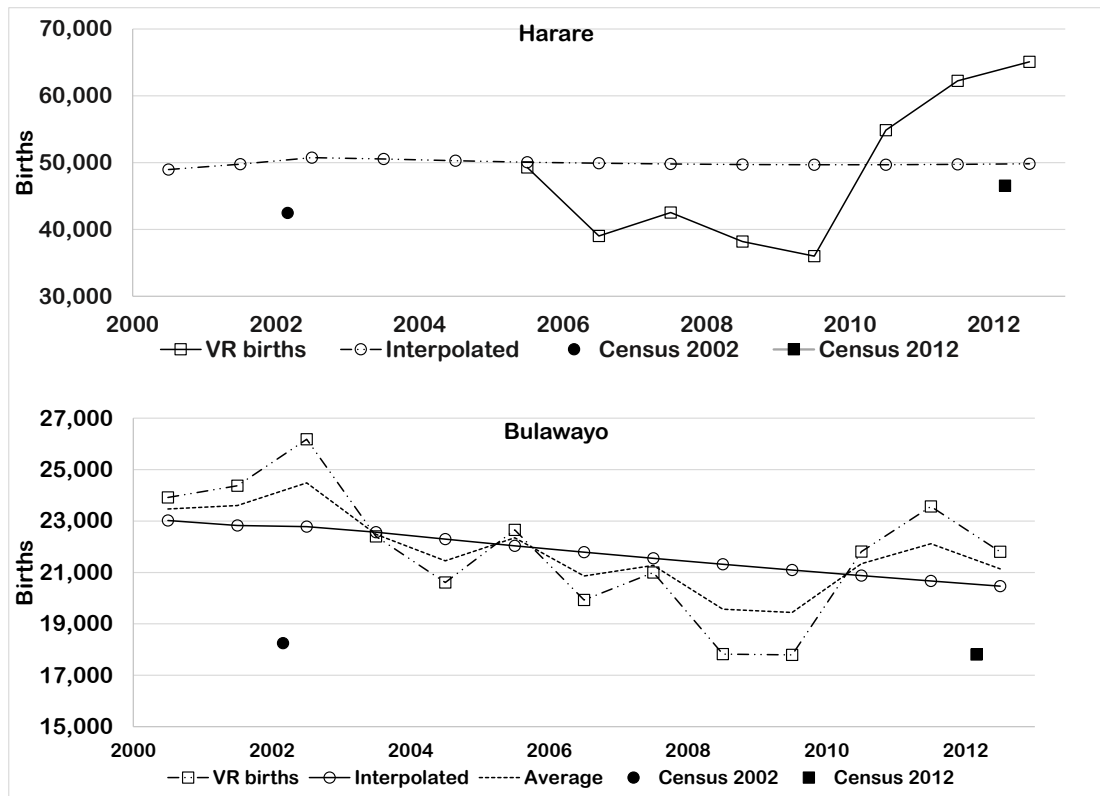


Figure 5.9 Births (2000-2012)

5.2.2 Infant and under five mortality

Infant and under-five mortality rates for Harare and Bulawayo, were calculated as described in section 3.3.4. Proceeding in the same manner as for adult mortality, irregularities in the infant and under-five mortality rates, stemming from irregularities in either the births or the deaths, were smoothed using a three-year moving average. Both the smoothed rates and the original estimates are plotted in Figure 5.10 and Figure 5.11 for under-five mortality rates, with the infant mortality rates being presented in Appendix C. The general trend of infant and under-five mortality for Harare and Bulawayo is essentially the same, with both suggesting a general decline in the respective measures from 2001, to the end of the period in question. Other notable features include the fact that Bulawayo's estimates appear to be higher than those of Harare throughout the period.

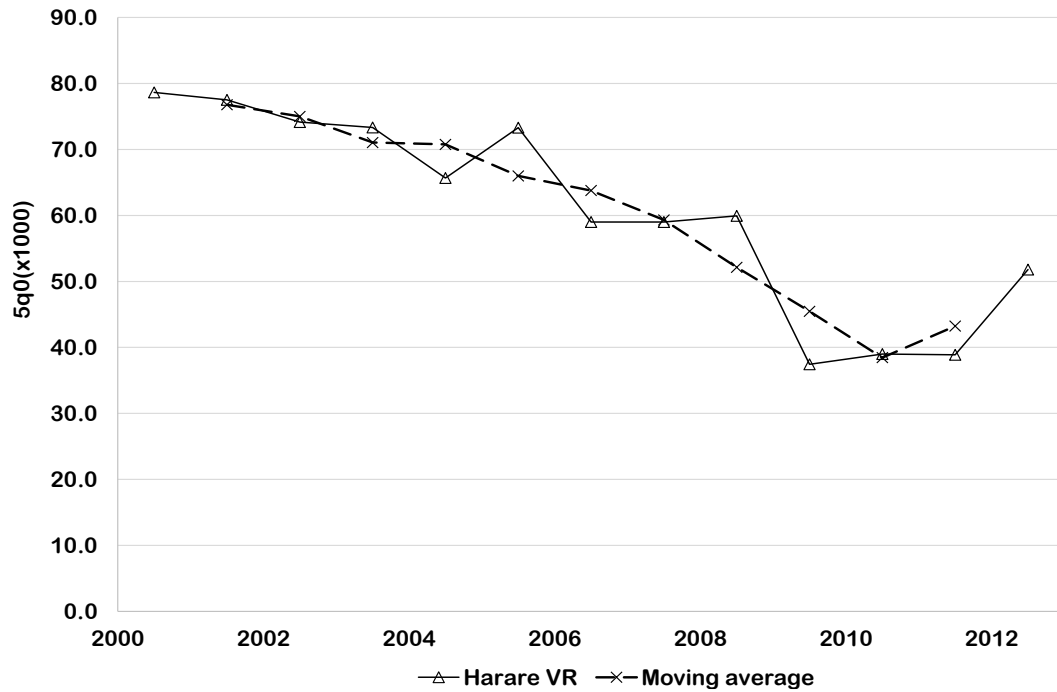


Figure 5.10 Under-five mortality rates (per thousand)-Harare vital registration

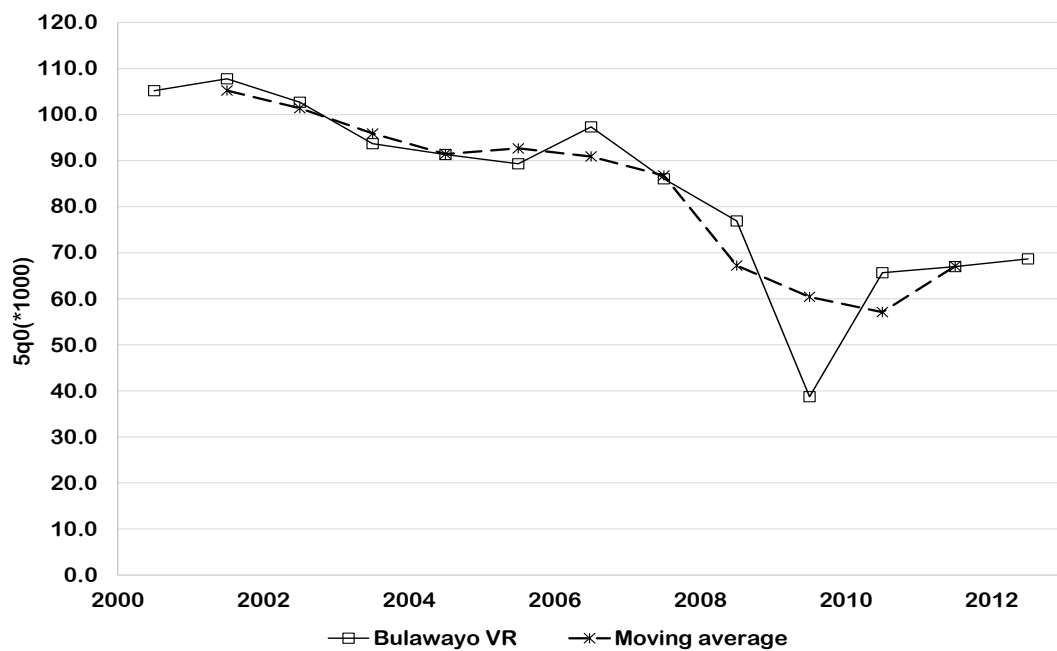


Figure 5.11 Under-five mortality rates (per thousand)-Bulawayo vital registration

5.3 Comparison of mortality estimates

In the absence of a 'gold standard' with which to compare the estimates from the vital registration data, estimates of mortality from vital registration data are compared to those obtained from the other methods in the period of interest. This can be done by plotting

the estimates for each respective population and measure, on the same scale, and identifying the salient features, specifically, the levels of the estimates and the trends suggested by the estimates.

5.3.1 Adult mortality

The comparisons of adult mortality estimates for Harare males and females are given in Figure 5.12 and Figure 5.13, respectively, while Bulawayo's comparison is given in Figure 5.14.

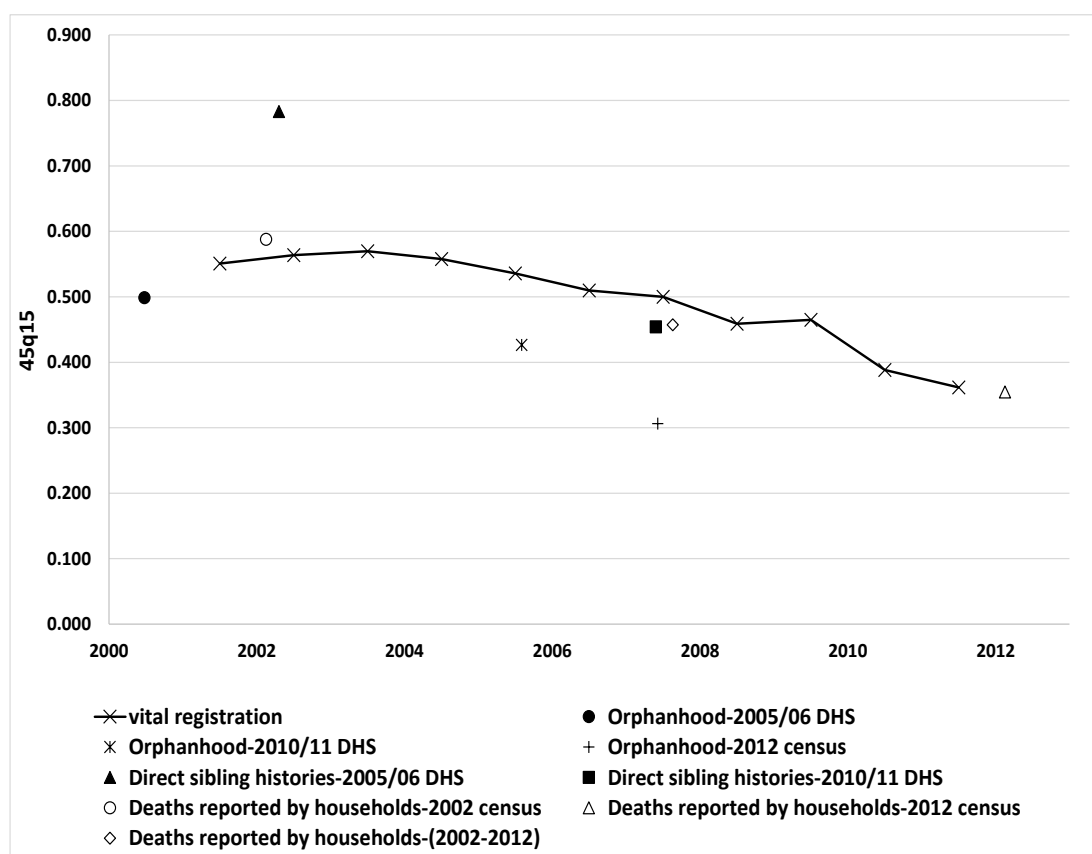


Figure 5.12 Comparison of the probability of a Harare male aged 15 dying before reaching the age of 60

Male adult mortality estimates from Harare's vital registration data appear to be supported by those from the deaths reported by households and the 2010/11 DHS's direct sibling histories, while orphanhood estimates and the 2005/06 DHS estimates appear to be out of line. The trends suggested by the various estimates are, however, quite similar.

While the trend in Harare's female adult mortality estimates from vital registration data is somewhat similar to that suggested by the rest of the data sources and methods, the levels differ significantly, with vital registration estimates being lower than all the other estimates from the other sources, except for the inter-censal deaths reported by

households estimate. This suggests that vital registration data may underestimate female adult mortality.

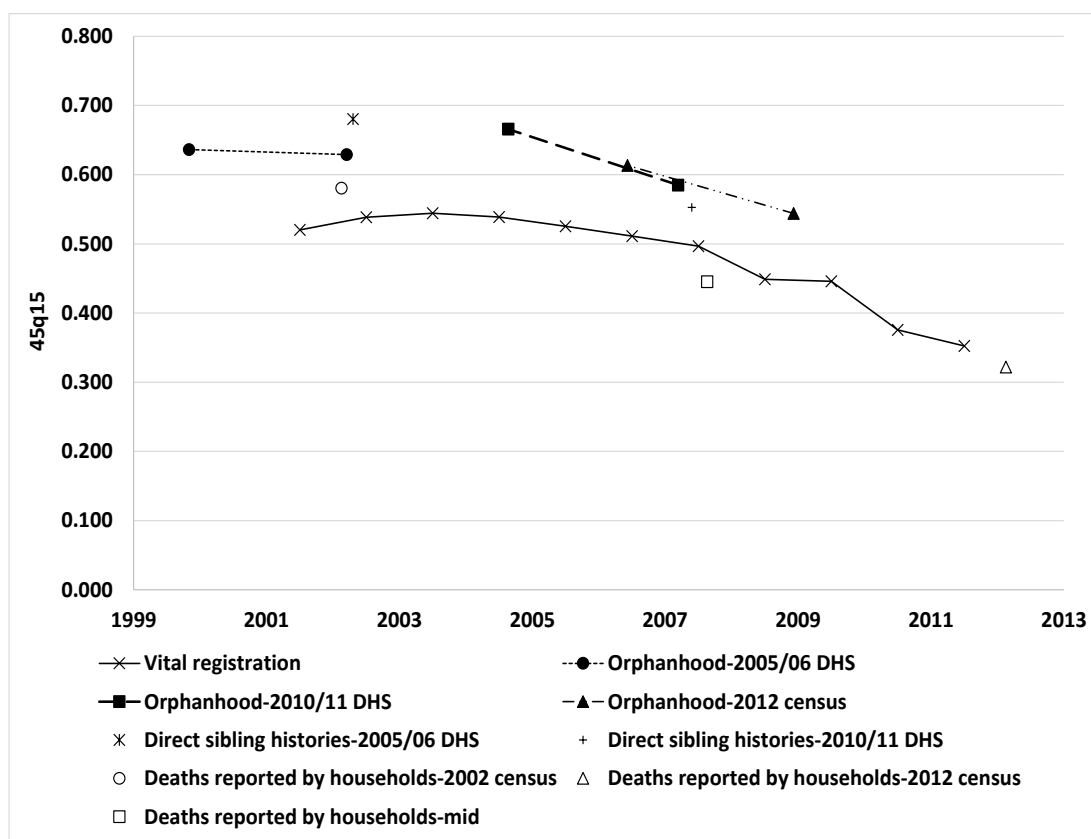


Figure 5.13 Comparison of the probability of a Harare female aged 15 dying before reaching the age of 60

The comparison of Bulawayo's vital registration estimates to other estimates (Figure 5.14) reveals that vital registration data estimates are slightly higher than the other estimates. The trend suggested by the respective data sources is again similar to that of the vital registration data, with the deaths reported by households and the direct sibling histories estimates depicting a decline in mortality over time, albeit a slight one for direct sibling histories.

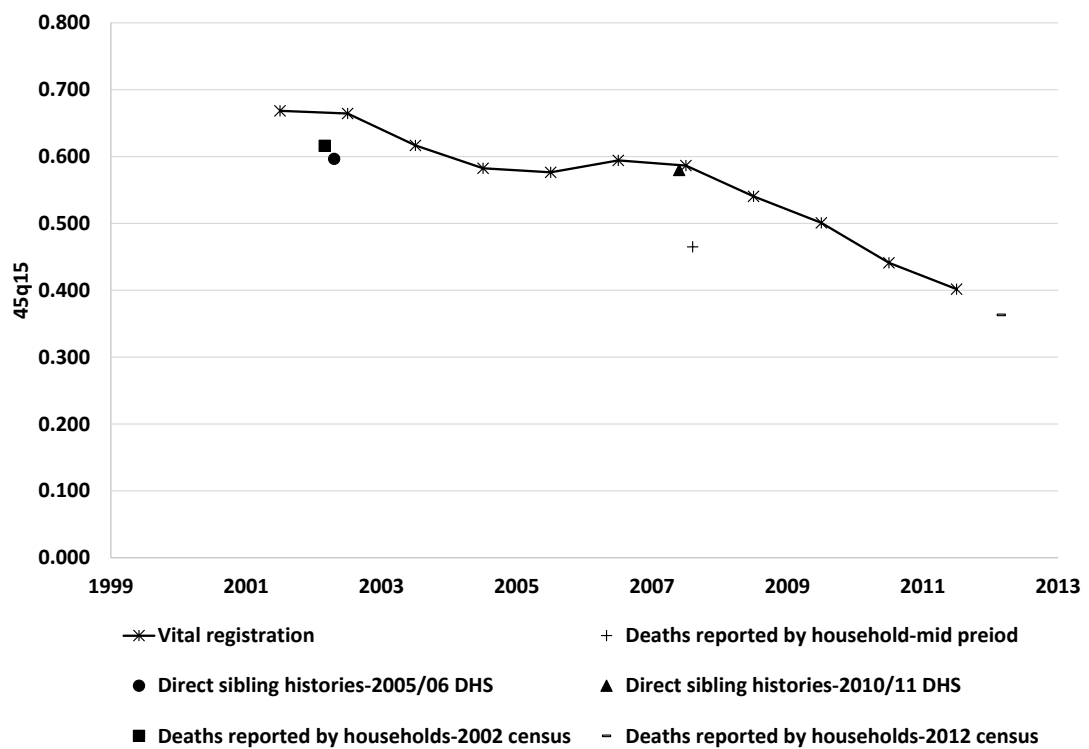


Figure 5.14 Comparison of the probability of a Bulawayo person aged 15 dying before reaching the age of 60

5.3.2 Infant and under-five mortality rates

The estimates of infant and under-five mortality obtained for Brass's CEB/CS method from the young mothers (15-19) are excluded from this comparison because most of the births to women in this age group are likely to be first births, which have generally much higher mortality than for any subsequent births, thereby leading to an overestimation of infant and under-five mortality. In addition, Ward and Zaba (2008) mention that adjustments to estimates produced from the first two and last two age groups are more likely to produce unreliable results if prevalence exceeds 12 per cent, hence, this will also need to be accounted for in the comparison as prevalence rates exceeded this limit.

The comparisons of under-five mortality rates for Harare and Bulawayo are given in Figure 5.15 and Figure 5.16, respectively. Barring the CEB/CS estimates from the 2005/06 DHS and the deaths reported by households from the 2002 census, vital registration data appears to underestimate the level of under-five mortality throughout the period. The vital registration estimates for Harare are almost similar to direct estimates from the deaths reported by households, however, this is of little consolation, especially considering the underreporting that plagues this data source. There appears to be a

reduction in the overall difference between the level of under-five mortality for Harare's vital registration data and the other data sources with time. This reduction, however, is probably spurious, due to the unreliability of the 2012 census data as highlighted in section 4.2.3.

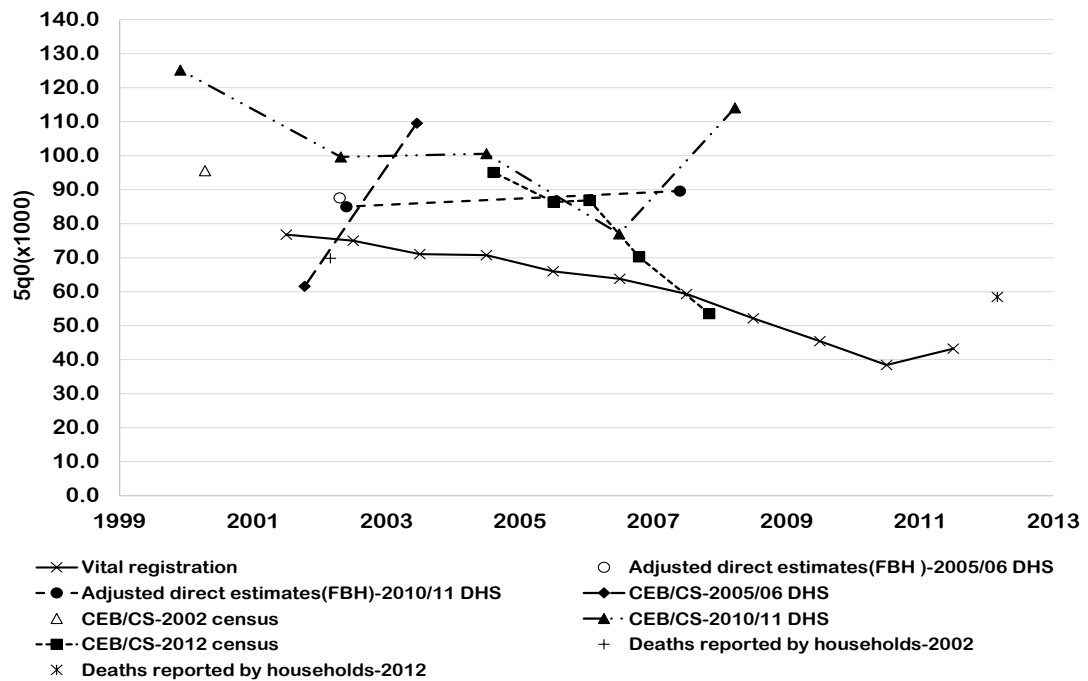


Figure 5.15 Under-five mortality rates (per thousand)-Harare comparison

Estimates from vital registration data for Bulawayo and those from the other data sources and methods, particularly those from the CEB/CS method on 2010/11 DHS data, are relatively similar. Disregarding the outliers from the 2005/06 DHS, the difference between the under-five mortality rates from vital registration data and the other estimates was generally less than 20 deaths per thousand.

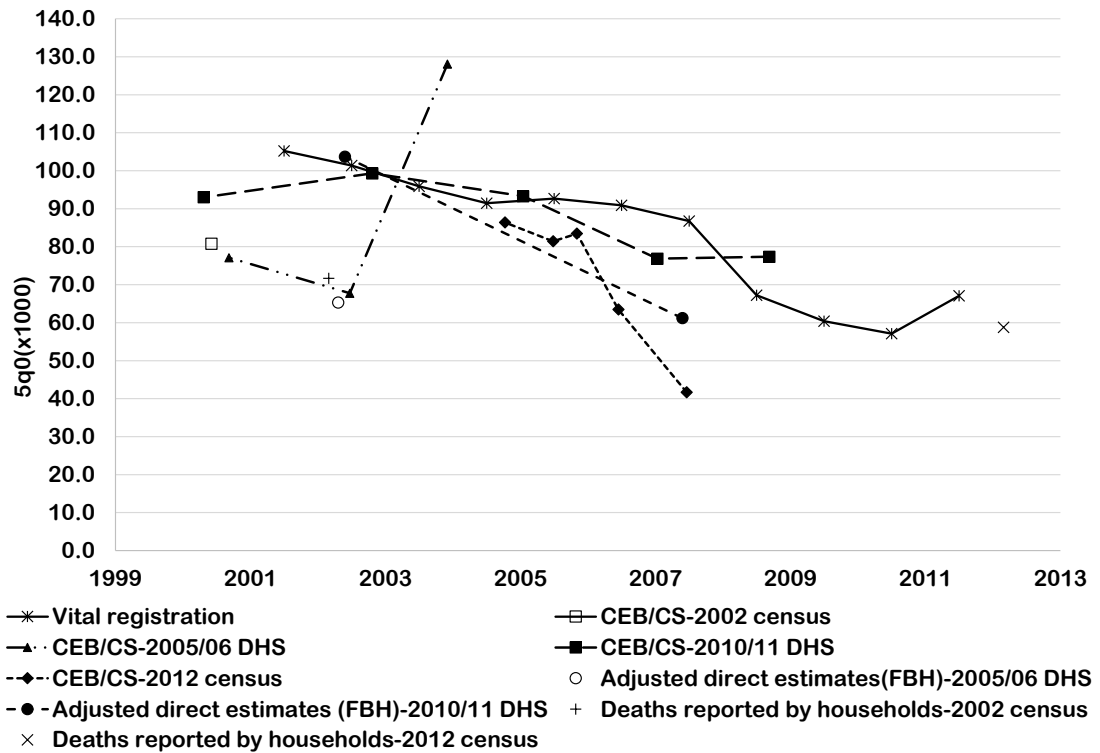


Figure 5.16 Under-five mortality rates (per thousand)-Bulawayo comparison

Infant mortality rates for the two populations are given in Appendix C. The infant mortality rates for Harare’s vital registration appear to be consistent with the corresponding under-five mortality rates as they are also lower than those from other methods and sources. Bulawayo’s vital registration estimates, on the other hand, do not tell the same story as the corresponding under-five mortality rates as they are higher than those from all the other methods and data sources.

6 DISCUSSIONS AND CONCLUSIONS

6.1 Introduction

The purpose of this study was to ascertain, on the basis of direct and indirect estimates from other data sources, the reasonableness of using vital registration data to track mortality of the populations of Harare and Bulawayo using vital registration data. The purpose of this chapter is to reflect on the results obtained from Chapters 5 and 6, to determine whether the objectives of the research were accomplished. The chapter considers the quality of the data, the estimates of adult mortality, and then infant and under-five mortality, in the context of the research objectives. Possible ideas for further research will then be highlighted before overall conclusions are drawn on whether these research objectives were met.

6.2 Discussions

6.2.1 Data quality

The main sources of data used in this study are vital registration, census and DHS. Each of these data sources was found to have its own inherent problems with regards to the successful undertaking of this research.

For the vital registration data, the significant reduction in the number of deaths from around 2003 can be attributed to the reduction of HIV/AIDS-related deaths, due to the rollout of antiretroviral treatment and the introduction of the prevention of mother to child transmission (PMTCT) interventions since 2004 (Zimbabwe Ministry of Health and Child Welfare 2007). The interventions curtail the risk of infection thereby leading to a drop in the level of incidence (and hence prevalence) of HIV/AIDS. Another possible reason for the reduction in the deaths is the out-migration of the working age population to South Africa and surrounding countries due to Zimbabwe's economic crisis. There were, however, some irregularities in the death data after 2008 for Harare, and in 2004 for Bulawayo. While the use of data from burial records explains the dip in the 2004 Bulawayo deaths, the reason for the irregular trend of Harare deaths after 2008 could not be ascertained.

It was assumed that the registered deaths were incomplete and would need to be corrected for incompleteness before being used to calculate mortality rates. While estimates of completeness are obtainable for adult deaths, such estimates are difficult to obtain for those under the age of five, hence any incompleteness in these ages was not corrected for. Both infant deaths and births are subject to omission from the registration

systems due to lack of coverage and late registration. According to Courbage and Fargues (1979), any unregistered births are also likely to escape registration if they died in childhood, suggesting similar levels of completeness of births and childhood deaths. Subsequent infant and under-five mortality estimates may therefore not be biased by any lack of completeness in the births or deaths. Palloni (1991), however, argues that the extent of omission in the infant deaths is likely to be higher than that of the births. Consequently, the omission of these deaths is expected to have a greater effect on the bias in the infant and under-five mortality estimates. Both Harare and Bulawayo exhibited levels of completeness of registered births that were higher than expected. This is plausible for metropolitan areas, as this may be due to births for mothers from other parts of the country being registered in the cities.

Migration is a confounding factor in the estimation of mortality from census data and vital registration data, for the population of Zimbabwe between 2000 and 2012, not to mention for the metropolitan areas. Failure to account for it, especially when using the death distribution methods, may lead to completeness estimates, and hence mortality estimates, that are biased for both the vital registration deaths and the deaths reported by households. The estimation procedure adopted for adult mortality estimation only provides rough estimates while infant and under-five mortality estimation methods do not directly take into account migration. Since the premise is that mothers will migrate with their children, and will also provide information on summary birth histories, the effect of high levels of migration on infant and under-five mortality estimates is assumed to be negligible. Apart from the effects of migration, there were also inconsistencies in the 2012 census data on paternal orphanhood, and average parity data. 2002 census data produced estimates that, more often than not, fell outside the period of interest.

The 2005/06 DHS produced estimates that were erratic and, for the most part, were not consistent with those from other data sources. The main data quality issue for DHS data, however, is the sampling errors that result from the small sample sizes, as seen in most of the mortality estimates that were derived from this data source for subnational populations.

6.2.2 Adult mortality

Estimates of completeness for Harare and Bulawayo, derived from the application of the death distribution methods to vital registration data were, 102 and 99 per cent for Harare males and females respectively, and 95 per cent for Bulawayo. An estimate of completeness above 100 per cent suggests that some of the deaths registered as Harare

deaths were in actual fact from elsewhere. This is plausible, due to the high levels of rural to urban migration experienced, particularly among males of a working age. It is also possible that there was a general undercount of young adult males in either census, though such a phenomenon is unlikely to raise estimates of completeness to more than 100 per cent (Dorrington 2013a).

Zimbabwe's level of adult mortality, ${}_{45}q_{15}$, from the deaths reported by households in the middle of the period between the 2002 and 2012 census was estimated at 59.2 per cent for males and 55.5 per cent for females, Harare's adult mortality estimates from vital registration data at the same time location were 48.4 per cent for males and 46.2 per cent for females. For Bulawayo (males and females combined), the estimate from vital registration data was 55.2 per cent. The vital registration estimates between 2001 and 2011 ranged from 36.0 to 57.0 per cent for Harare males, 35.0 to 55.0 per cent for Harare females and 40.0 to 67.0 per cent for Bulawayo (males and females combined).

Comparison of ${}_{45}q_{15}$ estimates from the various data sources and methods for Harare males, females and Bulawayo males and females combined, given in section 5.3.1 reveals that vital registration data produce estimates that are more or less in line with the other data sources and methods for Harare's male adult mortality, while they underestimate female adult mortality. Estimates of completeness for Harare males and females suggest that almost all the deaths to Harare's residents were registered (completeness close to 100 per cent). However, the level of female adult mortality appears to be too low, even after deaths are corrected for incompleteness, suggesting irregularities in the female data, or failure in the migration estimation procedure to account for all in/out migration of females in that population. Bulawayo's combined vital registration data appear to overestimate adult mortality, albeit slightly. The lack of sex-specific data for Bulawayo's vital registration data, however, makes it rather difficult to determine whether vital registration data underestimate or overestimate sex-specific adult mortality.

Supporting direct and indirect estimates from census and DHS data each had their own differences and inconsistencies when compared to the vital registration data estimates. Maternal orphanhood and direct sibling history estimates appear to be consistent with each other for Zimbabwe and Harare's female populations. In addition, these estimates were also consistent with those suggested by other researchers for the national population (Marera 2011; United Nations 2013). This suggests that these estimates are possibly a close representation of the true level of female adult mortality for the national population. The consistency of the national estimates and the sub-national

estimates for these methods may suggest that one could do worse than assume that the sub-national estimates from maternal orphanhood and sibling histories also give a close depiction of the true level of female adult mortality for Harare. The same holds for sibling history estimates for Bulawayo's combined population and Harare males, with the exception of Harare's 2005/06 DHS estimates. Seeing as vital registration estimates for Harare females are lower than both sibling history and maternal orphanhood, it is therefore reasonable to assume that these vital registration estimates possibly underestimate female adult mortality.

Estimates of paternal orphanhood, however, differ from sibling history estimates and those from deaths reported by households. Moreover, for the national population, estimates from the 2005/06 DHS and 2002 census are lower than those obtained from other researchers (Timæus and Jasseh 2004; Marera 2011; United Nations 2013). The reason for this is probably the estimation of l_{35+n+5}/l_{35} in this research, as specified in the spreadsheet that accompanies Timæus (2013b), instead of the original formulation which estimated l_{35+n}/l_{35} for the 5-9 age group in the regression equation. While the use of this modified estimation procedure produces more robust estimates, it appears to produce paternal orphanhood estimates that are slightly lower than those from other methods and researchers for Zimbabwe and its subnational populations.

Adult mortality rates obtained from the application of death distribution methods to the data on deaths reported by households produced differing results when compared to corresponding vital registration estimates. This is due, in part, to the completeness estimates obtained for the separate populations. For Harare, estimates of completeness of reporting of the deaths reported by households were 76 and 70 per cent for males and females, respectively. It seems rather peculiar that male completeness is significantly lower for Harare than nationally. A possible explanation for this is the disintegration of households upon the death of the breadwinner. This is plausible due to the higher likelihood of rural-to-urban and urban-to-urban migration taking place in Harare. Families that will have settled in Harare will have to relocate back to the rural areas or other relatively smaller towns upon the death of such a figure. Another explanation could be that the deaths of some Harare residents were not reported as they belonged to households in other parts of Zimbabwe, which is a consequence of internal migration dynamics. This, however, is unlikely to have much of an impact on completeness as it applies only to young adults (Dorrington 2013b). Despite these irregularities for male

deaths reported by household data, adult mortality estimates appear to support the male vital registration data estimates.

Female estimates from deaths reported by households on the other hand, appear to be too low when compared to estimates from vital registration data, sibling histories and also maternal orphanhood. For Bulawayo's combined population, the adult mortality estimates from both the deaths reported by households and sibling histories appear to support the vital registration estimates.

6.2.3 Infant and under-five mortality

Zimbabwe's under-five mortality rates in the period from 2000 to 2008 were generally between 90 and 100 deaths per thousand. Harare's under-five mortality rates from vital registration data, on the other hand, ranged from 50 to 80 deaths per thousand between 2001 and 2011. Bulawayo's estimates from vital registration data ranged from 55 to 105 deaths per thousand in the same period. Infant mortality rates for the same data, in the same period, were between 30 and 50 deaths per thousand in Harare, while they were between 40 and 70 deaths per thousand in Bulawayo.

Comparison of these infant and under-five mortality rates with those from other methods and sources reveals that vital registration data appear to underestimate Harare's infant and under-five mortality when compared to the other data sources and methods. It is not clear, however, whether the underestimation of infant and under-five mortality is a function of incompleteness of death registration or an overestimation of the births. It is likely, however, that the method adopted to estimate births, overestimated the births for Harare, thereby leading to the observed differences.

Bulawayo's vital registration data appear to overestimate infant mortality rates when compared to the direct and indirect estimates from DHS and census data. This may be due to an overestimation of infant deaths, which might possibly be explained by the influx of mothers to urban areas seeking medical attention either when giving birth, or after giving birth. This is plausible as urban areas like Bulawayo have better medical facilities than surrounding areas. Bulawayo's vital registration data, however, provide reasonable estimates of under-five mortality, which are somewhat validated by those from the supporting data sources and methods in both level and trend.

Much like for adult mortality, some of the estimates from the available census and DHS data that are used to decide on the reasonableness of using vital registration data in tracking mortality do not necessarily give a true representation of the level of infant and under-five mortality. Consistency, for the most part, between the full sibling history

estimates, adjusted for HIV/AIDS-related bias and possible transference of births, and the CEB/CS under-five mortality rates may suggest closeness of these rates to the true under-five mortality rates.

For the deaths reported by households, a key factor that has a bearing on the accuracy of the estimates produced is the births. Uncertainty in the deaths reported by households, coupled with the underreporting of census births implies that direct estimates from the deaths reported by households are not a correct representation of mortality.

While direct under-five mortality estimates produced from full birth history data and adjusted for HIV/AIDS-related selection bias for Zimbabwe (unadjusted for transference of births) were consistent with those estimated by Masquelier, Reniers and Pison (2014), and the Inter Agency Group for Mortality Estimation (IGME), random sampling errors are, however, apparent for the subnational populations, as evidenced by the level and trend suggested by both Harare and Bulawayo's estimates.

Estimates of the infant mortality rate from the Previous Birth Technique, are also plausible for the whole of Zimbabwe, while those for Harare and Bulawayo appear too erratic to be considered as valid. This suggests that applying the technique on a national scale provides more robust estimates than applying it to sub-national populations. Evidently, the usefulness of full birth history data and data from the most recent births, derived from DHS data, for estimating subnational infant and under-five mortality is somewhat curtailed by the relatively small sample sizes and the resulting random sampling errors.

CEB/CS estimates from the 2005/06 DHS and the 2012 census are somewhat erratic when compared to those of the 2002 census and the 2010/11 DHS. It is also important to note that the lack of HIV-prevalence estimates for Harare and Bulawayo probably had an adverse effect on the estimation of the exact levels of infant and under-five mortality from the CEB/CS method. The DHS reports provided by the Zimbabwe National Statistics Agency (ZIMSTAT) and ICF International (2007; 2012) on the 2005/06 and the 2010/11 DHS's, suggest that HIV prevalence rates for Harare and Bulawayo are different to those of Zimbabwe as a whole. In addition to this, the change in HIV prevalence experienced by Harare and Bulawayo in the period was different to that of Zimbabwe. The choice of HIV prevalence rates, therefore, may not reflect the actual changes in infant and under-five mortality that took place and possibly explains the observed differences between these CEB/CS estimates and vital registration estimates.

6.3 Scope for further research

From this research, it is evident that there are certain areas that call for further research and development. First, there is need for more research on the estimation of internal and external migration from censuses and other surveys. Second, there is also a need for research that delineates the specific causes of death for each measure of mortality as this would go a long way to explaining the changes in mortality observed in this research. Third, it may be useful to incorporate other supplementary data like health facility data in the analysis and to also investigate the usefulness of chosen indices to track mortality going forward.

6.4 Overall Conclusions

A major drawback of this research was its failure to quantify the differences between vital registration estimates and the supporting census and DHS data estimates. Moreover, the true level of infant, under-five and adult mortality in the period could not be ascertained from any of the data sources, although, similarity between some of the estimates gives an indication of the range in which the true level of the estimates might lie.

In light of all the issues highlighted here, it is evident that vital registration data can be used to follow mortality trends at the very least, suggesting that completeness didn't change much in the period of interest. With regards to the level of mortality, apart from some population specific measures that appear to clearly underestimate or overestimate mortality, vital registration data seem to produce plausible estimates of mortality for the metropolitan populations of Harare and Bulawayo in the period 2000 to 2012. It is therefore reasonable to conclude that, on the basis of estimates from censuses and DHS's, vital registration data can be used to produce estimates of mortality for the populations of Harare and Bulawayo between 2000 and 2012. The use of vital registration data, in conjunction with DHS and census data, will possibly allow for deeper understanding of the mortality dynamics of the populations in question and also for the whole of Zimbabwe.

For many countries, very little is known about mortality at a sub-national level. Sampling errors in the data make it even harder to obtain such estimates. While the lack of completeness of vital registration data in developing countries has often been given as the reason for preference of other national data sources, this research has demonstrated that they may still be usable, albeit at subnational strata. Adoption of the kind of approach taken in this research, for countries whose vital registration systems are deemed

incomplete, may fill in the gaps that are left by the other, often more favoured, data sources and methods.

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A. APPENDIX A

Table A.1 Sample sizes for Zimbabwe DHS

| DHS | Zimbabwe | | Harare | | Bulawayo | |
|---------|----------|------|--------|------|----------|-----|
| | Women | Men | Women | Men | Women | Men |
| 2005-06 | 8907 | 7175 | 1492 | 1274 | 697 | 483 |
| 2010-11 | 9171 | 7480 | 1722 | 1307 | 558 | 382 |

Table A.2 Male age distribution by survey (per cent)

| Age | Zimbabwe | | Harare | | Bulawayo | |
|-------|----------|---------|---------|---------|----------|---------|
| | 2005-06 | 2010-11 | 2005-06 | 2010-11 | 2005-06 | 2010-11 |
| 15-19 | 26.5 | 23.2 | 19.7 | 17.1 | 22.6 | 22.9 |
| 20-24 | 20.3 | 18.4 | 23.2 | 21.1 | 25.8 | 19.6 |
| 25-29 | 15.1 | 16.5 | 18.1 | 19.4 | 14.2 | 18.5 |
| 30-34 | 12.3 | 13.0 | 12.5 | 14.3 | 12.7 | 10.0 |
| 35-39 | 9.3 | 11.1 | 10.8 | 11.2 | 7.1 | 11.0 |
| 40-44 | 6.5 | 7.9 | 6.1 | 8.0 | 7.9 | 6.7 |
| 45-49 | 5.7 | 5.1 | 5.3 | 4.3 | 5.0 | 4.6 |
| 50-54 | 4.4 | 5.0 | 4.4 | 4.6 | 4.7 | 6.8 |

Table A.3 Female age distribution by survey (per cent)

| Age | Zimbabwe | | Harare | | Bulawayo | |
|-------|----------|---------|---------|---------|----------|---------|
| | 2005-06 | 2010-11 | 2005-06 | 2010-11 | 2005-06 | 2010-11 |
| 15-19 | 24.2 | 21.2 | 23.5 | 19.6 | 26.2 | 25.2 |
| 20-24 | 21.9 | 20.1 | 27.3 | 21.6 | 23.6 | 22.0 |
| 25-29 | 16.5 | 18.4 | 17.1 | 20.5 | 15.3 | 16.4 |
| 30-34 | 13.7 | 14.1 | 13.7 | 14.8 | 11.0 | 13.0 |
| 35-39 | 9.4 | 11.5 | 8.6 | 10.2 | 9.2 | 9.2 |
| 40-44 | 7.9 | 8.0 | 5.3 | 7.9 | 8.9 | 7.6 |
| 45-49 | 6.6 | 6.8 | 4.5 | 5.4 | 5.8 | 6.6 |

Table A.4 Age-specific mortality rates by population and sex (2005-06 DHS)

| Age | Males | | | Females | | |
|-------|----------|--------|----------|----------|--------|----------|
| | Zimbabwe | Harare | Bulawayo | Zimbabwe | Harare | Bulawayo |
| 15-19 | 0.0017 | 0.0032 | 0.0004 | 0.0027 | 0.0014 | 0.0019 |
| 20-24 | 0.0033 | 0.0029 | 0.0037 | 0.0055 | 0.0064 | 0.0044 |
| 25-29 | 0.0091 | 0.0149 | 0.0099 | 0.0123 | 0.0130 | 0.0096 |
| 30-34 | 0.0200 | 0.0222 | 0.0282 | 0.0204 | 0.0209 | 0.0208 |
| 35-39 | 0.0277 | 0.0377 | 0.0344 | 0.0250 | 0.0173 | 0.0261 |
| 40-44 | 0.0371 | 0.0435 | 0.0359 | 0.0252 | 0.0346 | 0.0366 |
| 45-49 | 0.0365 | 0.0437 | 0.0300 | 0.0255 | 0.0320 | 0.0168 |

Table A.5 Age-specific mortality rates by population and sex (2010-11 DHS)

| Age | Males | | | Females | | |
|-------|----------|--------|----------|----------|--------|----------|
| | Zimbabwe | Harare | Bulawayo | Zimbabwe | Harare | Bulawayo |
| 15-19 | 0.0023 | 0.0054 | 0.0023 | 0.0025 | 0.0029 | 0.0018 |
| 20-24 | 0.0034 | 0.0030 | 0.0018 | 0.0052 | 0.0044 | 0.0054 |
| 25-29 | 0.0064 | 0.0087 | 0.0100 | 0.0097 | 0.0075 | 0.0115 |
| 30-34 | 0.0141 | 0.0233 | 0.0196 | 0.0163 | 0.0148 | 0.0182 |
| 35-39 | 0.0229 | 0.0173 | 0.0250 | 0.0207 | 0.0241 | 0.0153 |
| 40-44 | 0.0300 | 0.0112 | 0.0329 | 0.0233 | 0.0220 | 0.0162 |
| 45-49 | 0.0320 | 0.0112 | 0.0252 | 0.0226 | 0.0198 | 0.0144 |

Table A.6 Probability of an individual aged 15 dying by age 50 (DHS)

| Survey | Males | | | Females | | |
|---------|----------|--------|----------|----------|--------|----------|
| | Zimbabwe | Harare | Bulawayo | Zimbabwe | Harare | Bulawayo |
| 2005/06 | 0.493 | 0.570 | 0.510 | 0.442 | 0.467 | 0.441 |
| 2010/11 | 0.427 | 0.330 | 0.443 | 0.395 | 0.379 | 0.339 |

B. APPENDIX B

Table B.1 Probability of a 15 year old individual dying before reaching the age of 60 for Deaths reported by households, 2002-2012

| Time Location | Zimbabwe | | Harare | | Bulawayo | |
|---------------|----------|--------|--------|--------|----------|--------|
| | Male | Female | Male | Female | Male | Female |
| 2002.1 | 0.767 | 0.743 | 0.573 | 0.586 | 0.616 | 0.616 |
| 2007.6 | 0.592 | 0.555 | 0.444 | 0.450 | 0.465 | 0.459 |
| 2012.1 | 0.424 | 0.394 | 0.344 | 0.343 | 0.363 | 0.334 |

Table B.2 Maternal orphanhood estimates

| Source | Zimbabwe | | Harare | | Bulawayo | |
|-------------|---------------|----------|---------------|----------|---------------|----------|
| | Time location | Estimate | Time location | Estimate | Time location | Estimate |
| 2012 Census | 2008.9 | 0.576 | 2008.9 | 0.544 | 2008.9 | 0.571 |
| | 2006.4 | 0.652 | 2006.4 | 0.613 | 2006.4 | 0.637 |
| 2010/11 DHS | 2007.2 | 0.626 | 2007.2 | 0.585 | 2007.2 | 0.597 |
| | 2004.6 | 0.717 | 2004.6 | 0.666 | 2004.6 | 0.714 |
| 2005/06 DHS | 2002.0 | 0.690 | 2002.2 | 0.629 | 2002.1 | 0.627 |
| | 1999.5 | 0.679 | 1999.8 | 0.636 | 1999.7 | 0.565 |
| 2002 Census | 1999.0 | 0.62 | 1999.01 | 0.61 | 1999.0 | 0.613 |
| | 1996.7 | 0.56 | 1996.72 | 0.55 | 1996.7 | 0.530 |

Table B.3 Paternal orphanhood estimates

| Source | Zimbabwe | | Harare | | Bulawayo | |
|-------------|---------------|----------|---------------|----------|---------------|----------|
| | Time location | Estimate | Time location | Estimate | Time location | Estimate |
| 2012 Census | 2007.3 | 0.409 | 2007.4 | 0.306 | 2007.4 | 0.382 |
| 2010/11 DHS | 2005.5 | 0.528 | 2005.6 | 0.427 | 2005.6 | 0.496 |
| 2005/06 DHS | 2000.4 | 0.611 | 2000.5 | 0.499 | 2000.5 | 0.459 |
| 2002 Census | 1997.3 | 0.469 | 1997.4 | 0.399 | 1997.4 | 0.422 |

Table B.4 Direct estimates from sibling histories (per thousand)

| | 2005/06 DHS | | | 2010/11 DHS | | |
|----------------------|-------------|--------|--------|-------------|--------|--------|
| | 1-5 | 6-10 | 11-15 | 1-5 | 6-10 | 11-15 |
| Zimbabwe | 56.3 | 36.8 | 38.6 | 56.3 | 46.4 | 44.3 |
| Harare | 48.4 | 31.9 | 41.5 | 59.2 | 34.3 | 25.6 |
| Bulawayo | 42.3 | 11.6 | 9.2 | 40.8 | 44.1 | 22.8 |
| Time location | 2002.3 | 1997.3 | 1992.3 | 2007.4 | 2002.4 | 1997.4 |

Table B.5 Direct under-five mortality rates from full birth histories (per thousand)

| | 2005/06 DHS | | | 2010/11 DHS | | |
|----------------------|-------------|--------|--------|-------------|--------|--------|
| | 1-5 | 6-10 | 11-15 | 1-5 | 6-10 | 11-15 |
| Zimbabwe | 77.0 | 53.6 | 55.2 | 82.5 | 64.4 | 61.3 |
| Harare | 75.0 | 41.6 | 41.5 | 79.1 | 59.8 | 37.2 |
| Bulawayo | 55.8 | 11.6 | 9.2 | 54.5 | 73.4 | 40.6 |
| Time location | 2002.3 | 1997.3 | 1992.3 | 2007.4 | 2002.4 | 1997.4 |

Table B.6 Full birth history estimates 10 years before the survey (per thousand)

| Population | 2005-06 DHS | | 2010-11 DHS | |
|----------------------|-------------|--------|-------------|--------|
| | Bulawayo | Harare | Bulawayo | Harare |
| IMR | 30.9 | 44.5 | 39.7 | 56.4 |
| U5MR | 41.9 | 62.5 | 60.1 | 76.1 |
| Time location | 2000.8 | 2000.8 | 2005.9 | 2005.9 |

Table B.7 Direct under-five mortality rates from full birth histories Adjusted for HIV/AIDS-related bias (per thousand)

| Period | 2005-06 DHS | | | 2010-11 DHS | | |
|---------------|-------------|--------|--------|-------------|--------|--------|
| | 0-4 | 5-9 | 10-14 | 0-4 | 5-9 | 10-14 |
| Zimbabwe | 90.5 | 71.3 | 73.9 | 89 | 94.6 | 95.3 |
| Harare | 91.5 | 55.2 | 64.4 | 91.8 | 81.1 | 57.3 |
| Bulawayo | 75.5 | 8.8 | 5 | 51.7 | 102.5 | 66.3 |
| Time Location | 2003.3 | 1998.3 | 1993.3 | 2008.4 | 2003.4 | 1998.4 |

Table B.8 CEB/CS estimates by time location-Zimbabwe

| 2002 Census | | | 2005/06 DHS | | | 2010/11 DHS | | |
|-------------|------|-------|-------------|-------|-------|-------------|-------|-------|
| TL | 1q0 | 5q0 | TL | 1q0 | 5q0 | TL | 1q0 | 5q0 |
| 2001.6 | 85.8 | 131.7 | 2004.8 | 104.9 | 159.2 | 2009.9 | 70.6 | 109.4 |
| 2000.3 | 73.7 | 115.8 | 2003.5 | 64.3 | 101.6 | 2008.5 | 64.1 | 101.3 |
| 1998.4 | 69.7 | 109.8 | 2001.6 | 57.7 | 91.5 | 2006.4 | 53.4 | 84.9 |
| 1996.1 | 76.5 | 120.0 | 1999.3 | 67.1 | 105.9 | 2004.0 | 66.9 | 105.6 |
| 1993.6 | 65.6 | 103.6 | 1996.7 | 61.0 | 96.6 | 2001.2 | 66.5 | 104.9 |
| 1990.9 | 62.9 | 99.6 | 1993.9 | 67.2 | 106.1 | 1998.4 | 74.6 | 117.2 |
| 1988.0 | 63.1 | 99.9 | 1991.0 | 85.1 | 132.8 | 1995.5 | 110.7 | 170.1 |

Table B.9 CEB/CS estimates by time location-Harare

| 2002 Census | | | 2005/06 DHS | | | 2010/11 DHS | | | 2012 Census | | |
|-------------|------|-------|-------------|-------|-------|-------------|-------|-------|-------------|------|-------|
| TL | 1q0 | 5q0 | TL | 1q0 | 5q0 | TL | 1q0 | 5q0 | TL | 1q0 | 5q0 |
| 2001.5 | 71.6 | 110.8 | 2004.7 | 110.1 | 166.6 | 2009.5 | 28.4 | 45.1 | 2009.3 | 9.2 | 14.8 |
| 2000.3 | 60.3 | 95.6 | 2003.5 | 69.6 | 109.6 | 2008.2 | 72.5 | 114.1 | 2007.8 | 33.2 | 53.6 |
| 1998.5 | 55.7 | 88.6 | 2001.8 | 38.3 | 61.6 | 2006.5 | 48.2 | 77.0 | 2006.8 | 43.9 | 70.2 |
| 1996.3 | 65.0 | 102.7 | 1999.8 | 74.0 | 116.3 | 2004.5 | 63.6 | 100.6 | 2006.0 | 54.6 | 86.8 |
| 1994.0 | 51.3 | 81.8 | 1997.6 | 58.0 | 92.1 | 2002.3 | 63.0 | 99.6 | 2005.5 | 54.3 | 86.4 |
| 1991.3 | 48.3 | 77.1 | 1995.1 | 73.3 | 115.2 | 1999.9 | 80.0 | 125.2 | 2004.6 | 60.0 | 95.1 |
| 1988.5 | 50.3 | 80.2 | 1992.3 | 76.4 | 119.9 | 1997.1 | 107.6 | 165.7 | 2002.4 | 94.8 | 147.1 |

Table B.10 CEB/CS estimates by time location-Bulawayo

| 2002 Census | | | 2005/06 DHS | | | 2010/11 DHS | | | 2012 Census | | |
|-------------|------|------|-------------|------|-------|-------------|------|-------|-------------|------|-------|
| TL | 1q0 | 5q0 | TL | 1q0 | 5q0 | TL | 1q0 | 5q0 | TL | 1q0 | 5q0 |
| 2001.6 | 53.4 | 83.6 | 2004.9 | 10.8 | 17.3 | 2009.8 | 69.2 | 107.3 | 2009.0 | 7.6 | 12.3 |
| 2000.4 | 50.7 | 80.8 | 2003.9 | 81.9 | 128.1 | 2008.7 | 48.5 | 77.4 | 2007.5 | 25.7 | 41.7 |
| 1998.7 | 48.6 | 77.5 | 2002.5 | 42.3 | 67.7 | 2007.0 | 48.1 | 76.9 | 2006.5 | 39.5 | 63.5 |
| 1996.5 | 56.1 | 89.1 | 2000.7 | 48.3 | 77.1 | 2005.0 | 58.8 | 93.3 | 2005.8 | 52.4 | 83.4 |
| 1994.1 | 47.0 | 75.1 | 1998.6 | 42.8 | 68.6 | 2002.8 | 62.8 | 99.3 | 2005.5 | 51.1 | 81.4 |
| 1991.5 | 41.5 | 66.6 | 1996.2 | 47.5 | 75.9 | 2000.3 | 58.6 | 93.0 | 2004.8 | 54.3 | 86.4 |
| 1988.6 | 44.2 | 70.8 | 1993.3 | 69.8 | 109.9 | 1997.4 | 95.6 | 148.1 | 2002.7 | 91.1 | 141.6 |

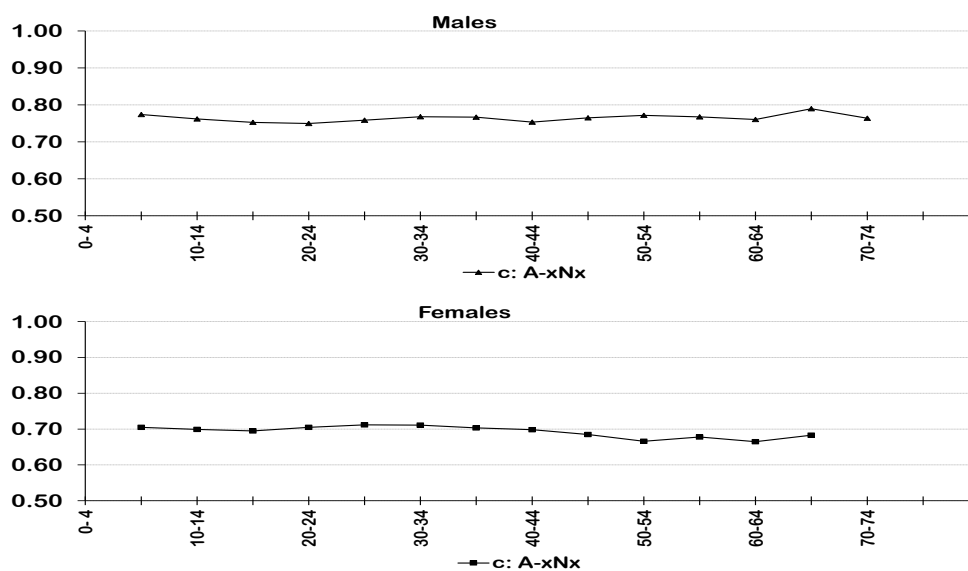


Figure B.1 Harare Completeness estimates - deaths reported by households

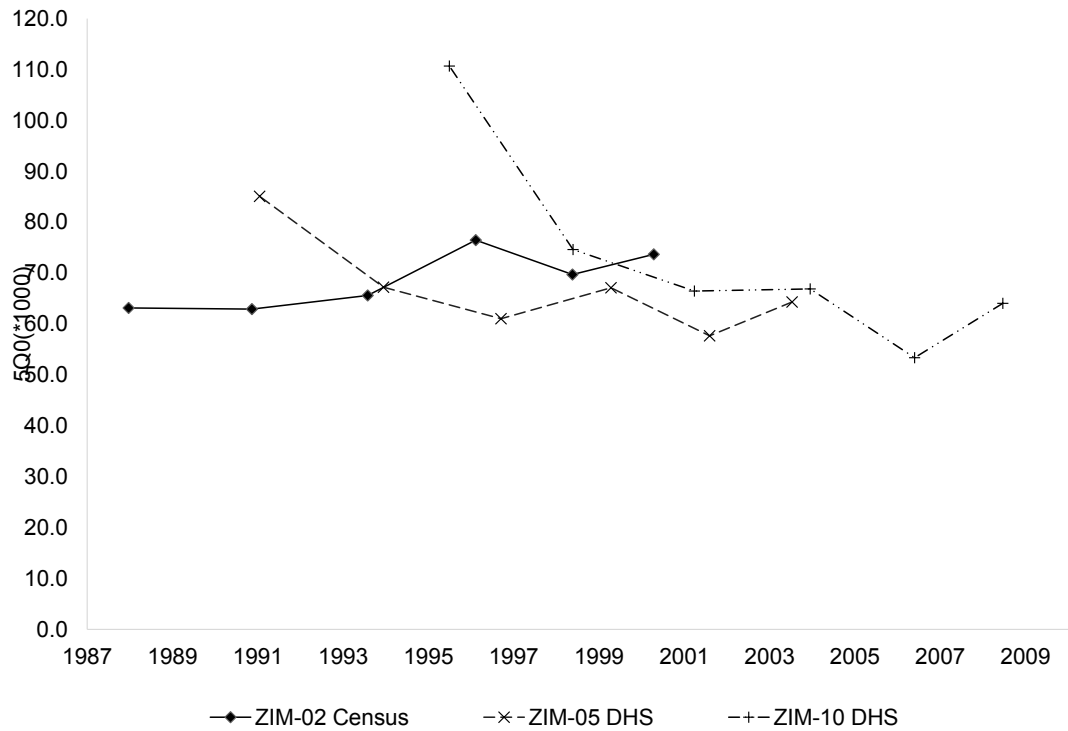


Figure B.2 Infant mortality rates (per thousand)-Zimbabwe

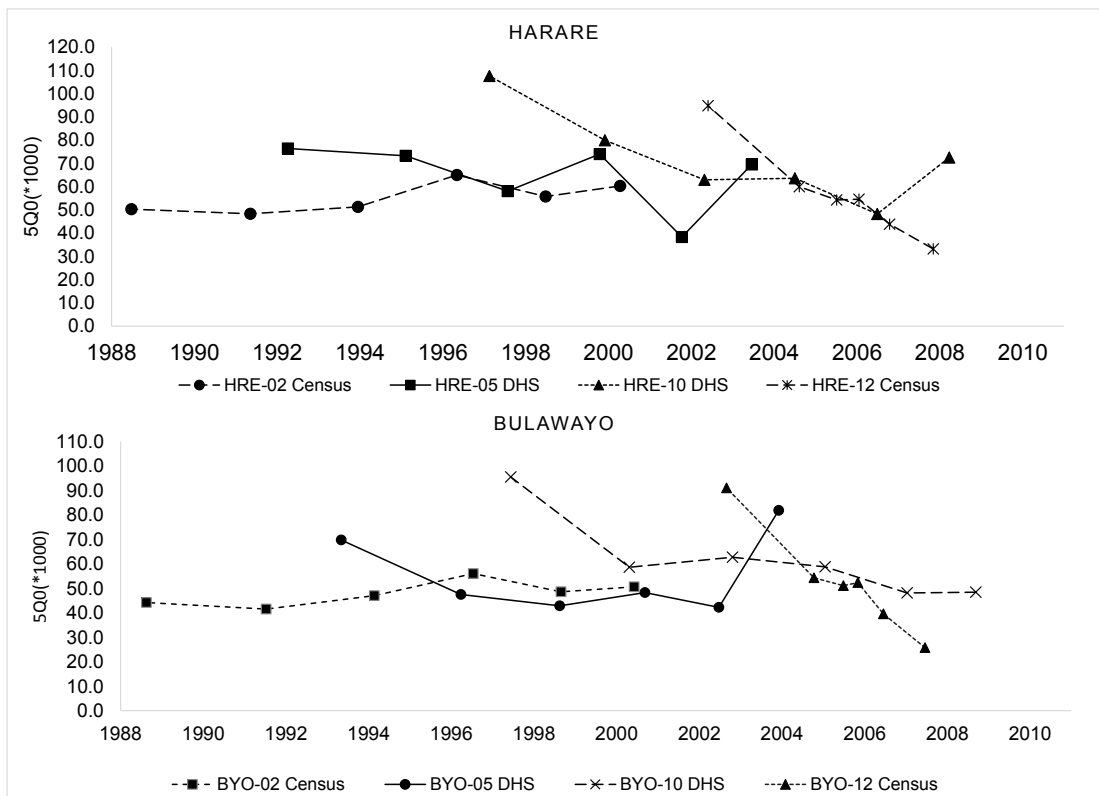


Figure B.3 Infant mortality rates (per thousand)-Bulawayo and Harare

Table B.11 Probability of an individual aged 15 dying before reaching the age of 60, Vital registration

| Year | Harare Males | Harare Females | Bulawayo |
|------|--------------|----------------|----------|
| 2000 | 0.532 | 0.490 | 0.649 |
| 2001 | 0.559 | 0.527 | 0.659 |
| 2002 | 0.561 | 0.544 | 0.698 |
| 2003 | 0.571 | 0.544 | 0.637 |
| 2004 | 0.577 | 0.544 | 0.516 |
| 2005 | 0.526 | 0.529 | 0.595 |
| 2006 | 0.505 | 0.504 | 0.619 |
| 2007 | 0.499 | 0.501 | 0.569 |
| 2008 | 0.497 | 0.485 | 0.571 |
| 2009 | 0.381 | 0.361 | 0.481 |
| 2010 | 0.517 | 0.492 | 0.450 |
| 2011 | 0.267 | 0.275 | 0.392 |
| 2012 | 0.300 | 0.291 | 0.363 |

Table B.12 Infant and under-five mortality rates (per thousand), Vital registration

| Year | Under-five | | Infant | |
|------|------------|--------|----------|--------|
| | Bulawayo | Harare | Bulawayo | Harare |
| 2000 | 105.2 | 78.7 | 75.1 | 55.5 |
| 2001 | 107.8 | 77.5 | 76.3 | 54.4 |
| 2002 | 102.7 | 74.2 | 67.1 | 50.6 |
| 2003 | 93.7 | 73.3 | 61.1 | 50.7 |
| 2004 | 91.3 | 65.7 | 66.1 | 43.8 |
| 2005 | 89.3 | 73.3 | 63.5 | 54.5 |
| 2006 | 97.3 | 59.0 | 69.1 | 40.5 |
| 2007 | 86.1 | 59.0 | 60.3 | 40.5 |
| 2008 | 76.9 | 59.9 | 51.8 | 41.0 |
| 2009 | 38.7 | 37.4 | 23.8 | 27.4 |
| 2010 | 65.6 | 39.0 | 47.9 | 30.7 |
| 2011 | 67.0 | 38.9 | 51.5 | 28.5 |
| 2012 | 68.7 | 51.8 | 53.1 | 40.0 |

C. APPENDIX C

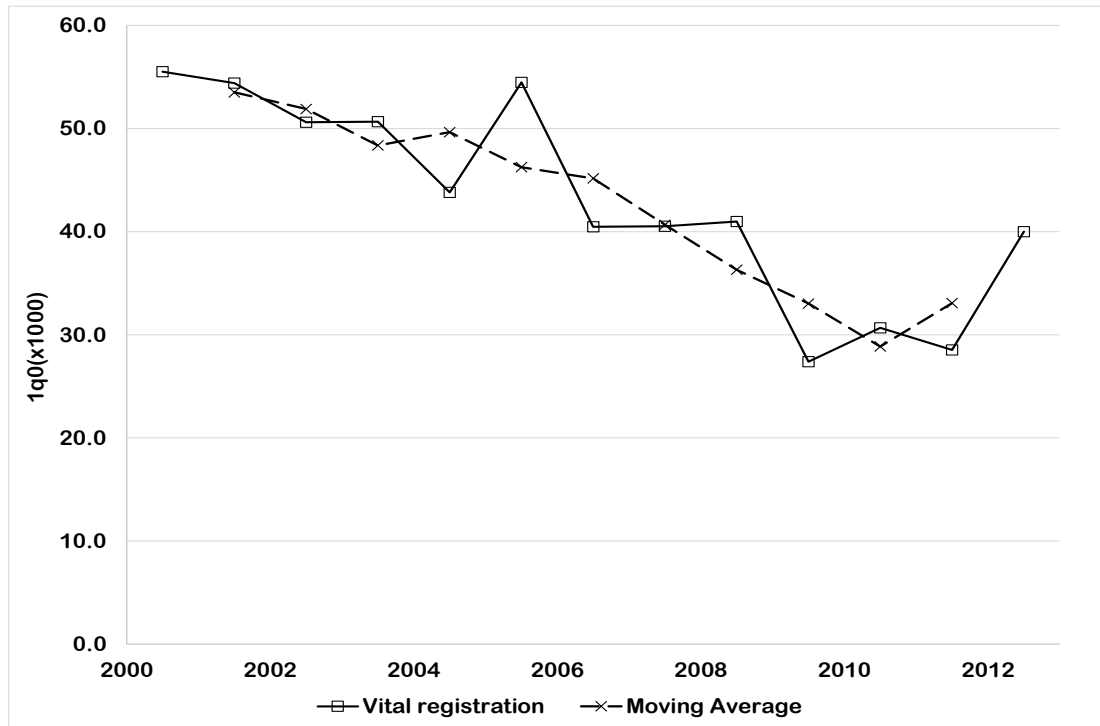


Figure C.1 Infant mortality rate (per thousand) – Harare

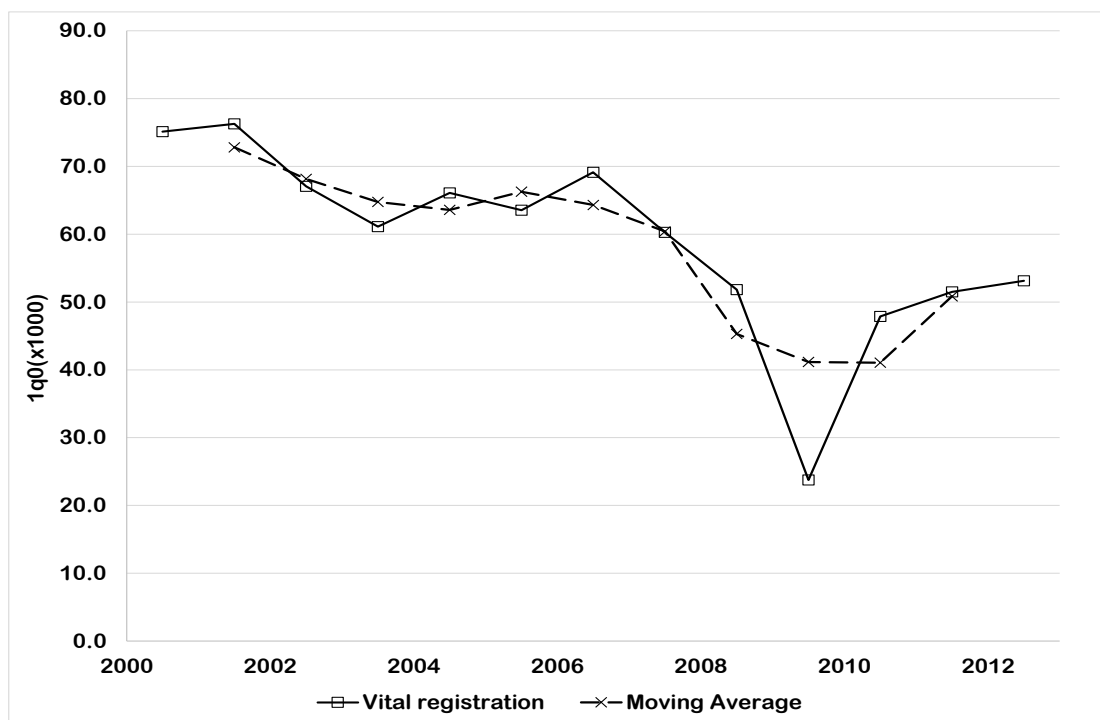


Figure C.2 Infant mortality rate (per thousand) – Bulawayo

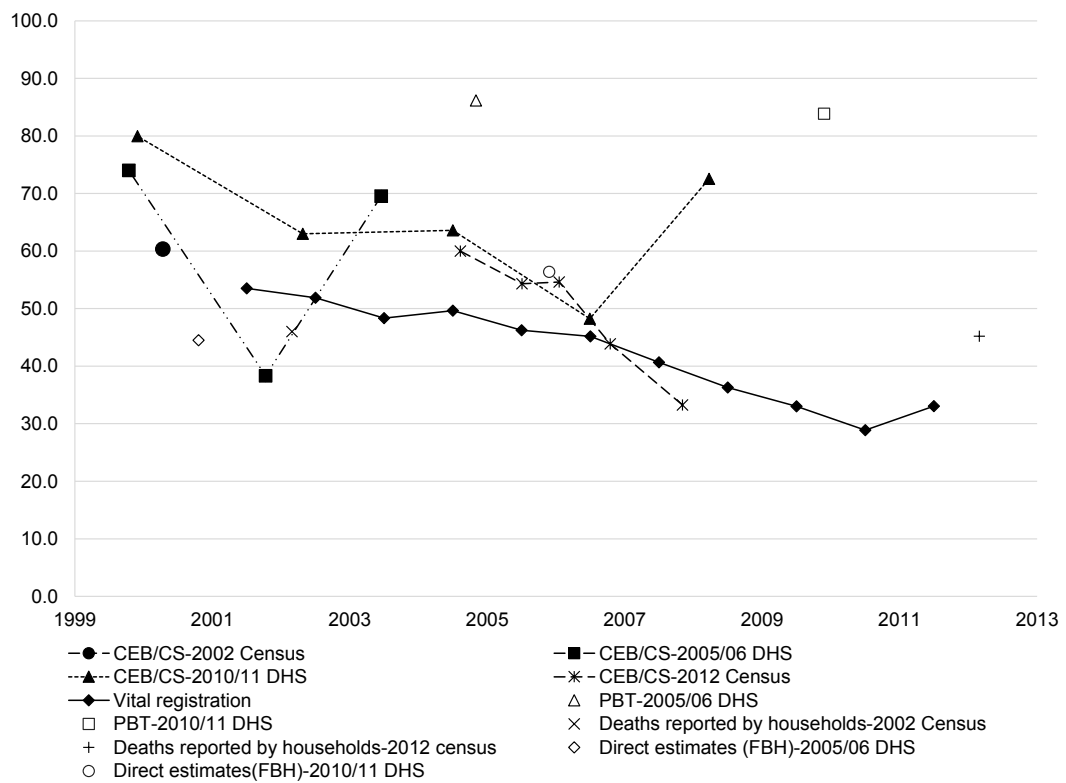


Figure C.3 Infant mortality rate (per thousand)-Harare comparison

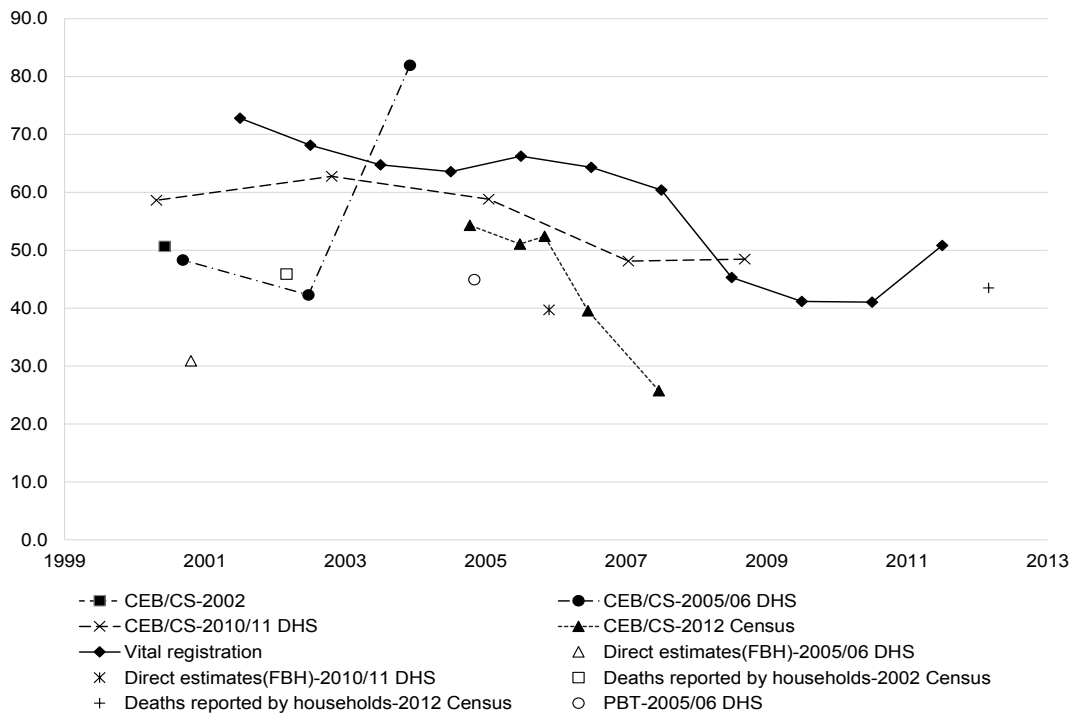


Figure C.4 Infant mortality rate (per thousand) - Bulawayo comparison

D. APPENDIX D

This code gives the exposure and the deaths for each age group. Probabilities were then calculated separately.

```
//This part estimates the deaths (numerators) corrected for the transference of births//
use "C:\Users\Elton\Documents\Thesis\DHS 2005\ZWBR51dt\ZWBR51FL.DTA",
clear
numlabel,add
keep v005 v008 b3 b4 b5 b6 b7 v002 v016 v024
egen rand1=cut(v002), group(10)
egen rand2=cut(v016), group(10)
gen random1= (rand1/10)+ 0.05
gen random2= (rand2/10)+ 0.05
gen dob = b3
gen aad= b7
gen dod = dob + aad //Imputed date of death
* Define lower limits of age categories for calculating probabilities i.e. 0, 1, 3, 6, 12, 24,
36, 48
forvalues i= 1/2 {
gen aggrp_`i'=`i'-1
}
forvalue i= 3/4 {
gen aggrp_`i'=(3*`i')- 6
}
forvalues i= 5/9 {
gen aggrp_`i'=(`i'-4)*12
}
*Set width of each period for analysis (minimum period of twelve months)
forvalues x= 1/5 {
gen per`x'=(12 * `x')
}
gen maxper = 6
*Set upper and lower limits for date of analysis period
gen upplim = v008-12- 1
```

```

foreach var of varlist per1-per5 {
gen lowlim`var' = v008 - (maxper * `var') - 13
}
*Selecting the dead children born in the analysis periods
foreach var of varlist lowlimper1-lowlimper5 {
gen xproc`var'= 0
replace xproc`var' = 1 if (`var' <= dob) & (dob <= upplim) & (b5 == 0)
}
keep if xproclowlimper5==1
*For the period 60 months before the survey only: values can be found for each 12 month
period before the survey
*Assigning the deaths to each of the age groups. After assigning, information on the age
group of death is used solely.
gen j=0
replace j=1 if (aggrp_1 <= aad & aad < aggrp_2) // Age at death = 0 months
replace j=2 if (aggrp_2 <= aad & aad < aggrp_3) // Age at death = 1-2 months
replace j=3 if (aggrp_3 <= aad & aad < aggrp_4) // Age at death = 3-5 months
replace j=4 if (aggrp_4 <= aad & aad < aggrp_5) // Age at death = 6-11 months
replace j=5 if (aggrp_5 <= aad & aad < aggrp_6) // Age at death = 12-23 months
replace j=6 if (aggrp_6 <= aad & aad < aggrp_7) // Age at death = 24-35 months
replace j=7 if (aggrp_7 <= aad & aad < aggrp_8) // Age at death = 36-47 months
replace j=8 if (aggrp_8 <= aad & aad < aggrp_9) // Age at death = 48-59 months
gen dthage = j - 1.
keep if (j != 0) //Select children who died under age 5
gen perborn = int((v008-13 - dob)/per5) // Determine period of birth and death
gen limlow = v008-12- ((perborn+1) * per5) // Calculate lower bound for the date of the
period in which the child was born
*Calculate earliest date a death could occur in age group j
gen age_e=0
forvalues i=1/8 {
replace age_e = dob + aggrp_`i' if (j == `i')
}
*Calculating the date the next age group starts (upper bound on date of death in age group
j)

```

```

gen age_nxt=0
forvalues i=1/8 {
replace age_nxt = dob + aggrp_`i'+1 if (j == `i')
}
*Calculate upper bound for the date of the period in which the child was born (limupp)
gen limupp = limlow + per5
gen n = 1
*Number of periods in which death could occur
gen iter = 0
*Death occurs in same period as birth
replace iter = 1 if (limlow <= dob & age_nxt <= limupp)
*Death could occur in period of birth or in the next period
replace iter = 2 if (age_e < limupp & limupp <= age_nxt)
*Death occurs in period after birth *.
replace iter = 1 if (dob < limupp & limupp <= age_e)
*Set perborn to period of death, i.e. next period *.
replace perborn = perborn - 1 if (dob < limupp & limupp <= age_e)
*All deaths to children born in the most recent period must occur in the most recent
period
replace iter = 1 if (perborn == 0)
replace n = n / iter if (iter != 0)
*Colper defines columns for table = time periods
gen colper = perborn
*Weight the data. Deaths that could have occurred in either of two time periods are
assigned 1/2 to each period (n)
gen rweight = n * v005/1000000
save "C:\Users\Elton\Documents\Thesis\Data\cmortality3.dta"
* Tabulate deaths that occurred to children born in the last 5 periods by age at death and
period ; procedure
gen xtabs = 0
replace xtabs = 1 if (iter != 0 & 0 <= colper & colper < 5)
tab dthage colper[iweight=rweight] if (xtabs == 1)
tab dthage colper[iweight=rweight] if (xtabs == 1 & b4==1)
tab dthage colper[iweight=rweight] if (xtabs == 1 & b4==2)

```

```

tab dthage colper [iweight=rweight] if (xtabs == 1 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==1 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==2 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & v024==10)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==1 & v024==10)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==2 & v024==10)
clear
use "C:\Users\Elton\Documents\Thesis\Data\cmortality3.dta", clear
* Retabulate deaths that could have occurred in the next period, in that period; procedure
output
replace colper = colper - 1 if (iter == 2)
gen xtabs = 0
replace xtabs = 1 if (iter == 2 & 0 <= colper & colper < 5)
tab dthage colper[iweight=rweight] if (xtabs == 1)
tab dthage colper[iweight=rweight] if (xtabs == 1 & b4==1)
tab dthage colper[iweight=rweight] if (xtabs == 1 & b4==2)
tab dthage colper [iweight=rweight] if (xtabs == 1 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==1 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==2 & v024==9)
tab dthage colper [iweight=rweight] if (xtabs == 1 & v024==10)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==1 & v024==10)
tab dthage colper [iweight=rweight] if (xtabs == 1 & b4==2 & v024==10)
*this second part estimates the exposure to risk of dying corrected for transference*
use "C:\Users\Elton\Documents\Thesis\DHS 2005\ZWBR51dt\ZWBR51FL.DTA",
clear
numlabel,add
keep v005 v008 b3 b4 b5 b6 b7 v002 v016 v024
egen rand1=cut(v002), group(10)
egen rand2=cut(v016), group(10)
gen random1= (rand1/10)+ 0.05
gen random2= (rand2/10)+ 0.05
gen dob = b3
gen aad= b7
gen dod = dob + aad //Imputed date of death

```

```

* Define lower limits of age categories for calculating probabilities i.e. 0, 1, 3, 6, 12, 24,
36, 48
forvalues i= 1/2 {
gen aggrp_`i'=`i'-1
}
forvalue i= 3/4 {
gen aggrp_`i'=(3*`i')- 6
}
forvalues i= 5/9 {
gen aggrp_`i'=(`i'-4)*12
}
*Set width of each period for analysis (in months), the program works for minimum
period of twelve months
forvalues x= 1/5 {
gen per`x'=(12 * `x')
}
gen maxper = 6
*Set months = number of months child lived
gen months = 0
replace months = aad if (b5 == 0)
replace months = (v008 - dob) if (b5 == 1)
*Calculate period of birth
gen perborn = trunc((v008-13 - dob)/per5)
save "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta"
*Tabulate exposure in the first age group (0 months) by period
gen ageexp = 0
gen agei = dob //set agei to CMC for start of age group
gen nxtage = dob + aggrp_2 //next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the second age group (1-2 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 1
gen agei = dob + aggrp_2 //set agei to CMC for start of age group

```

```

gen nxtage = dob + aggrp_3 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the third age group (3-5 months) by period *
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 2
gen agei = dob + aggrp_3 //set agei to CMC for start of age group
gen nxtage = dob + aggrp_4 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the fourth age group (6-11 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 3
gen agei = dob + aggrp_4 //set agei to CMC for start of age group
gen nxtage = dob + aggrp_5 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the fifth age group (12-23 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 4
gen agei = dob + aggrp_5 //set agei to CMC for start of age group
gen nxtage = dob + aggrp_6 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the sixth age group (24-35 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 5
gen agei = dob + aggrp_6 //set agei to CMC for start of age group
gen nxtage = dob + aggrp_7 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"
clear
* Tabulate exposure in the seventh age group (36-47 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta", clear
gen ageexp = 6

```

```

gen agei = dob + aggrp_7 //Set agei to CMC for start of age group
gen nxtage = dob + aggrp_8 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"

clear

* Tabulate exposure in the eighth age group (48-59 months) by period
use "C:\Users\Elton\Documents\Thesis\Data\Exposure.dta"
gen ageexp = 7

gen agei = dob + aggrp_8 //Set agei to CMC for start of age group
gen nxtage = dob + aggrp_9 //set next age to CMC for start of next age group
do "C:\Users\Elton\Documents\Thesis\Data\mort2.do"

clear

//Define the period of birth of the child and the number of iterations//
*Select children exposed for at least part of the age group ie children who enter the age
group
keep if (agei <= dob + months)
*Calculate lower bound for the date of the period in which the child was born
gen limlow = v008-12-((perborn+1) * per5)
*Calculate upper bound for the date of the period in which the child was born
gen limupp = limlow + per5
*Determine number of periods in which exposure occurred in the age group (iter)
gen iter = 0
replace perborn = perborn - 1 if (limupp <= agei)
replace iter = 1 if (limupp <= agei)
replace n = 1 if (limupp <= agei)
replace limlow = limlow + per5 if (limupp <= agei)
replace limupp = limlow + per5 if (limupp <= agei)
*All exposure occurs in period of birth *
replace iter = 1 if (nxtage < limupp)
replace n = 1 if (nxtage < limupp)
*Exposure occurs in period of birth and in the next period *
replace iter = 2 if (agei < limupp & limupp <= nxtage)
replace n = 0.5 if (agei < limupp & limupp <= nxtage)
replace iter = 1 if (agei < limupp & limupp <= nxtage & perborn == 0)
*Colper defines columns for tabulation = time periods

```

```

gen colper = perborn
* Exposure that occurs over two time periods is assigned 1/2 to each period (n)
gen rweight = n * v005/1000000
*Select 5 periods for tabulation
gen xproc = 0
replace xproc = 1 if (0 <= colper & colper < 5)
*First part of the exposure
keep if (xproc == 1)
tab ageexp colper [iweight=rweight]
tab ageexp colper [iweight=rweight] if b4==1
tab ageexp colper [iweight=rweight] if b4==2
tab ageexp colper [iweight=rweight] if v024==9
tab ageexp colper [iweight=rweight] if b4==1 & v024==9
tab ageexp colper [iweight=rweight] if b4==2 & v024==9
tab ageexp colper [iweight=rweight] if v024==10
tab ageexp colper [iweight=rweight] if b4==1 & v024==10
tab ageexp colper [iweight=rweight] if b4==2 & v024==10
* Second part of exposure
gen xproc2 = 0
replace colper = colper - 1
replace xproc2 = 1 if (0 <= colper & colper <= 4 & iter == 2)
keep if (xproc2 == 1)
tab ageexp colper [iweight=rweight]
tab ageexp colper [iweight=rweight] if b4==1
tab ageexp colper [iweight=rweight] if b4==2
tab ageexp colper [iweight=rweight] if v024==9
tab ageexp colper [iweight=rweight] if b4==1 & v024==9
tab ageexp colper [iweight=rweight] if b4==2 & v024==9
tab ageexp colper [iweight=rweight] if v024==10
tab ageexp colper [iweight=rweight] if b4==1 & v024==10
tab ageexp colper [iweight=rweight] if b4==2 & v024==10

```