The impact of HIV on the summary birth history method of estimating child mortality: A Zimbabwean demographic surveillance case study

Vivian Chitiyo

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PLAGARISM DECLARATION

This research is my original work, produced with supervisory assistance from my supervisor. I have used the Harvard convention for citation and referencing. Each contribution to this dissertation from the works of other people has been acknowledged, cited and referenced. In addition, this dissertation has not been submitted for any academic or examination purpose to any other university.

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Vivian Chitiyo Date

ABSTRACT

The summary birth history method has been an integral part of the measurement of childhood mortality in countries with incomplete and inaccurate vital registration systems. Estimates from this method are biased downwards in the presence of human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS), on account of the violation of the underlying assumptions of the method, mainly the correlation between the mortality of mothers and their children (Mahy, 2003; Ward and Zaba, 2008).

The estimation of the extent of bias in the summary birth history method attributable to the HIV/AIDS epidemic is important in order to provide more accurate estimates of the levels and trends in childhood mortality. This ensures the appropriate monitoring and evaluation of the socio-economic development and health status of the population, and the topical progress towards the Millennium Development Goal No. 4, as the year 2015 draws near.

The longitudinal survey data of the Manicaland HIV/STD Prevention study in Zimbabwe conducted between 1998 and 2005 were analysed to assess the extent of bias in the summary birth history method due to the impact of HIV/AIDS. The results demonstrate that the increased correlation between the mortality of mothers and their children, induced by HIV, is the principal contributor to the aggregate bias in the method. The aggregate bias in the summary birth history method was found to be significant; between five per cent and eleven per cent. However, in practise, the downward bias due to the impact of HIV may be counteracted to some extent by other possible biases in the summary birth history method in general, and hence, the impact of HIV on the estimates may not be as significant.

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1. INTRODUCTION

1.1 Background

Many developing countries rely on the birth history data that are collected in population censuses and household surveys to measure childhood mortality because of the lack of complete vital registration systems. The indirect and direct approaches are used with the birth history data, in order to derive the estimates of child mortality[1].

An indirect technique, the summary birth history method, for measuring childhood mortality uses reports on the total number of children ever born, and the number of these who have survived, by women aged 15 to 49, alive at the time of the census or survey (United Nations, 1983). This method assumes negligible dependence between the mortality of mothers and that of their children such that reports by women alive at the time of the survey represent the mortality experience of children born at a certain point in time. In addition, the summary birth history method assumes that the mortality of children does not depend on the mother's age. The time location of the childhood mortality estimates is calculated, based on the assumption that the rate of change in mortality is approximately constant over time (United Nations, 1983; Ward and Zaba, 2008). Furthermore, the conversion of mortality estimates to a common index, usually the under-five mortality rate, is based on the assumption that a specified model life table can represent the shape of the mortality experience of children in the population of interest.

Direct estimate from the full birth history data make use of reports on the dates of birth of children, their survival status, and the dates of death for the children who died, by women aged 15 to 49 still alive at the time of the survey (Rutstein and Rojas, 2003). The method assumes that the dependence between the mortality of mothers and their children is not significant.

Of these two methods, direct estimation is preferred, as it is thought to give more accurate estimates compared with the indirect method, because it is less dependent on assumptions; and the detailed birth histories ensure greater accuracy and better time referencing, at least when the responses are accurate (Mahy, 2003). However, the detailed birth histories required for direct estimation are expensive and difficult to collect; and thus the samples tend not to have sufficient data to enable estimation for

[1] Note: Child mortality in the current research is used to refer to mortality risks throughout childhood.

small geographical areas; hence, the need to continue using summary birth history technique with census and household survey data.

The advent of the HIV/AIDS epidemic has introduced bias in the child mortality estimates derived from birth history data through the violation of the theoretical underpinnings of the techniques principally, through the correlation of mother's mortality with that of her children (Ward and Zaba, 2008). The mortality of HIV positive mothers is associated with increased childhood mortality, due to the direct effects of mother-to-child transmission, and indirectly when the mother is ill or has died (Adetunji, 2000; Hill, Cheluget, Curtis *et al.*, 2004; Ng'weshemi, Urassa, Isingo *et al.*, 2002; Walker, Schwartlander and Bryce, 2002).

The correlation between deaths of the mothers and children from AIDS results in a significant underestimation of childhood mortality using the birth history data because of the absence of dead mothers from the census or survey - who would otherwise have been able to report on the survival of their children. Furthermore, such children generally experience higher mortality risks. This and the violation of the other assumptions of the summary birth history method could result in erroneous assessments of the levels and trends in childhood mortality (Mahy, 2003; Ward and Zaba, 2008).

Research by Ward and Zaba (2008) on the impact of HIV/AIDS on the indirect technique indicates that the epidemic results in a significant underestimation of childhood mortality rates. In an effort to correct the estimates, a model was developed to estimate the magnitude of the error due to HIV/AIDS assuming a stable population, that is, age-specific fertility and mortality are constant over time and a stable epidemic (i.e. incidence of HIV is constant over time).

However, the assumption of stability is not realistic, as the epidemic is not stable due to the natural course of the epidemic and the various efforts towards prevention and treatment(Mahy, 2003). Thus, the proposed correction factors could be inappropriate thereby, prompting the need for further investigation into the impact of HIV on the summary birth history method.

Hallett, Gregson, Kurwa *et al.* (2010) use data from a longitudinal study site in Manicaland province of Zimbabwe to estimate, empirically, the bias in direct childhood mortality rates attributable to the correlation between AIDS-related mortality among women and their children. A mathematical model, calibrated to fit the empirical data, was developed to produce estimates of the bias, in direct estimates of infant and under-

five mortality from cross-sectional survey data in countries affected by the generalized HIV epidemic. The bias is then applied to correct the estimates for the impact of HIV.

The current research contributes to an understanding of bias and the possible adjustments required for correcting child mortality estimates produced by the summary birth history method when applied to populations affected by a generalised HIV epidemic.

1.2 Aims and Objectives of the research

The overall aim of this research is to investigate and estimate the extent of bias in the summary birth history method attributable to HIV/AIDS, using the longitudinal survey data of Manicaland province in Zimbabwe for the period 1998-2005.

The specific objectives of the research include the following:

1. To calculate the corrected estimates of childhood mortality, using the data from the longitudinal survey, as was done by Hallett, Gregson, Kurwa *et al.* (2010) but for women in the five-year age groups, 15-49.
2. To calculate childhood mortality rates based on the summary birth history data on children born to surviving women.
3. To examine and quantify the aspects that contribute to the overall bias in the summary birth history mortality estimates due to HIV/AIDS.
4. To compare and contrast the overall and aggregate bias due to HIV, against that produced by applying the adjustments suggested by Ward and Zaba (2008).

1.3 Structure of the thesis

The next chapter will present a review of the literature relevant to this dissertation. This includes a review of the methods for measuring childhood mortality and the impact of HIV on these methods and trends in childhood mortality in Zimbabwe in the era of the HIV epidemic. Chapter 3 looks at the source of the data used and assesses the quality of the survey datasets. In addition, Chapter 3 details the method used to analyse the datasets. Chapter 4 provides the results and the analysis of the results. Finally, Chapter 5 discusses the results, the limitations of the research, and offers ideas for future research, and draws conclusions from the study.

2. THE LITERATURE REVIEW

This chapter reviews the literature on measuring child mortality and discusses the impact of the HIV/AIDS epidemic on the methods of measuring child mortality. In addition, the chapter looks at the models for correcting the methods of measuring child mortality in countries affected by the generalised HIV epidemics. Lastly, the childhood mortality trends and the HIV epidemic in Zimbabwe are reviewed.

2.1 Measures of child mortality

Mortality has a direct relationship on human wellbeing. Childhood mortality is an important indicator of overall health and socioeconomic development, as it is the result of factors that affect the population's wellbeing (Hill, 1991; Wood and Peggy, 1990). The estimates of child mortality are important because they enable an assessment of the population, health programmes and interventions. In addition, childhood mortality estimates are an integral component of population projections (Hill, 1991; Sullivan, Rutstein and Bicego, 1994).

There are several measures of childhood mortality, including the neonatal mortality rate, post-neonatal mortality rate, infant mortality rate, early child mortality rate, child mortality rate, late child mortality rate, and under-five mortality rate. Of these measures, the infant and the under-five mortality rates are widely used and can be regarded as standard measures for childhood mortality. The level of mortality in the first year of life is measured by the infant mortality rate, IMR, which is the number of deaths under one year per 1,000 live births in a specified year or period.

The under-five mortality rate, U5MR, refers to the probability of dying between birth and exact age five per 1,000.

The IMR is widely used because it is the most sensitive index of mortality and thus an important indicator of the wellbeing of a population. On the other hand, the U5MR is a good summary measure of childhood mortality, as it incorporates the probability of dying during infancy and between one to four years.

2.2 Sources of data for estimating child mortality

Childhood mortality rates can be calculated from the data derived from the vital registration, population census, longitudinal or prospective sample surveys and household surveys.

2.2.1 Vital registration

A complete vital registration system, i.e. one that covers at least 90 per cent of a population's vital events, is the best source of childhood mortality rates (Ahmad, Lopez and Inoue, 2000; World Bank, 2003). The number of births and deaths in each age cohort are used to derive age-specific mortality rates per annum. A complete vital registration system enables the calculation of accurate and timely childhood mortality rates. The data are not subject to sampling errors and mortality rates for small areas can be obtained (Hill, 1991). However, such vital registration systems are costly to maintain and many less developed countries have yet to implement an ideal vital registration system. Sub-Saharan Africa is one of the regions in which countries have incomplete vital registration systems; hence, other sources of data have to be relied upon for measuring child mortality (Mahy, 2003).

2.2.2 Population census

Childhood mortality rates derived from population census data are generally based on retrospective reports of women of reproductive age on the total number of live births and the number surviving (Mahy, 2003; United Nations, 1983). Census data on household deaths by age and sex during some period prior to the census, say 12 months, could be used to estimate child mortality, but there is still some doubt as to the accuracy of the estimates they produce. In addition, some censuses include questions on the survival status of the most recent birth, asked of women of reproductive age; and this could be another source of data for measuring child mortality.

2.2.3 Longitudinal survey

Longitudinal or prospective surveys entail repeated visits to the selected households to record demographic events. A baseline census is conducted at the onset of the longitudinal survey to collect data on the initial household and population structure and could include the summary and full birth history data. Thereafter, follow-up rounds collect data on demographic events since the last round of data collection. These data are used to estimate childhood mortality. Assuming accurate reporting in the survey, longitudinal surveys produce accurate estimates of the level and age pattern of child mortality. However, the limited geographical coverage of longitudinal surveys results in estimates that do not necessarily represent the nation as a whole (Hill, 1991). In addition, longitudinal surveys are prone to loss to follow up and this could lead to significant bias in the estimates derived from these data.

2.2.4 Household survey

The Demographic and Health Surveys (DHS) are an important source of data for childhood mortality measurement in many developing countries (Zaba, Marston and Floyd, 2003). The survey initially collects data on the total number of children ever born, and their survival status; and thereafter, the full birth history of each live-birth of women of reproductive age. The full birth history data are used to derive child mortality rates. The retrospective nature of data collection results in data that are subject to recall errors, such as the omission of deceased children and the misreporting of dates of births and deaths (Hill, 1991; Sullivan, Rutstein and Bicego, 1994).

Multiple Indicator Cluster Surveys (MICS) have been another important source of data for measuring child mortality since their introduction in the mid-1990s. These were developed to fill the data gaps in countries which do not have a complete vital registration system and have not conducted any DHSs. The data on reports by women of reproductive age on the total number of children ever born, and children surviving are used to estimate childhood mortality rates (Mahy, 2003). However, coverage errors and content errors may result in incorrect estimates.

2.3 Methods of estimating child mortality

The lack of complete vital registration systems in many developing countries has resulted in the development of alternative methods of estimating mortality (Hill, 1991). The methods of estimation can be divided into two categories: indirect methods and direct methods of estimation. These differ in the data requirements and the underlying assumptions. This section is a detailed review of the Brass indirect method of estimating child mortality, also known as the summary history birth method or children ever born/children surviving method, and the direct estimation using full birth history data.

2.3.1 Estimating child mortality using the summary birth history method

The summary birth history method, developed by William Brass in 1964, has been the cornerstone of indirect child mortality measurement (United Nations, 1983, 1990). Many developing countries have relied heavily on this indirect method because of the lack of ideal vital registration systems and scant full birth history data (Brass and Coale, 1968; United Nations, 1983). This method is still widely used in developing countries, such as those in sub-Saharan Africa to estimate childhood mortality levels and trends (United Nations, 1990).

The summary birth history method requires data on the total number of women of reproductive age, 15-49 years old, classified in five-year age groups. Data on the total

number of children ever born and those who have died or survived, reported by each woman of reproductive age, are required (United Nations, 1983, 1990).

An underlying assumption of the summary birth history method is that fertility and mortality rates have been constant in recent years. If the assumption holds, then the proportion of dead children among those ever born would be approximately equal to the life table probability of dying between birth and an exact childhood age, x (Brass and Coale, 1968). If $D(i)$ denotes the proportion of children dead among those ever born, and $q(x)$ denotes the probability of dying between birth and exact childhood age x, then the relationship between $D(i)$ and $q(x)$ will be determined by the fertility conditions, mainly the starting age of childbearing (Sullivan, 1972).

Brass developed a polynomial function, based on the level of fertility and earliest age of childbearing, in order to derive fertility schedules, denoted as $f(a)$, calculated as:

$$f(a) = K(a-s)(s+33-a)^2 \text{ for } s \le a \le s+33,$$

where a is the age of the woman, s is the earliest age of childbearing and K is the level of fertility. The fertility schedules were used together with a model life table similar to the Princeton West family, to derive a set of multipliers, denoted as k_i, that can be used to convert the $D(i)$ into life table mortality estimates, $q(x)$. The probability of dying between birth and exact childhood age x is calculated as:

$$q(x) = k_i \times D(i),$$

where i is the age group of the mother, with $i = 1$ for women aged 15-19, $i = 2$ for women aged 20-24, ..., $i = 7$ for women aged 45-49. The multipliers are selected according to the ratio of the average parity for women in the 15-19 age group compared with that of women in the 20-24 age group. This ratio is highly correlated with the age of starting childbearing (Sullivan, 1972; United Nations, 1983). Brass found that the approximate values of childhood ages x for the age groups of women 15-19, …, 45-49 were 1, 2 ,3, 5, 10, 15, and 20, respectively.

The summary birth history method also assumes negligible dependence between the mortality of mothers and that of their children such that reporting by women alive at the time of census or survey represents the mortality experience of all children born at a certain point in time (United Nations, 1983). In addition, the method assumes that the mortality of children does not depend on the mother's age, and that a specified model life table can represent the mortality experience of the children. The same model

life table is then used to convert the mortality estimates to a common measure, usually the U5MR.

Efforts to improve the Brass' summary birth history method have resulted in several variants to the method developed by Sullivan (1972), Trussell (1975), Coale and Trussell (1977), Feeney (1980) and others. This research will use the Trussell version of the Brass summary birth history method, because it produces the probabilities of dying from birth to exact age x, as well as time locations of the mortality estimates (United Nations, 1990). The computational procedure of the Trussell version of the Brass method involves a series of steps, which are described below.

The first step entails calculation of the average number of children ever born to a woman in a given age group, i, called the average parity, denoted as $P(i)$. The average parity is calculated as follows:

$$P(i) = \frac{CEB(i)}{W(i)},$$

where $CEB(i)$ is the total number of children ever born by women in the i^{th} age group, and $W(i)$ is the total number of women in age group i. The next step involves the calculation of the proportions dead among the $CEB(i)$, $D(i)$,; and this is calculated as :

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

where $CD(i)$ is the total number of dead children reported by women in the i^{th} age group. To convert the calculated proportion of those dead into life table probabilities of dying, the Trussell multipliers, k_i, are given by the following formula:

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

The coefficients for estimating child mortality, $a(i)$, $b(i)$ and $c(i)$, are selected to correspond to the appropriate family of the Princeton model life tables, which represent the mortality experience of the population under investigation. The probability of dying between birth and exact age x, i.e. $q(x)$, can then be calculated, using the above formula.

To obtain the point in time from the census or survey date to which the childhood mortality estimates apply, Coale and Trussell (1977) assumed that mortality rates change linearly over time, i.e. no longer assuming that mortality is constant over time (United Nations, 1990). We denote the time location as, $t(x)$. Linear regression was used to estimate the coefficients, $a(i)$, $b(i)$ and $c(i)$, which are also model life

table specific, to estimate the time location. The equation for estimating the time location is as follows:

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

The last step entails the derivation of a common childhood mortality measure such as infant mortality, $q(1)$ and under-five mortality, $q(5)$, in order to analyse trends and make comparisons between data sets and countries (United Nations, 1990). This is done using the Brass logit relational transformation, assuming a model life table which has a similar age pattern of mortality as the derived child mortality estimates, $q(x)$. It has been shown that two life tables with the same pattern of mortality have a linear relationship on the logit scale (Zaba, 1979). The logit transformation is as follows:

$$\text{logit}(q(x)) = \frac{1}{2}\ln(\frac{q(x)}{1-q(x)}).$$

If two life tables have the same pattern of mortality then:

$$\text{logit}(q(x)) \;=\; \alpha + \beta\,\text{logit}(q_s(x)),$$

where α is a constant representing the level of mortality, β, the shape of mortality and $q_s(x)$ is the mortality of the model life table. Assuming we can find an appropriate model life table, such that the shape of the mortality is the same as the observed $q(x)$, i.e. β=1, then the level of mortality implied by each of the childhood mortality estimates can be calculated as:

$$\alpha = \text{logit}(q(x)) - \text{logit}(q_s(x)).$$

The alpha for each $q(x)$, is then used to generate $q(1)$ and $q(5)$ using the following formula:

$$q(x) = 1 - [1 + \exp(2(\alpha + (0.5\ln(\frac{q_s(x)}{1-q_s(x)}))))]^{-1}, \text{ for } x = 1 \text{ and } 5, \text{ respectively.}$$

Feeney (1980) developed an estimation procedure to derive the number of years before the census or survey to which Brass's summary birth history estimates of each age group of the women applied. This is an extension of Brass's summary birth history method and is based on the assumption that the infant mortality (ω at the time of the census) has been declining linearly (at the rate of r infant deaths per 1,000 births in the t years before the survey). In addition, the procedure assumes that childhood mortality is independent of the age of the mother at the birth of her child and that the mortality experience in the years before the survey can be represented by a one-parameter model life table family. Feeney then uses the following equation:

$$Q_i = 1 - \sum_{t=1}^{n(i)} c_i(t)\, p(t; r, \omega),\ i = 1, 2, \ldots, N,$$

where Q_i denotes the proportion of children dead among the children ever born to women in the i^{th} age group, $c_i(t)$ denotes the proportion of the children ever born to women in the i^{th} age group who were born t years before the census and $p(t; r\ \omega)$ is the proportion of the children born t years before the census who survive to the census date. N represents the number of age groups of mothers. Thus there are *N* equations in the unknowns r and ω, and $n(i)$ is defined such that $c_i(t) = 0$ for $t > n(i)$. The $c_i(t)$, could be estimated from the mean age at childbearing, and used in conjunction with Q_i to estimate r and ω that satisfy the N equations. Feeney established that linear trends in childhood mortality intersect at the unique point in time at which the level of infant mortality based on the reports of women in the i^{th} age group is the same as the synthetic cohort mortality measured at that point in time.

This procedure differs from the work by Coale and Trussell (1977) in that it does not assume that the rate of change in overall mortality is known and hence uses the summary birth history data to estimate both the level and rate of change in childhood mortality during the years before the census or survey.

The summary birth history method of estimating child mortality has the advantage that the data required are relatively simple and easy to obtain from a census or a survey (Hill, 1991; Mahy, 2003). Since the method uses data on lifetime fertility, it is not subject to time reference errors that are associated with data over specified periods, such as one year before the census or survey. However, it is not possible to obtain plausible estimates for a period of, say, the most recent three years, because births from young women 15-19 years generally experience higher than average mortality risks (Brass and Coale, 1968; United Nations, 1983). The retrospective nature of the data required is subject to the omission of some children ever born, as well as those deceased. The omission of deceased children relative to the children surviving, results in an underestimation of child mortality (Hill, 1991). The mortality estimates from this method are also prone to the misreporting of the ages of the women.

Deviations from the underlying assumptions result in inaccurate estimates of child mortality from this method; and if errors are significant, the method can be rendered useless.

2.3.2 Estimating child mortality using full birth history

When information on the date of birth and date of death for each live birth is recorded, then age and period specific child mortality rates can be calculated directly. There are three approaches to direct child mortality estimation: the vital statistics approach, the true cohort life table approach and the synthetic cohort life table approach.

2.3.2.1 *The vital statistics approach*

The vital statistics approach uses data on the number of deaths by age and the number of births from the vital registration system and census data to calculate childhood mortality rates. Information from a complete and reliable vital registration system can be used to obtain the infant mortality rate, IMR, by calculating the ratio of the total number of deaths in the first year of life in a specified calendar year to the total number of births in the same year. To estimate the level of mortality for children under the age of five, the number of deaths aged 0-4 years last birthday, from the vital registration system in a specific year, is divided by the population aged 0-4 years last birthday from the population census or mid-year population projections. However, the lack of complete vital registration systems in many developing countries results in the use of other approaches to that of the direct estimation of child mortality (United Nations, 1992).

2.3.2.2 *The true cohort life table approach*

The true cohort life table approach entails the calculation of the number of people, say, aged x, during a given period, and then following them up until their next birthday or earlier death (depending on which comes first). Since the age range of interest for childhood mortality estimation is 0-5 years, the time constraints that are associated with true cohorts are not significant; hence, the use of this approach in estimating child mortality in research (United Nations, 1992). The infant mortality, $q(1)$, is calculated by dividing the number of deaths under one year for a given cohort, by the births of the cohort. However, to calculate under-five mortality, $q(5)$, using the true cohort approach requires the observation of a birth cohort for five years to obtain complete years of exposure; thus, this approach is not appropriate for estimating mortality rates in the recent periods (Rutstein and Rojas, 2003). In addition, the true cohort child mortality estimates relate to the mortality experience of the birth cohort at different times, rather than at one specific point in time.

2.3.2.3 *The synthetic cohort life table approach*

The synthetic cohort life table approach requires data on the full birth history report of each live birth of women aged 15-49 years at the survey date (Rutstein and Rojas, 2003). These data include the date of birth for each child, the survival status and the date of death, or age at death, for deceased children.

The synthetic cohort probabilities of dying are calculated for specific age groups. The DHS classifies children into the following age groups: 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. The age-specific probabilities of dying over a specified period are calculated by relating the deaths of a specific age group to the sum of person-years lived in that age group over a specified period of time usually, 0-5, 5-10 and 10-15 years before the survey. The age-specific probability of survival is calculated by subtracting the age specific probability of dying from one.

This research will focus on the derivation of common measures of child mortality, i.e. infant and under-five mortality. For a complete description of the calculations of survival probability for the specified groups, the reader is referred to Rutstein and Rojas (2003).

The infant mortality, $q(1)$, is calculated by subtracting from one, the product of age-specific probabilities of survival up to age 12 months. This is multiplied by 1,000 to obtain the infant mortality rate per 1,000 live births. The under-five mortality, $q(5)$, is obtained from the calculation of the product of survival probabilities of each age segment up to the 48-59 months and subtracting this figure from one. This is multiplied by 1,000 to obtain the under-five mortality rate per 1,000 live births.

The method assumes negligible dependence between the mortality of mothers and their children, such that reports by women alive at the time of the census or survey represent the mortality experience of children born in the whole population (Mahy, 2003; Rutstein and Rojas, 2003). The violation of this assumption results in the underestimation of child mortality due to the absence of information from deceased mothers.

2.3.3 The consistency of the childhood mortality estimates derived from the birth history data

Previous work has investigated the consistency of the child mortality rates derived directly using the full birth history data and the summary birth history method (Adetunji, 1996; Hill, 1991; United Nations, 1992). It was found that the two

approaches could result in different levels of childhood mortality, in the period before the HIV epidemic.

The United Nations (1992) observed the differentials in the child mortality estimates and concluded that there is no one universal method of accurately measuring child mortality. Both the full and summary birth history data are subject to data errors which could bias the child mortality estimates. This highlights the need to thoroughly assess the quality of the data, in order to improve the accuracy of the estimate and could possibly minimise the discrepancies between the direct and summary birth history estimates.

Hill (1991) point out that the differentials in the direct and summary birth history estimates could be a result of the difference in the allocation of childhood deaths and the exposure to mortality risks to given time periods.

Adetunji (1996) analysed birth history data from African countries and found that the summary birth history method produced higher infant mortality rates than the direct approach. He examined the sources of the discrepancies and concluded that the different forms of the data are prone to different data errors which could bias the estimates. In addition, the violation of the underlying assumptions of the methods and the biases inherent in the methods could explain the differences in the mortality rates.

2.4 The impact of HIV on the measurement of child mortality

The summary birth history method and direct estimation based on full birth history data both rely on retrospective reporting by women alive at the census or survey date. The HIV/AIDS epidemic introduces bias into the estimates, as it invalidates the underlying assumption that the correlation between maternal and child mortality is negligible (Mahy, 2003; Ward and Zaba, 2008). The mortality of HIV positive mothers is associated with increased child mortality (Crampin, Floyd, Glynn *et al.*, 2003).

Several studies have confirmed that child mortality increases in children with HIV positive mothers, due to the direct effect of mother-to-child transmission and indirectly when the mother is ill or dead (Adetunji, 2000; Hill, Cheluget, Curtis *et al.*, 2004; Ng'weshemi, Urassa, Isingo *et al.*, 2002; Walker, Schwartlander and Bryce, 2002). Therefore, the reports of surviving women do not represent the survival status of all children ever born in the population, as such reports on the survival of some of the children born to HIV positive mothers are likely to be missed due to higher mortality rates among women associated with HIV infection. This results in the underestimation of childhood mortality rates, as the children of women who die before the survey are

expected to have experienced higher mortality than those of women alive at the time of the survey in countries affected by the generalised HIV epidemic.

HIV prevalence varies with age; and its impact on adult mortality is age dependent (Stover, Stanecki and The UNAIDS Reference Group on Models Estimates and Projections, 2001; UNAIDS Reference Group on Estimates Models and Projections, 2009). This results in the lack of independence between child mortality and the mother's age; thereby, introducing bias in the summary birth history method, as reports by women in a particular age group will not represent the mortality of children in the whole population (Ward and Zaba, 2008).

Additional bias in the summary birth history method is introduced through the regression coefficients that are used to convert the proportions of children dead, $D(i)$ into life table mortality rates, $q(x)$ and the time to which the rates apply, $t(x)$. This is because the regression coefficients were derived using the model schedules of fertility and particularly mortality (Princeton model life tables) whose age patterns are different from the mortality experience in HIV populations. The empirical evidence from countries affected by the HIV epidemic has shown higher levels of child mortality relative to infant mortality than those predicted by the model life tables (Mahy, 2003). HIV introduces further bias through the regression coefficients used to estimate the time location of the estimates, $t(x)$ since it invalidates the assumptions that childhood mortality is independent of the age of the mother and that the rate of change in mortality is constant over time.

Finally, HIV/AIDS may also introduce bias in common measures of child mortality, $q(1)$ and $q(5)$, from the summary birth history method, since these are based on standard model life tables, mainly the Princeton model life tables, which are inappropriate in HIV settings.

The impact of the HIV epidemic on the basic assumptions of summary birth history method has necessitated research into the magnitude of error introduced by the epidemic, thus correcting child mortality estimates in countries affected by the generalised HIV epidemic.

2.5 Techniques for correcting methods of estimating child mortality for the bias due to HIV/AIDS

The measurements of child mortality in countries affected by the generalised HIV epidemics have been subject to bias emanating from the violation of the underlying assumptions on the available methods. Efforts to measure the bias in child mortality

estimates introduced by HIV have resulted in the development of the Ward and Zaba (2008) prevalence dependent correction factors for the summary birth history method, and the Hallett, Gregson, Kurwa *et al.,* (2010) model for correcting child mortality estimates derived from the full birth history data. This section will also review the method proposed by the Inter-agency Group for Child Mortality Estimation (IGME) to correct child mortality estimates from full birth history reports for populations affected by the generalised HIV epidemic.

2.5.1 The model of Ward and Zaba's for correcting indirect child mortality estimates

Research by Ward and Zaba (2008) on the impact of HIV/AIDS on estimates derived using the summary birth history method of estimating childhood mortality has shown that the epidemic introduces significant bias in childhood mortality estimates. They attribute this to the violation of basic assumptions of the method, principally to the correlation of mothers' mortality with that of their children.

The estimation of the bias introduced by HIV/AIDS in child mortality estimates produced by the summary birth history method is based on simulations using stable populations with constant HIV prevalence at different levels. The assumptions implicit in the use of stable populations are that the age-specific fertility and mortality rates and incidence of HIV remain constant over time.

These data were used to derive the true probability of dying by age z in a given population, denoted as $q(z)^t$. The true probability of dying is a function of the mortality of children who were HIV-positive and of those who were HIV-negative at birth, weighted by the proportion of children born HIV-positive and HIV-negative, i.e.

$$q(z)^t = B^+ q(z)^{HIV+} + (1 - B^+) q(z)^{HIV-},$$

where B^+ is the proportion of children born HIV-positive, $q(z)^{HIV+}$ and $q(z)^{HIV-}$ are the probability of dying between birth and age z of children born HIV-positive and born HIV-negative, respectively. The proportion of children born HIV-positive is determined by the level of prevalence in mothers and mother-to-child transmission (MTCT) through vertical transmission. The model also assumes that the level of MTCT does not vary with the age of the mother, the duration of the infection or the clinical stage of the disease.

The model was also used to derive the child mortality estimates from the summary birth history method, denoted as $q(z)^e$. Since the calculation of the proportion of deceased children is based on reports by women who were HIV-positive and women who were HIV-negative at the time of the census or survey, they developed

a mathematical formula to account for the reduction in the deaths reported by the HIV-positive women. The number of deaths reported by all women aged x, denoted as $d(x)^r$, is calculated as:

$$d(x)^r = p(x)d(x)^+ + (1-p(x))d(x)^-,$$

where $p(x)$ is the HIV prevalence at exact age x and $d(x)^+$ are deaths reported by HIV-positive women, and $d(x)^-$ are deaths reported by HIV-negative women. The $d(x)^r$ are used to calculate the reported proportions dead by women classified into five-year age groups. These are then multiplied by the appropriate multipliers, k_i, to obtain $q(z)^e$.

The difference between the true probability of dying by exact age z and the mortality estimate from the standard summary birth history procedure estimates the magnitude of bias in the child mortality estimates from the summary birth history method, denoted as $n(z)$. The bias is calculated as:

$$n(z) = q(z)^t - q(z)^e.$$

To derive the correction factors for the summary birth history method of estimating child mortality in countries affected by the generalised HIV epidemic, Ward and Zaba examined the relationship between the bias, $n(z)$ and the HIV prevalence. They observed that the bias increases with HIV prevalence and varies with the age group of the mother.

Regression models based on the estimated bias were developed to obtain correction factors, denoted as $n(z)$, for the child mortality estimates. The first or basic regression model calculates the correction factors as follows:

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

where $PREV$ is the HIV prevalence for women aged 15-49. The proportion of variation explained by the regression model was improved by extending the regression model to include the prevalence in women aged 15-19, denoted as $PREV15$. The extended regression model is as follows:

$$n(z) = aPREV + b(PREV)^2 + cPREV15.$$

Ward and Zaba used the predicted $n(z)$ values from the two regression models to obtain the corrected $q(z)^t$ and the errors associated with it. The calculated errors were then used to derive the maximum prevalence at which the bias in child mortality estimates is not significant, i.e. less than five per cent, for each age group of the women

of reproductive age. They concluded that the basic and the extended regression model accurately adjust child mortality estimates from the summary birth history method for HIV in prevalence settings as high as 45 per cent, when using the reports of women in the fourth age group, and up to 30 per cent, when using the reports of women in the third and fifth age groups.

For the first age group, the maximum prevalence at which the bias in estimates is less than five per cent is 12 per cent, when using the basic model, and 44 per cent, when using the extended regression model. Reliable estimates from the seventh age group can be obtained at maximum prevalence of three per cent using the basic model and 12 per cent using the extended model. Thus, information of seroprevalence for the 15-19 age group enables the use of the extended regression model; thereby, increasing the prevalence level at which child mortality estimates from the summary birth history method can be accurately adjusted for the impact of HIV.

However, the validity of the proposed correction factors, $n(z)$, is questionable due to the unrealistic underlying assumptions of the Ward and Zaba model. The assumption of stability is not realistic, as the population is not demographically stable and HIV prevalence is not constant, due to the natural course of the epidemic and the various efforts towards prevention and treatment (Mahy, 2003). Gregson, Garnett, Nyamukapa *et al.,* (2007) report that HIV prevalence in Zimbabwean adults aged 15-49 years was 29 per cent in 1997, but declined to 20 per cent by 2005, indicating that prevalence has not been constant with time, as was assumed by Ward and Zaba in their model.

In addition, the assumption of a constant level of vertical transmission by duration of infection and progression of the disease is violated in reality. Studies have shown that the rate of MTCT varies with the clinical stage of the disease, which is determined by the duration of HIV infection and the progression of the disease (John and Kreiss, 1996; Newell, Brahmbhattb and Ghysc, 2004). The model assumed vertical transmission of HIV from mother to child at birth of 30 per cent thereby incorporating the transmission through breastfeeding. In the absence of interventions, vertical transmission rates lie between 15 per cent and 45 per cent, with the additional risk of transmission being associated with breastfeeding in populations where breastfeeding is prevalent and proceeds into the second year (Newell, Brahmbhattb and Ghysc, 2004). This suggests that the model could possibly underestimate the adjustments required in populations where additional risk of MTCT through breastfeeding is relatively high.

Empirical evidence has shown that HIV-positive women have lower levels of fertility than women who are HIV-negative. This violates the assumption of the model that fertility experiences of women do not differ with HIV status, but the effect of violation of this assumption is likely to be minimal (Gregson, Lewis, Ronsmans *et al.*, 2004). The proposed correction factors ideally apply to populations that can be described by the UN General Model life tables, as the model assumed these for simulating the HIV-negative populations, although, again, this is unlikely to be a significant factor.

Therefore, the proposed correction factors may be inappropriate, prompting the need for further investigation into the impact of HIV on the summary birth history method of estimating childhood mortality in countries affected by HIV/AIDS.

2.5.2 The Hallet, Gregson, Kurwa *et al.* model for correcting direct child mortality estimates

Hallett, Gregson, Kurwa *et al.* (2010) used data from a longitudinal population survey in Manicaland, Zimbabwe, for the period 1998-2005, in order to estimate the bias in childhood mortality estimates due to the HIV/AIDS epidemic. They observed that the correlation between the deaths of the mothers and their children from AIDS results in a significant underestimation of childhood mortality produced from full birth history data, owing to the absence of ill and dead mothers at the time of the survey to report on the survival of their children.

The synthetic cohort life table approach was used to derive infant and under-five mortality estimates of the children of surviving mothers aged 15-49. These were an underestimation of the true childhood mortality rates. Corresponding estimates of infant and under-five mortality rates for children born to deceased mothers were calculated using full birth history reports from the verbal autopsy interviews. Corrected infant and under-five mortality estimates were then calculated by combining estimates for children born to surviving and deceased mothers, allowing for the recruitment of women into the open cohort, and the loss, to follow up for deceased women. The difference between the corrected and uncorrected estimates represents the bias in the direct estimates of childhood mortality based on the cross-sectional survey data.

A mathematical model calibrated to fit the empirical data for rural Zimbabwean women was developed to generate a data-set equivalent to that from a cross-sectional survey of birth histories. The model uses the estimated number of births for rural Zimbabwe, to simulate the number of women in each birth cohort from 1920 to 2005. Their mortality, in the absence of HIV, was described by a piecewise Exponential

distribution from birth to one year, and one to four years; and thereafter, their mortality was described by a Weibull distribution to obtain an expected date of death due to causes other than HIV.

The women were assumed to be exposed to the risk of HIV infection; and the rate of infection was determined by the age together with the calendar time. Of those infected, a Weibull distribution was used to simulate their survival times, classified by age at infection to obtain an expected date of death due to HIV. The women were exposed to age-specific fertility rates that prevailed in rural Zimbabwe prior to the HIV epidemic, in order to obtain the number of births per woman. After the advent of HIV, the model assumed that women infected with HIV experience lower fertility than uninfected women; and the rate of reduction is determined by the time since infection. The children born to infected women were at risk of MTCT through intra-partum transmission and breastfeeding. The rate of MTCT depends on the clinical stage of the disease of the mother, as determined by the CD4 cell count, the calendar time and the presence or absence of prevention of mother-to-child transmission (PMTCT). The model assumes that the rate of MTCT is zero for women on antiretroviral therapy. In addition, the model assumes that the age-specific fertility rates for women on antiretroviral therapy are the same as those for uninfected women.

The survival time for HIV-positive children was calculated as the minimum of the life expectancy in the absence of AIDS.

The model then generates a dataset similar to that obtained from the DHS, which includes the mother's date of birth, the date of death for deceased women, and the full birth history for each woman. These data are used to derive three time series of infant and under-five mortality rates. The first time series, called the "DHS analogue", involves the calculation of infant and under-five mortality rates, using the synthetic cohort life table approach, using data from surviving women aged 15-49.

The synthetic cohort life table approach to direct estimation of child mortality is used to derive the second time series, called the "DHS continuous". The "DHS continuous" calculates the childhood mortality rates on a continuous basis, assuming that the data came from a very large number of closely spaced-cross-sectional surveys, and without censoring child survival times. The third time series, known as the corrected time series, calculates the infant and under-five mortality rates in a similar way as the "DHS continuous" time series, but includes the data on children born to women who died of AIDS prior to the survey. The difference between the "DHS continuous"

time series and the corrected time series estimates the extent of bias in infant and under-five mortality estimates from the data obtained from a cross-sectional survey that is attributable to HIV.

They observe that the bias in childhood mortality estimates increases with the duration of the HIV epidemic. In addition, the bias in the under-five mortality is higher than that for the infant mortality, because children born to women infected further back in the past are under-represented at the survey, due to the increased HIV mortality risks (Mahy, 2003). Furthermore, the extent of bias varies with the background mortality of the children, with significant bias observed in countries with low background mortality, as the proportion of deaths due to HIV would be high (Zaba, Marston and Floyd, 2003). Since MTCT increases with the clinical stage of the disease, bias in the child mortality estimates increases with the mother's disease progression, as women in the late stages are under-represented in the survey, due to increased HIV related mortality.

To assess the impact of interventions on the bias in child mortality estimates, the model introduces antiretroviral therapy to women after the year 2000, assuming that this therapy reduces the MTCT by 50 per cent and 50 per cent of the infected women eligible for antiretroviral therapy can be treated by the year 2003. The model also assumes that interventions reduce the background mortality for children by 30 per cent, and introduces PMTCT after the year 2000. Hallett, Gregson, Kurwa *et al.* (2010) observe that interventions may reduce the bias in child mortality estimates as the mortality among HIV-infected women and their children will be decreasing.

However, the model does not estimate the extent of bias in child mortality estimates by smaller age groups of the mother. The bias is likely to vary according to the age of the mother, since the HIV prevalence is not constant with age; and neither is its impact on the mortality of women. The model does not allow for any differences in the survival of HIV-negative children, as it does not differentiate between the children born to HIV-negative and those born to HIV-positive mothers. The HIV-negative children born to HIV-positive mothers may experience high mortality risks due to maternal illness or death. However, the effect is likely to be minimal, due to the relatively low fertility among HIV-positive women.

2.5.3 The IGME model for correcting direct child mortality estimates

The UN Inter-agency Group for Child Mortality Estimation (IGME), which coordinates the annual production of child mortality estimates for different United Nations agencies, observes that HIV/AIDS introduces bias in child mortality estimates,

derived from birth history reports by women of reproductive age at the dates of a population census or household survey. They attribute this to the correlation of the mortality of the mothers and their children associated with the HIV epidemic.

The IGME has developed a method to correct child mortality estimates derived from full birth histories for countries significantly affected by the HIV epidemic, i.e. countries with HIV prevalence exceeding five per cent (UNICEF, WHO, World Bank *et al.*, 2010).

The model uses the latest annual data on the number of births and the HIV prevalence among pregnant women aged 15-49. The HIV prevalence is used to calculate the number of births to HIV-positive and those to HIV-negative women. The model assumes that births to HIV-negative women are HIV-negative. The births to HIV-positive women are subdivided into HIV-negative and HIV-positive, as determined by the level of MTCT. The Princeton West family life table is used to calculate the number of under-five deaths among the HIV-negative children. The data from demographic surveillance sites in populations affected by HIV are used to derive the mortality schedule for HIV-positive children. These are then used to calculate the number of deaths of these children under the age of five. These data provide the true number of births and under-five deaths in a population affected by the HIV epidemic.

To generate the number of births and under-five deaths similar to those reported by women in cross-sectional surveys, the model assumes that HIV-negative women have lower rates of mortality. In addition, the model assumes that births to HIV-positive women occur on average four years after infection to allow for the reduction in fertility associated with HIV-positive women. The mortality schedule for HIV-positive women, is derived from cohort studies, assuming a median survival time of 9.5 years after four years of infection. This is used to obtain the number of deaths among HIV-positive women before the survey date. The proportions of deaths among HIV-positive women are used to calculate the number of births and deaths under-five years reported by HIV-positive women in the survey.

The magnitude of the bias introduced by the HIV epidemic in full birth history data collected in surveys is calculated as the ratio of the reported number of under-five deaths divided by the reported births to the true number of under-five deaths divided by the true number of births. To correct child mortality rates for the bias introduced by HIV, the IGME recommends that the under-five mortality rate derived from full birth

history data obtained from cross-sectional surveys should be divided by the calculated bias for each five-year period before the survey.

Although the model is simple to apply, the violation of the underlying assumptions of the model results in errors in the estimated bias. The model does not allow for differences in the survival of HIV-positive children, as it does not differentiate between the children infected intra-partum and through breastfeeding. This introduces errors in the calculated under-five deaths, resulting in an overestimation of the bias due to HIV. Also, considering that cohort studies are associated with small sample sizes, the results may not be nationally representative. This may render the cohort studies used by the model to obtain mortality schedules for HIV-positive children and HIV-positive women, inappropriate; thereby, introducing errors in the calculated bias.

In addition, the model is not appropriate for correcting child mortality estimates in countries with high coverage of antiretroviral therapy, as it does not allow for the impact of antiretroviral treatment.

2.6 Derivation of model life tables incorporating the impact of HIV/AIDS

The application of the summary birth history method, as mentioned previously, entails the conversion of the estimated mortality rates, $q(x)$, to a common childhood mortality measure, namely: infant and under-five mortality rates. Ward and Zaba (2008) point out that countries affected by the generalized HIV epidemic should use model life tables that incorporate the impact of HIV on the age pattern of mortality, in order to convert the estimated mortality rates, $q(x)$, into these common childhood mortality measures. Given that some countries affected by a generalized HIV epidemic, such as Zimbabwe, lack the data to provide complete life tables, there is a need to generate the full life tables that can be used with the summary birth history method.

The Spectrum system of policy model computer programs can be used to produce life tables for countries and regions affected by the generalised HIV epidemic. The component, called DemProj in the Spectrum suite, is used to make population projections for countries and regions in the absence of the HIV epidemic (Stover and Kirmeyer, 2008). The population projections in DemProj are based on the cohort component projection model for a specified period, up to a maximum of 150 years into the future. The cohort component projection model is given by the following formula:

$$ {}^{s}P_{x+n}^{t+n} = {}^{s}P_{x}^{t} \times {}^{s}S_{x}^{t} + {}^{s}M_{x}^{t}, $$

where ${}^{s}P_x^t$ represents the number of lives of sex s aged x last birthday at time t, ${}^{s}S_x^t$ represents the probability of a life of sex s aged x last birthday at time t surviving to time $t+n$ and ${}^{s}M_x^t$ represents the net number of in-migrants of sex s between time t and $t+n$ who survived to time $t+n$ and were aged $x+n$ last birthday.

To incorporate the demographic impact of the HIV epidemic into the population projection, the AIDS impact model in Spectrum, AIM, is used to project the impact of the HIV epidemic (Stover, 2009). The detailed descriptions of the computer programs, DemProj and AIM, are given by Stover and Kirmeyer (2008) and Stover (2009) respectively. AIM requires assumptions on the current and future course of adult, i.e. 15-49 years, HIV incidence rates. The computer package called Epidemic Projection Package (EPP), produced by the UNAIDS, is used to estimate the HIV prevalence and incidence of the population aged 15-49 based on the data from the sentential surveillance sites and the HIV prevalence surveys (UNAIDS Reference Group on Estimates Models and Projections, 2009).

The projected population in single years derived from DemProj, incorporating the impact of HIV, can be used to calculate the survival ratios for the population. These are a measure of the probability of survival of a birth cohort of sex s, from one age to the next, ${}^{s}S_x^t$. The survival ratios for single years of age x and for males and females combined, denoted as S_x, are calculated as follows:

$$S_x = \frac{P_{x+1}^{t+1}}{P_x^t}.$$

The calculated S_x is used to provide an approximation to the life table survival ratios, $\frac{L_{x+1}}{L_x}$, where L_x is the number of person-years lived between ages x and $x+1$, based on the assumption that the population is closed to international migration.

The estimated L_x for the ages x=1, 2, 3 and 4 are used to estimate the number of people surviving to the exact age x, l_x, out of the starting number, l_0, which can be assumed to be 1, using the mathematical model of mortality in infancy and childhood proposed by Blacker and Brass (2005). The curve of the life table survivors, l_x, is given as follows:

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

where α is a constant representing the level of mortality and β, is the shape of mortality. This function appears to be flexible enough to produce acceptable estimates for

situations where the prevalence of HIV varied from very low to very high. The method that was used to estimate α and β is outlined in section A of the Appendix.

The life table survivors from age five and above are calculated using the following formula by Preston, Heuviline and Guillot (2001):

$$ {}_nL_x = n(l_x - {}_nd_x) + {}_na_x \times {}_nd_x, $$

where n is the age interval, and in this case $n = 1$, ${}_na_x$ denotes the average number of person-years lived in the age interval by those who die in the age interval and it is assumed that deaths occur on average halfway through the interval, and ${}_nd_x$ denotes the number deaths between exact age x and $x + n$ (Preston, Heuviline and Guillot, 2001). Since the parameters of a life table are closely related, the ${}_nd_x$ in the above equation is replaced with $l_x - l_{x+n}$ and the equation is rearranged to give an equation that can be used to generate the life table l_x, values from age five and above, thereby generating full life tables for Zimbabwe that incorporate the impact of the HIV epidemic.

2.7 Trends in child mortality and the HIV epidemic in Zimbabwe

The measurement of child mortality in Zimbabwe is based on birth history data reported by women of reproductive age from the population census and household survey, since the vital registration is incomplete (Registrar General's Department and Central Statistical Office, 1994). Zimbabwe has conducted three population censuses since 1980 (post-colonial era): in 1982, 1992 and 2002, with intercensal demographic surveys (ICDS) in 1987, 1997 and 2008. In addition, the country has conducted a Reproductive Health Survey (ZRHS) in 1984, and four DHS surveys (ZDHS): in 1988, 1994, 1999 and 2005-2006.

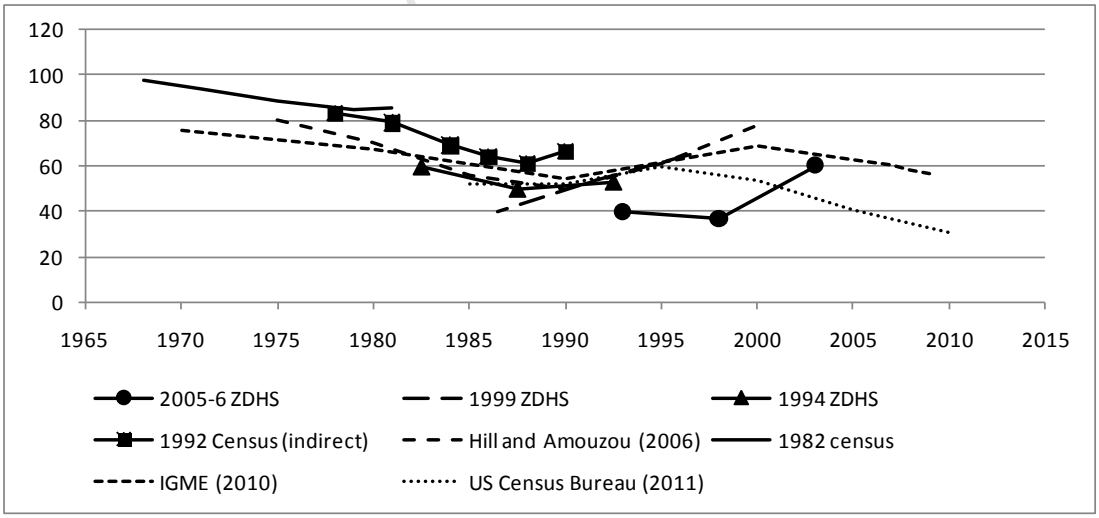
The country experienced declines in child mortality from the 1960s to the mid-1980s. Marindo and Hill (1997) reported that a significant decline occurred after the colonial era between 1980 and 1987. They attribute this to the rapid expansion of health services to the previously marginalised communities, access to education, and to general improvements in the standard of living. Zimbabwe had achieved relatively low levels of child mortality before the HIV epidemic took hold in the mid-1980s, placing it among countries with the lowest childhood mortality rates in Africa (Hill, 1993; Hill and Amouzou, 2006).

However, since the late 1980s, the downward trend in child mortality slowed down with the early 1990s showing a reversal in the child mortality trends. The reversal

in child mortality trends have been attributed mainly to the HIV epidemic (Korenromp, Arnold, Williams *et al.*, 2004; Marindo and Hill, 1997). However, Walker, Schwartlander and Bryce (2002) argue that HIV related mortality alone cannot completely explain the changes in child mortality trends in sub- Saharan Africa, which includes Zimbabwe. The reversal in child mortality trends in Zimbabwe coincides with the effects of the Economic and Structural Adjustment Programme (ESAP), which led to the reduction in government spending on health services, education and other public services, thereby negatively affecting child survival.

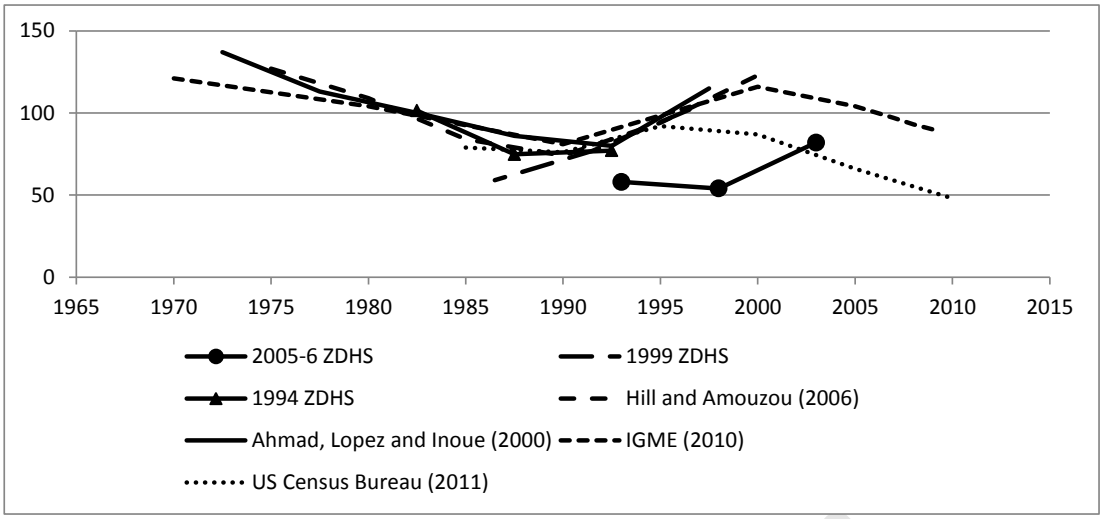
The lack of a vital registration system and information on the cause of death has resulted in the assessment of the impact of HIV infection on child mortality being based on either relatively small longitudinal surveys or models using more extensive population data and assumptions to produce HIV related mortality among children. These data have been used to derive the proportion of child mortality attributable to HIV. Zaba, Marston and Floyd (2003) estimated that proportion to have been approximately 50 per cent of the child mortality of Zimbabwe and Botswana between 1990 and 2001. This indicates that the HIV epidemic can significantly explain the reversal in the child mortality trend in Zimbabwe.

Figure 2.1 Infant mortality trends from different sources *(per 1,000 live births)*



Note: The 1982 census as reported by the Central Statistical Office (1992).

Figure 2.2 Under-five mortality trends from different sources *(per 1,000 live births)*



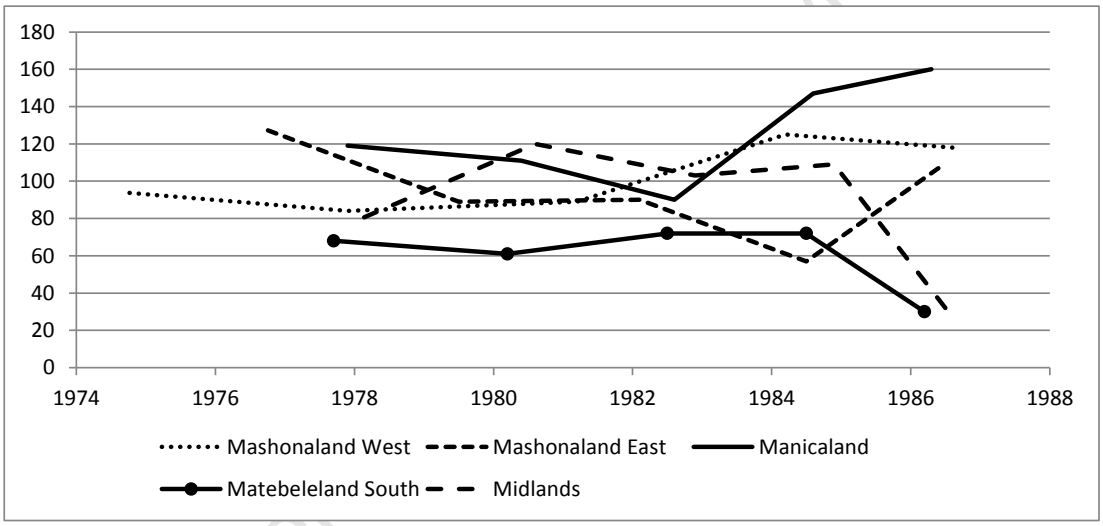
The infant and under-five mortality trends from the different sources of data and methods generally show a decline in childhood mortality prior to 1990, and a reversal of the mortality trends in the late 1990s. Figure 2.1 and Figure 2.2 above show that the 2005-6 ZDHS has lower levels of mortality than other sources, thereby indicating the significant underestimation of childhood mortality, which may be a result of the HIV/AIDS epidemic, as only surviving women are able to report on their birth histories at the date of the census or survey.

The IGME (2010) and US Census Bureau (2011) project a declining trend in infant and under-five mortality rates from 2000. This is consistent with the expected general decline in background mortality and the projected declining trend in HIV prevalence associated with efforts towards the prevention and treatment of HIV infections. The US census Bureau assume that HIV related mortality rates will decline to zero by 2070 (Bulatao, 2006).

It is important to note that child mortality in Zimbabwe varies between the country's ten provinces. The differentials in childhood mortality can be explained by the health services and socio-economic imbalances in the country, together with differences in the incidence and prevalence of diseases. However, Root (1997) attributed the observed variation in child mortality levels by province to differences in the population density. In the case of 2005-6 ZDHS, Manicaland province had the highest infant and under-five mortality rates, whilst Matabeleland South province had the lowest infant and under-five mortality rates, in the five years before the survey (Central Statistical Office and Macro International Inc, 2007).

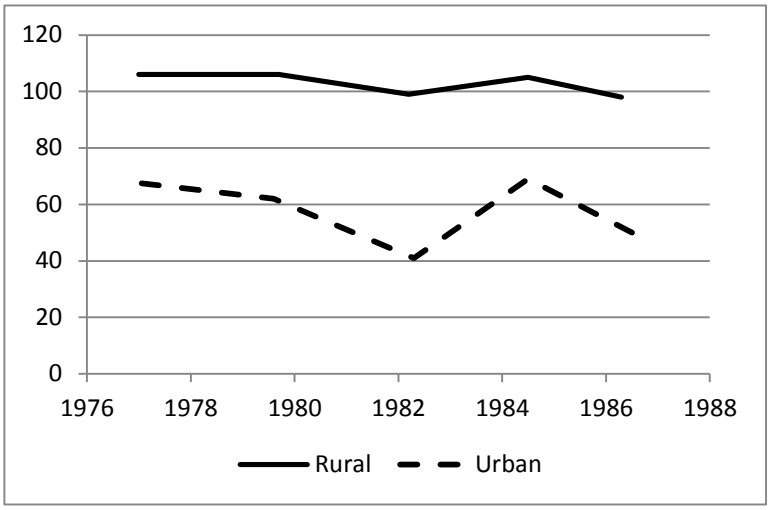
The preceding surveys and census reports also show that the Manicaland province generally has higher childhood mortality rates, compared with other provinces and national rates (Central Statistical Office, 1992). The rural areas of Zimbabwe have higher levels of child mortality than the urban population, with the 2002 Census reporting that IMR was 73 deaths per 1,000 in rural areas, compared with 55 deaths per 1,000 in urban areas, as at February 2002, if we assume that deaths occur uniformly in the 12 months before the census (Central Statistical Office, 2004a). Bah (1993) analysed the 1988 ZDHS and observed the following provincial, and rural and urban trends in under-five mortality:

Figure 2.3 Provincial under-five mortality trends from the ZDHS 1988 (per 1,000 live births)



Source: Derived from Bah (1993)

Figure 2.4 Residential under-five mortality trends from the ZDHS 1988 (per 1,000 live births)



Source: Derived from Bah (1993)

Zimbabwe has experienced one of the worst HIV/AIDS epidemics in sub-Saharan Africa. The HIV epidemic in Zimbabwe started in the late 1980s and it rose very quickly with the peak around 1997, when the HIV prevalence among adults aged 15-49 was more than 25 per cent (Ministry of Health and Child Welfare and National AIDS Council, 2004). The epidemic has since declined although the prevalence was still high, at 16 per cent in 2007 (Gregson, Gonese, Hallett *et al.*, 2010; Gregson, Terceira, Kakowa *et al.*, 2002; Halperin, Mugurungi, Hallett *et al.*, 2011). Gregson, Gonese, Hallett *et al.* (2010) point out that the substantial decline in HIV prevalence is a result of the reduction in HIV incidence associated with the changes in sexual behaviour and the saturation of infection among the high-risk groups as the epidemic matures. In addition, the decline in HIV prevalence is due to the high HIV-related mortality (Gregson, Gonese, Hallett *et al.*, 2010).

Research has shown that perinatal and intrapartum HIV infection is associated with significantly increased mortality in the first years of life (Spira, Lepage, Msellati; *et al.*, 1999). Zijenah, Mbizvo, Kasule *et al.* (1998) used the longitudinal survey data from Harare, 1991 to 1995, to observe that mortality among infants born to HIV-infected women was 19.6 per cent, compared with 5.4 per cent among infants of uninfected mothers. The results are consistent with those of other studies in African countries affected by the generalised HIV epidemic.

The ZDHS (2005-6) reported that 98 per cent of children under-five years are breastfed with a median duration of breastfeeding of 18.8 months. Considering the high HIV prevalence in Zimbabwe, the breastfeeding pattern increases the exposure to HIV infection of children born to HIV-positive women. Zimbabwe has experienced a significant increase in the mortality of women, due to the HIV/AIDS epidemic in the 1990s (Bicego, Boerma and Ronsmans, 2002). Since maternal death negatively affects child survival, the high mortality risks experienced by HIV positive women indirectly contribute to the observed increases in childhood mortality in Zimbabwe (Kurewa, Gumbo, Munjoma *et al.*, 2010).

Given the high levels of HIV prevalence, the high mortality risks associated with paediatric HIV infection and the indirect impact of maternal HIV-related deaths on child survival, it is logical to conclude that the epidemic significantly accounts for the reversal in child mortality trends in Zimbabwe. The significant correlation between the mortality of mothers and their children, due to HIV, results in the under-estimation of

the implied increase in child mortality owing to the absence of deceased women at the time of the census or the survey.

Hence, the need to estimate the extent of bias in child mortality estimates attributable to the HIV/AIDS epidemic, in order to provide more accurate estimates from which the trends in childhood mortality can be assessed.

3. DATA AND METHODS

This chapter presents a description of the data used in this dissertation and an evaluation of their quality. Thereafter, the chapter provides the methods that are applied to estimate the extent of bias in the summary birth history method of estimating childhood mortality.

3.1 Source of the data

The research is based on data taken from the longitudinal survey of the Manicaland HIV/STD Prevention study in Zimbabwe conducted between 1998 and 2005. The Manicaland survey is one of the few longitudinal surveys that collect birth history data from adult females. The Manicaland HIV/STD Prevention study is sponsored by the Wellcome Trust and UNAIDS (Gregson, 2008). It is a long-term study of the HIV epidemiology with the collaboration of the Imperial College, London, the Ministry of Health and Child Welfare of Zimbabwe, and the London School of Economics.

The objectives of the Manicaland HIV/STD Prevention study include the measurement of the trends in HIV prevalence, HIV incidence, AIDS mortality and the socio-demographic effects of the HIV/AIDS epidemic from a sample of the eastern population of Zimbabwe (Gregson, 2008). The study seeks to explain the major factors that contribute to the spread of the HIV infection and the effects of the HIV/AIDS epidemic in the population. In addition, the study provides data for the monitoring and evaluation of the effectiveness of HIV prevention and treatment programmes.

The research findings from the survey have contributed to the formulation and the implementation of policy on HIV/AIDS at local, national and international levels. Approximately, 10,000 adult men and women have participated at each round of the longitudinal survey (Gregson, 2008).

3.2 Background of the Manicaland province

The Manicaland province is located in the eastern part of Zimbabwe on the border with Mozambique. It had a total population of 1,568,903 people out of the Zimbabwean population of 11,634,664, as at 17/18 August 2002 (Central Statistical Office, 2004a). The province is largely rural, with 80 per cent of the population residing in rural areas in 2002 (Central Statistical Office, 2004b). Given the large proportion of the population in the rural areas, the main economic activities are subsistence farming and employment on commercial farms. The province is subdivided into nine census districts with the Mutare

Urban district constituting 75 per cent of the provincial urban population (Central Statistical Office, 2004b). The population of Manicaland is young, with 44 per cent being under the age of 15 at the 2002 population census(Central Statistical Office, 2004b).

3.3 Study population

The longitudinal survey was conducted in 12 sites covering the four socio-economic classes of the Manicaland province. These are: subsistence farming communities, small towns, large-scale commercial tea, forestry, and coffee estates, and roadside trading centres (Gregson, 2008). The sites include four subsistence-farming areas, four large-scale tea, coffee and forestry estates, two roadside trading settlements and two small towns. These were all selected from the Mutasa, Makoni and Nyanga districts.

The first round (baseline census) of the survey consisted of a random sample of adult household residents recruited between July 1998 and February 2000 (Gregson, Garnett, Nyamukapa *et al.*, 2006). Members who had slept in the household for at least four nights in the previous month, and were staying in the same household at the same time a year prior to the baseline census, were eligible for recruitment into the survey. For married couples, the selection criteria was restricted to one member per couple (Gregson, Garnett, Nyamukapa *et al.*, 2006). The baseline census was conducted in a phased manner, i.e. the survey was carried out in one site at each point in time (Hallet, Gregson, Kurwa *et al.*, 2010).

The first follow-up survey (Round 2) was conducted three years later, between July 2001 and February 2003. The cohort in the follow-up survey consisted of all baseline respondents, household members who had not been included in the baseline survey because of age restrictions, i.e. being under the age 15 for females and 17 for males, but was now eligible. The individuals who were present, but failed to meet the residence criteria set at the baseline census were also included (Gregson, Garnett, Nyamukapa *et al.*, 2006).

The restriction of one member per married couple was maintained. However, individuals who had migrated into the study sites in the inter-survey period were considered only in seven of the 12 sites due to financial constraints (Gregson, Garnett, Nyamukapa *et al.*, 2006).

A further follow-up survey (Round 3) was conducted between July 2003 and June 2005, using Round 2 recruitment criteria. However, the restriction of one member per married couple was relaxed and immigrants were considered for recruitment at all the

survey sites (Gregson, Garnett, Nyamukapa *et al.*, 2006). This resulted in a large sample of women in Round 3, from whom birth history data were collected.

At each round of the longitudinal survey, a questionnaire was administered to the members of the open cohort to collect data on the individual's sexual behaviour, demographic and socio-economic background (Lopman, Barnabas, Hallet *et al.*, 2006). The baseline census collected, *inter alia*, data on summary birth and full birth histories from all the respondents. The subsequent rounds of the survey collected full birth history data on new births since the previous round from follow-up respondents, i.e. those who were previously interviewed. Summary birth and full birth histories were collected from new respondents in the subsequent rounds of the survey.

The two follow-up surveys collected data on deceased cohort members through verbal autopsy interviews with caregivers of the cohort members (Hallet, Gregson, Kurwa *et al.*, 2010). With respect to birth history information, the verbal autopsy interview collected full birth history data on births that had occurred between the last round of the survey and the date of death of the cohort member. The verbal autopsy interview also collected data on the survival status of the children under the age of 16, born before the last survey with the deceased cohort member (partial birth history).

Of the households identified in the survey sites, 98 per cent, 94 per cent and 96 per cent were enumerated at baseline census and the subsequent rounds, respectively (Hallet, Gregson, Kurwa *et al.*, 2010). The participation rates of women were 80 per cent, 81 per cent and 87 per cent at the baseline census and the subsequent surveys, respectively. Sixty per cent of the women interviewed at the baseline census and 65 per cent at the first follow up were re-interviewed in the follow up surveys (Gregson, Garnett, Nyamukapa *et al.*, 2006).

The main reason for failure to follow up was out migration, attributable to the Zimbabwe land resettlement programme in 2000 and the decline of the formal sector economy, which significantly changed the employment patterns of the population.

The following data fields were provided:

1. From the individual questionnaire for female respondents only
   i. Date of interview for each questionnaire
   ii. Date of birth
   iii. Age last birthday
   iv. Fertility histories.
2. From the verbal autopsy questionnaire on deceased women only
   i. Date of interview for each questionnaire

ii. Birth histories of children born before the baseline survey
iii. Birth histories of children born since the last survey.

3. Household census dataset with a listing of every usual member of the household and visitors, their ages, gender, survival status and ages at death for deceased members.

3.4 Data quality

Evaluation of the quality of the data from birth histories is an important component of child mortality measurement and as such, the estimation of the bias due to HIV because the estimates of the levels and trends depend on the accuracy and completeness of reporting by the respondents. The potential errors in birth history data include omission of births and deaths, misreporting of dates of birth for the mothers and their children, and the dates of death for the deceased children (Ewbank, 1982; Potter, 1977; Rutstein and Rojas, 2003).

The omission of births and deaths and errors due to the misreporting of dates and ages will be investigated in the longitudinal survey datasets. The accuracy and completeness of reporting will also be assessed.

3.4.1 Omission of births

Generally, there is a tendency to omit children who have died, children who have moved away, illegitimate children, infants and females in societies with a strong preference for male children (Potter, 1977). The selective omission of birth history data for deceased children results in the underestimation of childhood mortality rates and vice versa. In addition, the effects of birth history omissions depend on their distribution by age and period (Potter, 1977). The omission of birth history data for very young children by all women results in the underestimation or overestimation of child mortality rates in the most recent period.

3.4.1.1 The average parities of women

Analysing the relationship between the average parity of women according to the age group of the mother, is a tool that can be used to detect large-scale omission of births in birth history data (Arnold, 1990). If fertility is constant over time, the average parities would be expected to increase with age as older women are expected to have had more children. Although fertility has been falling in Zimbabwe, the average parities of women of reproductive age still increase with age (Muhwava and Timaeus, 1996). The average parities of women aged between 15 and 49 at the third round of the longitudinal survey

in Table 3.1 increase with age to a similar extent; hence, we can be reasonably sure that there has not been significant omission of births.

Table 3.1 Average Parities of women, 15-49 years

Age group of women	15-19	20-24	25-29	30-34	35-39	40-44	45-49
Average Parity	0.1	1.1	2.1	2.7	3.3	3.9	4.3

3.4.1.2 Sex ratios of children ever born to women aged 15-49

The examination of sex ratios is generally used to determine whether there is a sex selective omission of births in the birth history data. The sex ratio at birth is calculated as the number of male per 100 female live births, and it is expected to be stable across women of reproductive age (United Nations, 1983). Since the women are expected to report their children ever born, irrespective of their survival status, it is expected that the reported sex ratios behave in a similar fashion to the sex ratio at birth unless there is sex selective omission of the children ever born.

The populations in eastern and southern Africa have a sex ratio at birth that is close to one (Garenne, 2004). The sex ratios at the third round of the survey are generally stable, with the overall sex ratio being 98 males per 100 females, which is consistent with what is expected. However, the sex ratio of the children born to women aged 35-39 is lower than the expected, and this could be the result of random fluctuations, as the sample size is relatively small.

Table 3.2 Sex ratios of the children ever born to women, 15-49 years

Age group of women	15-19	20-24	25-29	30-34	35-39	40-44	45-49	Overall
Sex Ratio	1.03	1.02	0.98	0.98	0.94	0.98	0.99	0.98

3.4.1.3 Omission of deceased children

The omission of children who die soon after birth is investigated through a comparison of the levels of neonatal mortality and those of infant mortality. Childhood mortality is characterised by a sharp decline in the first few days and weeks of life and thereafter, declines less sharply through late infancy and early childhood. Generally, children who die soon after birth are most likely to be omitted from birth histories resulting in a low ratio (Sullivan, Rutstein and Bicego, 1994). Table 3.3 shows the neonatal and infant mortality rates, as well as the ratio of neonatal to infant mortality rate at the third round of the longitudinal survey. The ratios are relatively high, indicating that there is no evidence of significant underreporting of deaths.

Table 3.3 Ratio of neonatal mortality to infant mortality

	Period before the survey (years)			
	0-2	0-4	5-9	7-12
Neonatal mortality rate (per 1000 live births)	38.1	34.4	21.2	21.8
Infant mortality rate (per 1000 live births)	45.1	42.4	26.6	31.9
Ratio	0.84	0.81	0.80	0.68

3.4.2 Age last birthday of women 15-49 years

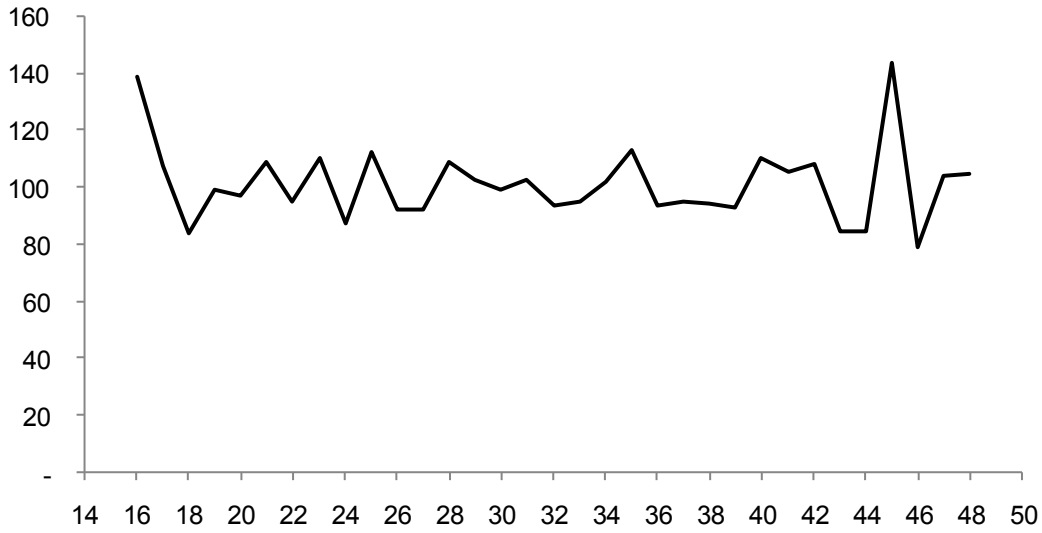
The misreporting of ages and dates of birth for women affects child mortality estimation as the selection criteria for birth history data collection is premised on the age of the respondent. Research by Rutstein and Bicego (1990) has shown significant exclusion of women at the boundary age groups 15-19 and 45-49. The age reporting of women is associated with heaping at ages ending with zero or five, and younger women's ages are generally more accurate than the ages of older women (Pullum, 2006). Inaccurate ages for women will introduce errors into the summary birth history mortality estimates, as the data on the numbers of children ever born and those surviving are classified according to the age group of the mother.

As shown in Figure 3.1, the percentage distribution of women at the third round of the survey by single years reveals some irregularities in the age reporting of women. The low percentage of 15 year-old women indicates the exclusion of women at this boundary age. There is evidence of a preference for ages ending with five, as shown by heaping at 25, 35 and 45 years.

The age ratios were calculated on the assumption that the number of people progress linearly with age (Shyrock, Siegel and Associates, 1980). An age ratio of 100 is expected, and a ratio greater than 100 indicates heaping while a ratio of less than 100 indicates the avoidance of particular ages. The plot of age ratios in Figure 3.2, shows evidence of heaping at the ages identified in the percentage distributions, as well as heaping at 16, 21 and 40 years indicating the misreporting of ages by women at the third round of the longitudinal survey.

Figure 3.1 Per cent distribution of the age at last birthday of women, 15-49 years

Figure 3.2 Age ratios of the age at last birthday of women, 15-49 years



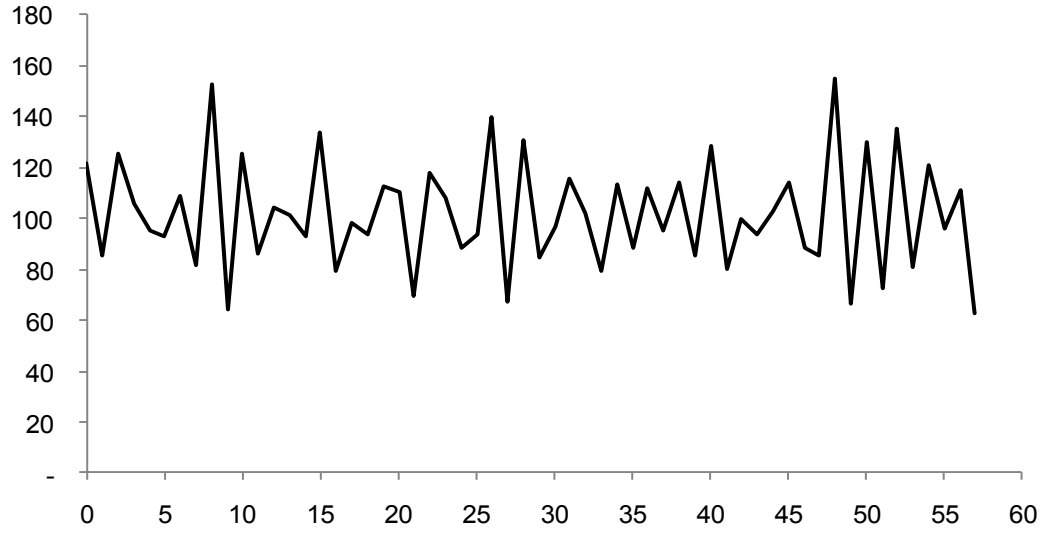
3.4.3 Reporting of ages of the children

The misreporting of the ages and dates of children's births could significantly distort the calculated number of deaths and the person years of exposure resulting in inaccurate age specific mortality rates. Full birth history data are generally affected by heaping at 12 months, and to a lesser extent at six months and 18 months (Pullum, 2006; Rutstein and Rojas, 2003). Errors in the reporting of dates of births of children could result in the transference of births between reference periods, resulting in underestimation or overestimation of the period mortality rates (Arnold, 1990).

The erratic fluctuations in the age ratios of the surviving children, as shown in Figure 3.3, suggest the misreporting of the ages of the children. There is significant age heaping at 9, 27 and 49, months and an avoidance of ages 10, 28 and 48 months.

However, the misreporting of ages does not follow a particular pattern suggesting that these may be random fluctuations due to the relatively small sample size and hence, may not result in the displacement of births between the age segments and the period mortality rates.

Figure 3.3 Age ratios for the children 0 to 59 months



The misreporting of the age at death among deceased children was not investigated in the study as the survey collected the age at death in months for the children aged 12 months and below. Thus, it does not allow for a reasonable assessment of the reported childhood ages at death in months, from 0 months to 59 months.

3.4.4 The accuracy and completeness of reporting

The assessment of the accuracy of reporting of the births to surviving women was performed by comparison of the proportion of children surviving among the children ever born. The data were derived from the summary birth history data (SBH), on the one hand and from data constructed from complete full birth histories (complete FBH) on the other. The proportion of children surviving derived from partial birth history data (partial FBH) of the surviving women were calculated and compared with those of the complete birth history data. Table 3.4 shows the proportion of children surviving and the percentage difference between the two sources.

The results show that there is consistency in the reporting of births by women as the percentage differences between the proportions of children surviving derived from the summary and complete full birth history data are negligible. The percentage differences in the proportions derived from the complete and partial full birth history

data are not significant, except for the children born to women in the oldest age group. This is to be expected, as more of the children born to women aged 45-49 are likely to be older than 16 years, but were not included in the partial birth histories, resulting in a significant difference.

Table 3.4 Proportion of children surviving among the children ever born derived from the summary and full birth history data and their differences

	Proportion of children surviving			Percentage difference (%)	
Age group of women	SBH	Complete FBH	Partial FBH	SBH and complete FBH	Complete FBH and partial FBH
15-19	0.904	0.909	0.908	-0.5	-0.4
20-24	0.956	0.958	0.958	-0.2	-0.2
25-29	0.942	0.943	0.943	-0.2	-0.1
30-34	0.940	0.947	0.946	-0.7	-0.7
35-39	0.941	0.947	0.936	-0.5	0.6
40-44	0.941	0.946	0.915	-0.6	2.7
45-49	0.926	0.934	0.847	-0.8	8.5

It is worth noting that the birth history data on the children born to deceased women had a higher proportion with unspecified or unknown year of birth, 4.4 per cent compared with 1.2 per cent for the children born to surviving women. Of the children who died, 15.6 and 5.7 per cent of the children born to women who died and survived had unspecified or unknown ages at death, respectively. These were proportionately distributed, based on the assumption that the distribution of deaths with unspecified or unknown ages at death was the same as the ages of reported deaths.

3.4.5 The effects of data quality on data analysis

An investigation of the data quality above reveals that the retrospective data collected in the longitudinal survey have some of the errors commonly associated with birth history data, such as the misreporting of ages of the surviving children and the misreporting of the ages of the mothers. However, the errors identified are not so large as to nullify the datasets for use in the estimation of childhood mortality, and hence, the extent of bias due to HIV, although the effects should be considered when interpreting the results.

The assessment of the quality of the birth history data collected in the verbal autopsy interviews was not performed, because the sample size was too small. This could result in some random fluctuations which could lead to spurious conclusions on the quality of the birth history data of the children born to women who died.

3.5 Methods of estimating childhood mortality and the bias due to HIV

This section looks at the direct and indirect methods for estimating child mortality that are applied to the Manicaland longitudinal survey data. Thereafter, the section describes the method of estimating the extent of bias in the child mortality rates derived from the summary birth history method attributable to the HIV epidemic. Lastly, the method that was used to estimate the bias in childhood mortality estimates derived from the summary birth history data using the Ward and Zaba model is described.

3.5.1 Direct childhood mortality rates corrected for the impact of HIV

The full birth history data from the third round of the survey for children born to surviving women and the full birth history data from the verbal autopsy interviews for children born to deceased women were used directly to produce infant and under-five mortality rates, as described below. The initial step was to reproduce the estimates of Hallett, Gregson, Kurwa *et al.* (2010) to ensure that the datasets received and the method of correcting the estimates derived directly for the impact of HIV are consistent with the published results.

Considerable difficulties were encountered in attempting to match the data that were published, requiring several corrections of the dataset originally provided.

The synthetic cohort life table approach similar to that applied to DHS surveys, was used to calculate uncorrected infant and under-five mortality rates for children born to surviving women in the five years before the survey. The SPSS program published by the Measure DHS was converted into STATA 11 code, to derive the numbers of deaths and person-years of exposure for each age segment, in order to obtain the direct estimates of childhood mortality of the children born to surviving women. This code was checked using data from the Zimbabwe 2005-06 DHS.

This code was applied to the full birth history data collected in the verbal autopsy interviews at the second and third rounds of the longitudinal survey to obtain the infant and under-five mortality rates for the children born to women who died in the five-year period before the third round survey.

The corrected mortality rates were calculated by combining the experience of the children born to surviving women with those of the children born to deceased women allowing for the recruitment of women into the open cohort and potential loss to follow up among the women who died (Hallet, Gregson, Kurwa *et al.*, 2010). The corrected rates were derived as a weighted average of the births to surviving and deceased women in the five years before the survey. The bias in the direct estimates attributable to the non-survival of women due to HIV related mortality was then calculated as the

percentage difference between the mortality rates of the children born to all women and of the children born to surviving women. The corrected mortality rates are regarded as the "true" levels of the infant mortality, $q^t(1)$, and the under-five mortality, $q^t(5)$.

Table 3.5 shows the childhood mortality estimates in the five years before the survey and the bias in the estimates as published, labelled "Reported" and those derived in the current research, labelled "Calculated".

Table 3.5 Direct estimates of infant and under-five mortality rates and their bias due to the non-survival of women attributable to the HIV epidemic

	Surviving mothers		Deceased mothers		All mothers		Bias %	
	Reported	Calculated	Reported	Calculated	Reported	Calculated	Reported	Calculated
IMR (per 1,000 live births)	45.9	42.4	146.8	141.8	49.0	45.5	6.7%	7.2%
U5MR (per 1,000 live births)	67.1	65.7	283.8	279.6	73.7	72.3	9.8%	10.1%
Number of births in the past five years	5,325	5,393	167	172	5492	5565	N/A	N/A
Number of women 15-49, 2003-2005	10,315	10,331	1,253	1,268	N/A	N/A	N/A	N/A

Source of the reported estimates: Hallett, Gregson, Kurwa *et al.* (2010)

The differences in the estimates of childhood mortality and of the bias are not considered to be significant, indicating that the available data closely match those used in the paper and that the method has been adequately replicated. The discrepancies in the number of births and women shown are considered to emanate from editing changes made to the database during data cleaning done after the publication of the paper. These, in turn, explain the differences in the calculated rates (personal communication with Professor Gregson, 2011). The same method was then applied to derive $q^t(1)$ and $q^t(5)$ for the periods 0-2, 5-9 and 7-12 years before the third round of the survey.

Since the direct estimates apply for a specified interval, to allow for comparison with the summary birth history mortality estimates, it was assumed that the estimates apply at the mid-point of the interval. The mid-points were used to approximate the dates at which the direct estimates apply. Linear interpolation was then used to produce the $q^t(1)$ and $q^t(5)$ at times consistent with those estimated for the summary birth history estimates, $t(i)$. The non-standard period, 7-12 years was selected because there were too few events in the 10-14 years for the women who died, making the rates from the 10-14 period relatively unstable. This may be due to the procedure that was applied

in the verbal autopsy interviews where data on children under the age of 16 were collected; and the low numbers suggest that some children who were closer to this age limit could have been missed. Since the goal was to obtain a corrected estimate, which was consistent with the summary birth history estimate derived from the data on the children born to women aged 35-39, this period was selected as the reference date was close to that of the summary birth history estimate, thereby allowing for interpolation.

3.5.2 Estimating child mortality using the summary birth history estimation technique

The estimation of childhood mortality using Brass's summary birth history method requires data on the number of women of reproductive age 15-49, classified by five-year age groups. In addition, the method requires data on the total number of children ever born and children surviving, tabulated by the five-year age group of the mother, i =1, 2, …, 7. These data were extracted from the STATA file with the summary birth history data for surviving women at the third round of the longitudinal survey (the raw data as extracted are presented in Table B1). These data were used to derive the proportions of children surviving among those ever born by age group of the mother, denoted as $S(i)$, and the average parities for the women, $P(i)$.

The mid-point of the data collection at the third round of the longitudinal survey was expressed in years, in order to obtain the reference date of the survey.

The Trussell version of Brass's summary birth history method was used to convert the proportions of the deceased children, $D(i)$, calculated as 1- $S(i)$, into the life table probabilities of dying between birth and exact childhood age x, $q_i(x)$, and the time location, $t(i)$, to which the $q_i(x)$ apply. The Trussell coefficients from the Princeton North model life table were used, as it has been observed that Princeton North family best fit the mortality experience of most African countries; and, hence is probably appropriate for the Manicaland province of Zimbabwe (Brass and Coale, 1968; Hill, 1993; United Nations, 1992).

The North family is characterised by relatively low infant mortality and relatively high levels of mortality between one and five years (Brass and Coale, 1968).

To derive the common measures of childhood mortality, namely, the infant mortality rate, $q_i(1)$, and the under-five mortality rate, $q_i(5)$, the Brass logit relational transformation with one parameter, i.e. with the shape parameter β=1, was used with the Princeton North model life table level 20 as the standard. The North family level 20 was selected because it is relatively close to the observed mortality estimate, $q_i(5)$, for

the women aged 30-34. The sex ratio at birth of 102 male per 100 female live births was used to obtain the combined the life table probability of survival from birth to age x, l_x, for males and females from the North family.

3.5.3 Comparison of the direct and indirect mortality rates not corrected for the impact of HIV

Since the estimation of the overall bias in the summary birth history method is premised on the basis that the direct childhood mortality rates, corrected for the impact of HIV, are the "true" rates, it was necessary to compare the summary birth history method and direct estimates before adjustments for the impact of HIV. The comparison of the two sets of estimates gives an indication of the relative bias due to the different methods and possibly the data, found in other studies before the era of the HIV epidemic. The comparison of the estimates before the adjustments for the impact of HIV was done by plotting of the infant and under-five mortality rates derived from the two methods.

3.5.4 Estimation of the bias in the summary birth history method attributable to HIV/AIDS

The overall bias in the childhood mortality rates derived from the summary birth history method introduced by the HIV epidemic consists of a combination of biases emanating from the increased correlation between the mortality of mothers and their children, the use of non-HIV model life tables to convert the $q_i(x)$ to $q_i(1)$ and $q_i(5)$ and the regression coefficients to convert the $D(i)$ to $q_i(x)$, and the time to which the estimates apply. The overall bias in the infant and under-five mortality rates was calculated as follows: $\frac{q_i(1)}{q_i^c(1)} - 1$ and $\frac{q_i(5)}{q_i^c(5)} - 1$ respectively, at time $t(i)$.

Although the estimates of the contribution of the various component biases to the overall bias depend on the order in which they are accounted for, this effect will be ignored.

3.5.4.1 Quantification of the bias induced by HIV-related mortality among women in the summary birth history method

To estimate the bias in the summary birth history method due to the increased correlation between maternal and child mortality as a result of the impact of HIV, the proportions of children surviving, corrected for the survival of children of mothers who died of HIV, denoted as $S^c(i)$, are calculated as described below.

The summary birth history data of the children born to surviving women at the third round of the longitudinal survey were used to derive the proportions of children

surviving among those ever born by five-year age groups of the women of reproductive age.

The full birth history data from the verbal autopsy interviews on the survival of children born to deceased cohort members who would have been between 15 and 49 years at the third round of the longitudinal survey were used to construct the summary birth history data (presented in Table B2). These data are used to calculate the proportions of children surviving among those ever born, of the children born to deceased women.

The corrected proportions of the children surviving among the children ever born, $S^c(i)$, are the calculated as the weighted average of the proportions of the children born to surviving women and those born to deceased women. The standard application of the summary birth history method in section 3.5.2 to the $S^c(i)$, results in infant and under-five mortality rates corrected for the bias attributable to the impact of HIV on the mortality of mothers and their children, and these are denoted as $q_i^c(1)$ and $q_i^c(5)$, respectively. The bias in the infant and under-five mortality rates derived from the summary birth history method due to the increased correlation between the mortality of mothers and their children due to HIV was then calculated as $\frac{s(i)}{s^c(i)} - 1$.

3.5.4.2 Quantification of the bias due to the regression coefficients for converting, $D(i)$ to $q(x)$, and the time to which the estimates apply, $t(i)$

The regression coefficients used to convert the proportions of children dead among those ever born, $D(i)$, to the childhood mortality rates, $q_i(x)$, and the time to which the estimates apply, $t(i)$, were derived using fertility and mortality schedules in the absence of the HIV. This could bias the estimates of childhood mortality in countries affected by the HIV epidemic, as it affects the age pattern of both the fertility and mortality. Assuming that the bias, due to the non-survival of women in the proportion of children dead, $\mathrm{D(i)}$, is the same as that in the childhood mortality estimate, $\mathrm{q(x)}$, then the comparison of this bias gives an indication of the relative bias due to the regression coefficients. Therefore, the difference estimates the extent of bias introduced by the regression coefficients.

3.5.4.3 Quantification of the bias due to the use of a non-HIV model life table for converting $q(x)$ to $q(1)$ and $q(5)$

Since Zimbabwe has been significantly affected by the HIV epidemic, it may be desirable to estimate the infant and under-five mortality rates using model life tables that

incorporate the impact of the HIV epidemic on the age pattern of mortality. The full life tables for Zimbabwe generated from the Spectrum model were used to convert the childhood mortality estimates corrected for the non-survival of infected mothers, $q_i^c(x)$, to infant and under-five mortality rates, denoted as $q_i^{c+m}(1)$ and $q_i^{c+m}(5)$, respectively. The default assumptions in the Spectrum model from the United Nations World Population Prospects 2008 were used to project the population for Zimbabwe in the absence of the HIV epidemic from 1970 to 2015 (Stover and Kirmeyer, 2008) with international migration set to zero to allow for the estimation of the survival ratios. The AIM component was used to incorporate the impact of AIDS mortality into the population projection for Zimbabwe. The input data into the AIM model on adult HIV incidence was derived from the national curve for Zimbabwe fitted using the Estimation and Projection Package (EPP) using available data from sentinel surveillance sites from 1989 to 2009, and the 2005 household HIV prevalence survey[2]. Assumptions on the current and future coverage of anti-retroviral therapy and the prevention of mother-to child-transmission, (PMTCT), were based on the available data from sentinel surveillance sites from 2004 (personal communication with Professor Dorrington, 2011).

The output from DemProj on the projected population for each age from zero to 80+, and the number of births in single years were extracted and used to generate the life tables for Zimbabwe from 1991 to 2004. The mathematical formulae described in section 2.6 were used to derive the survival ratios for single years of age, x, for males and females combined, S_x, the approximation to the number of person-years lived between ages x and $x+1$, L_x, and thereafter the estimate of the number of people surviving to exact age x, l_x, out of the starting number l_0=1. The life table survivors, l_x, generated for Zimbabwe that incorporate the impact of the HIV epidemic up to age 20 are given in Table B3 of the Appendix.

The $q_i^{c+m}(1)$ and $q_i^{c+m}(5)$ were calculated, using the life table for 1999 as it is on average representative of the time reference to which the infant and under-five mortality rates apply. It is worth noting that the 1999 life table incorporates the impact of HIV on the age pattern of mortality among children, as the number of HIV deaths for children aged zero to 14 years in the AIM model reached its peak in 2000. The estimate of the bias in the summary birth history method attributable to the use of a

[2] Assisted by Professor Dorrington to obtain the estimates of HIV prevalence from the sentinel surveillance sites and the 2005 HIV prevalence survey in Zimbabwe.

non-HIV model life table to convert the $q_i(x)$ to infant and under-five mortality rates, was calculated as $\frac{q_i^c(1)}{q_i^{c+m}(1)} - 1$ and $\frac{q_i^c(5)}{q_i^{c+m}(5)} - 1$, respectively.

To compare the model life tables used to convert the $q(x)$ to $q(1)$ and $q(5)$, the time series of the fitted model life tables that are used to derive the implied childhood mortality trends were derived. The mean absolute deviation between the observed childhood mortality rates, $q(x)$, and the fitted rates at each time point was calculated using the following formula:

$$\text{Mean absolute deviation} = \frac{\sum \left| 1 - {}_nq_x(fitted) \Big/ {}_nq_x(observed) \right|}{N},$$

where *N* is the number of age groups (Murray, Ahmad, Lopez *et al.*, 2000). The model life table (the Princeton North family or the generated life table) that produce lower mean absolute deviations provide a better fit for the observed data compared with the other.

Finally, the estimated overall bias in childhood mortality estimates derived from the summary birth history method was compared with the sum of the component biases.

3.5.5 Estimating bias in indirect childhood mortality rates using the Ward and Zaba model

The extended regression coefficients of Ward and Zaba (2008) are used to calculate the correction factors, $n(z)$, for correcting child mortality estimates from the summary birth history method for the impact of HIV/AIDS. The bias in the model is calculated as $\frac{q^e(z)}{q^e(z) + n(z)} - 1$, where $q^e(z)$ is derived from the standard application of the summary birth history. Computation of the correction factors is based on the assumption that the HIV prevalence has been constant over time. However, changes in the HIV epidemic, and hence, the prevalence has been observed in Zimbabwe and other countries affected by the epidemic.

The HIV prevalence in the study population at the base line census (July 1998 to January 2002), estimated to be 7 per cent and 25.5 per cent for women aged 15-19 and 15-44, respectively, was used assuming that these prevalence rates were constant over time (Gregson, Terceira, Kakowa *et al.*, 2002). The prevalence of women aged 15-44 was used as a proxy for the prevalence of women aged 15-49. In general, the prevalence of women aged 15-49 can be expected to be lower than that of women 15-44, in a stable

epidemic, due to the effect of HIV related mortality among older women. The effect of this assumption is small because the small changes in the HIV prevalence have a negligible effect on the estimates of the bias in the summary birth history method derived from the Ward and Zaba model.

The bias of the women in the sixth and seventh age group was not calculated because the assumption that prevalence has remained constant is patently not applicable for these older women and, in addition, the model does not allow for the effect of the older children becoming infected themselves later in life.

The average of the infant and under-five overall and aggregate bias in childhood mortality derived from the comparison of the estimates derived from the summary and full birth history data were compared with that derived from the Ward and Zaba model to see what could be learnt.

4. RESULTS

This chapter presents the childhood mortality estimates and their bias attributable to the HIV epidemic obtained from the analysis of the Manicaland longitudinal survey data for the period from 1998 to 2005. The last section provides a comparison of the bias in the summary birth history estimates due to the impact of HIV according to the Ward and Zaba model and the estimated overall and aggregate bias, based on the assumption that the prevalence of HIV has remained stable at current levels.

4.1 Direct childhood mortality rates corrected for the impact of HIV

The direct estimates of childhood mortality for the Manicaland province were estimated for the period from 1995 to 2003. The direct estimates of infant and under-five mortality corrected for the correlation between the mortality of the mothers and their children, (all mothers), due to the HIV epidemic are shown in Table 4.1 and Table 4.2, respectively. The trends indicate higher mortality in the most recent years, consistent with the impact of the HIV epidemic observed in Zimbabwe.

Table 4.1 Direct estimates of infant mortality corrected for HIV (All mothers)

Infant mortality rate (per 1000 live births)	Surviving mothers	Deceased mothers	All mothers	Bias %	Reference date
0-2 years before the survey	45.1	127.9	46.2	-2	2003
0-4 years before the survey	42.4	141.8	45.5	-7	2002
5-9 years before the survey	26.6	110.5	37.9	-30	1997
7-12 years before the survey	31.9	34.5	32.4	-2	1995

Table 4.2 Direct estimates of under-five mortality corrected for HIV (All mothers)

Under-five mortality rate (per 1000 live births)	Surviving mothers	Deceased mothers	All mothers	Bias %	Reference date
0-2 years before the survey	69.8	221.5	71.9	-3	2003
0-4 years before the survey	65.7	279.6	72.3	-9	2002
5-9 years before the survey	43.1	145.0	56.8	-24	1997
7-12 years before the survey	49.9	62.5	52.4	-5	1995

The significantly higher mortality rates associated with children born to deceased women reflects the higher correlation between child survival and maternal death, a characteristic of the HIV epidemic. The observed increase in the bias with the number of years before the survey (at least up until 5-9 years) indicates the increase in the under-representation of children born to HIV-infected women who would have experienced

higher mortality risks, as their mothers are increasingly likely to die before the survey. While it is reasonable to expect the bias to increase the further back in time one goes (at least up to a point), the dramatic increase from the 0-4 to 5-9 years before the survey could possibly indicate that the later estimates are unreliable. This could be as a result of the random fluctuations due to the relatively small sample size. It is worth noting that, with the exception of the 5-9 years before the survey, the biases in the infant mortality rates are lower than those of under-five mortality rates for the same period, as observed by Hallett, Gregson, Kurwa *et al.* (2010). Although, it is not clear why there is an anomaly in the estimated bias (bias in the infant mortality rate is higher than that of the under-five) in the 5-9 years before the survey, again this could possibly be as a result of the random fluctuations due to the small sample size.

4.2 The summary birth history mortality estimates

The summary birth history data of the children born to surviving women at the third round of the longitudinal survey were used to calculate the proportions of children surviving among those ever born, $S(i)$, which were then used to obtain the proportions dead, $D(i)$, for each five year age group of the women aged 15-49. The average parities, $P(i)$, were calculated from these data and found to increase monotonically with the age of the women to 4.3 for the women aged 45-49, as would be expected. Generally, the results indicate that the proportion of children dead among those ever born, increase with the age of the mothers, except for the women in the 15-19 age group. Again, this is as expected, because the children born to older women are, on average, born further back in the past when compared with children born to younger women and hence have been exposed to the mortality risks for longer.

There is evidence of relatively high mortality among the children born to women aged 15-19. This could be due to the higher mortality risks associated with the first births and possibly to teenage mothers from socio-economically disadvantaged backgrounds. In addition, this estimate could be unreliable because of the small number of the children ever born and children surviving born to these women.

Table 4.3 shows the childhood mortality estimates calculated when using the standard summary birth history method. The calculated proportions of children dead among the ever born might be expected to be biased downwards, as the births to women who have died, particularly due to HIV related mortality among women, are not reported.

In addition, the regression coefficients used to convert the proportions dead could bias the estimated, $q(x)$, as these were derived using fertility and mortality schedules before the HIV epidemic.

Table 4.3 The summary birth history mortality estimates of the children born to surviving women at the survey, 2003-2005

Age group of women	Proportion of children dead, D(i)	Average parity, P(i)	Multipliers, k(i)	Age, x	Indirect mortality estimates, q(x)	Reference date, t(x)
15-19	0.095	0.14	1.168	1	0.111	2003.7
20-24	0.048	1.07	1.010	2	0.048	2002.4
25-29	0.065	2.09	0.930	3	0.060	2000.4
30-34	0.067	2.72	0.955	5	0.064	1997.9
35-39	0.061	3.30	1.012	10	0.061	1995.1
40-44	0.062	3.91	1.000	15	0.062	1992.1
45-49	0.075	4.30	0.986	20	0.074	1989.2

The implied infant and under-five mortality rates shown in Table 4.4 below were derived using the Princeton North model life table.

Table 4.4 The summary birth history infant and under-five mortality rates of the children born to surviving women at the survey, 2003-2005

Age group of women	Reference date, t(x)	Infant mortality rate (per 1,000 live births)	Under-five mortality rate (per 1,000 live births)
20-24	2002.4	38.0	55.4
25-29	2000.4	42.4	61.7
30-34	1997.9	39.5	57.6
35-39	1995.1	35.4	51.7
40-44	1992.1	32.7	47.8
45-49	1989.2	36.3	53.0

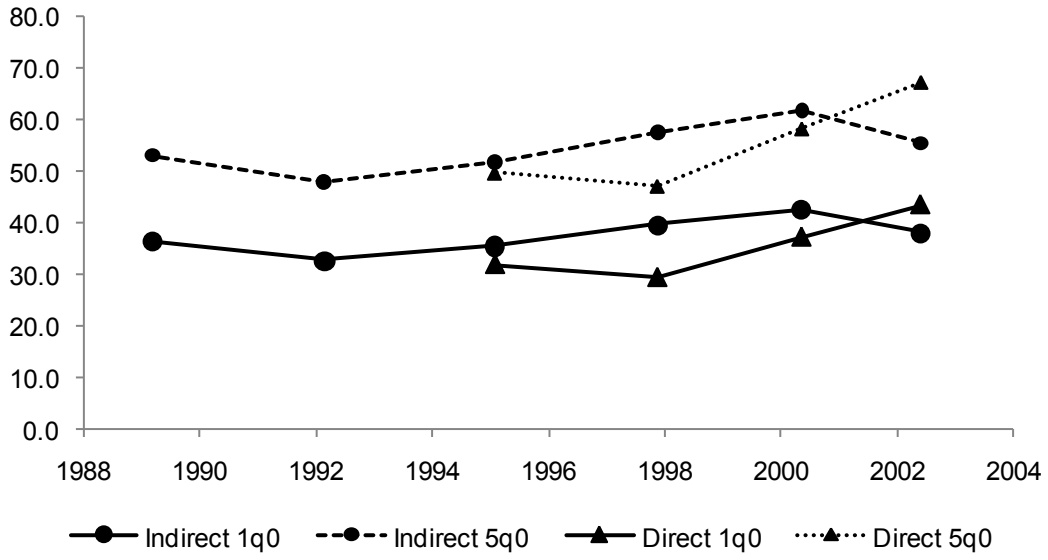
The implied trends in infant and under-five mortality suggest that childhood mortality has been rising for the period from 1992 to 2000. The observed trends are consistent with the reversal in the childhood mortality decline observed in some sub-Saharan Africa countries due to the impact of the HIV/AIDS epidemic. However, the implied levels and trends might be under-estimated, as the model life table that has been used was developed in the pre-HIV era, and hence, its age pattern of childhood mortality could be different from that experienced by children in populations affected by the epidemic.

Given the biases that could be induced by HIV/AIDS, it is necessary to estimate the extent of bias in these summary birth history estimates, as the province has been significantly affected by HIV/AIDS.

4.3 Comparison of the direct and indirect mortality rates before correcting for the impact of HIV

The comparison of the infant and under-five mortality estimates derived from the summary birth history method and the direct estimates before any adjustment for the HIV epidemic, are shown in Figure 4.1. The results reveal that the summary birth history mortality estimate derived from the women aged 20-24 is lower than the direct estimate, while that of women 25-29 is much the same. This is in contrast to Adetunji (1996), who found that the summary birth history mortality estimates for women in these age groups are much higher than the direct estimates. This is consistent with that HIV/AIDS reducing the bias due to the method. The summary birth history estimate derived from the women 30-34 is odd, as the two adjacent ages of the women produce estimates that are reasonably close to the direct estimates. The two methods show an upward trend in childhood mortality due to the impact of HIV/AIDS. These discrepancies need to be taken into consideration when interpreting the estimate of the overall bias in the summary birth history mortality estimates.

Figure 4.1 Trends in childhood mortality derived from the direct and indirect method, before correcting for the impact of HIV



4.4 Bias in the summary birth history method

The estimates of the overall bias in the childhood mortality rates derived from the summary birth history method introduced by the HIV epidemic, on the assumption that the direct estimates corrected for the impact of HIV are true rates, are shown in Table 4.5. The bias in the estimates derived from the children born to the women aged over 40 has not been calculated, as some of the children born to these women may have been exposed to HIV infection through sexual activity and could experience higher mortality risks. This could further increase the mortality rates; however, the elevated risk of dying would not be determined by the age and HIV status of the mother alone, and hence, cannot be estimated using the birth history data.

Table 4.5 Estimate of the overall bias in the summary birth history mortality rates

Age group of women	Reference date, t(x)	Indirect mortality rates (per 1,000 live births)		Direct mortality rates corrected for HIV (per 1,000 live births)		Overall Bias %	
		IMR	U5MR	IMR	U5MR	IMR	U5MR
20-24	2002.4	38.0	55.4	45.8	72.2	-17	-23
25-29	2000.4	42.4	61.7	42.9	67.1	-1	-8
30-34	1997.9	39.5	57.6	39.2	59.4	1	-3
35-39	1995.1	35.4	51.7	32.5	52.5	9	-1

The under-five mortality rates derived from the summary birth history method are consistently lower than the direct estimates corrected for the impact of HIV, indicating an underestimation of childhood mortality. It is interesting to note that the overall bias[3] decreases with the age group of the mother. The bias might be expected to increase with the age of the mother, as the increase in time since HIV infection is associated with higher rates of mother-to-child transmission and mortality risks; hence, the older cohorts are expected to be significantly under-represented when compared with children born to women in the 20-24 years. However, this could reflect that the overall bias represents both the bias due to HIV, as well as other biases inherent in the method and the data.

The overall bias in the infant mortality rates is lower than that of under-five mortality rates as might be expected. The low overall bias (positive for the infant mortality rates) associated with the childhood mortality rates of the children born to women aged 30-34 and 35-39 could possibly indicate that the summary birth history method, in the absence of HIV, would overestimate childhood mortality rates. Thus, the

[3] Throughout this chapter and chapter five, bias is used to refer to the magnitude of the bias and the sign indicates the direction of the bias, with negative bias reflecting underestimation and positive bias reflecting overestimation of childhood mortality.

bias induced by HIV/AIDS counters the bias in the method. However, this pattern is not consistent across the age groups of the women, indicating that the overall bias confuses our interpretation of the impact of HIV on the summary birth history method.

Table 4.6 shows the estimated bias in the summary birth history mortality estimates introduced by the HIV epidemic through the underestimation of the proportions of children surviving among those ever born due to maternal deaths.

Table 4.6 Bias in the summary birth history method due to the non-survival of mothers

Age group of women	Proportion of deceased women	Proportion of children dead (surviving mothers)	Proportion of children dead (deceased mothers)	Corrected proportion of children dead	Bias %
15-19	0.005	0.096	-	0.095	1
20-24	0.015	0.044	0.257	0.047	-8
25-29	0.045	0.059	0.253	0.064	-10
30-34	0.075	0.060	0.169	0.066	-10
35-39	0.071	0.059	0.090	0.060	-3
40-44	0.080	0.059	0.107	0.062	-4
45-49	0.133	0.074	0.106	0.075	-2

The estimated bias in the proportion of children dead among the children ever born, and hence, the summary births history estimates attributable to the increased correlation between the mortality of mothers and their children vary with the age group of the mother. This is a characteristic of the HIV epidemic, as the HIV prevalence varies with age, which in turn affects the age pattern of mortality of the women. The bias is higher for younger women, except for the youngest age group, showing the strong age-specific impact of HIV on female adult mortality. This in turn, affects the childhood mortality. It is worth noting that the bias in the estimates of the children born to older women, 35-39 to 45-49 is low. This could be associated with reports of older women who gave births when the HIV prevalence was relatively low and mothers were not likely to be infected then, and hence were alive at the survey to report on the survival of their children. It is interesting to note that the bias due to the non-survival of women aged 20-24 is substantial in contrast to the simulation by Ward and Zaba (2008), who found that the bias was more significant among older women, due to the cumulative effect of HIV infection and mortality, on the assumption of unchanging prevalence overtime.

In the absence of rising childhood mortality, the proportions of children dead should increase consistently with the age group of the mother due to the increase in the

period of exposure to mortality risks. The results show a drop proportion of children dead among those ever born to surviving women aged 35-39 and 40-44. Although the sample size of the children born to women who died is small, it is apparent that childhood mortality has been rising because the proportions of children who died are decreasing with the age group of the mother, assuming that the proportion of children born to women in the 45-49 age group could be the result of random fluctuation.

There is clear evidence of higher mortality risks among the children born to deceased cohort members, as the proportions dead are consistently higher than those of children born to surviving mothers. This shows that the proportions of children dead derived from cross-sectional surveys are no longer representative of the childhood mortality in the population. The small numbers of children ever born among women aged 15-19 will necessarily affect the stability and reliability of the estimates. No deaths were reported among the children ever born to deceased women, and hence, the corrected proportion of children dead was lower than that reported by surviving women.

It is important to note that the proportions of women who died in the five years before the third round of the survey are lower than the expected for a population experiencing a mature HIV epidemic. However, this could be attributed to the small numbers due to the breakdown of the survey population into mother's reporting age since Hallet, Gregson, Kurwa *et al.* (2010) concluded that overall, the proportion of the women who died was consistent with the estimates of female adult mortality in Manicaland.

Table 4.7 presents the estimated bias due to the regression coefficients that were used to convert the proportions of children dead, $D(i)$, into the life table mortality rates, $q(x)$ and the time to which the rates apply. The estimated bias is negligible, indicating that the HIV/AIDS does not significantly affect the conversion of $D(i)$ to $q(x)$ and the time location of the estimates.

Table 4.7 The estimate of bias in the summary birth history estimated due to the regression coefficients

Age group of women	Adjustment in the proportions of children dead, D(i), %	Adjustment in the mortality rates, q(x), %	Bias due to regression coefficients, %
20-24	-8.11	-8.09	0.02
25-29	-9.87	-9.90	-0.02
30-34	-9.69	-9.78	-0.09
35-39	-3.31	-3.37	-0.06
40-44	-4.41	-4.50	-0.09
45-49	-1.69	-1.75	-0.05

The bias due to the use of non-HIV model life tables to convert estimated mortality rates, $q(x)$, into infant and under-five mortality rates has been calculated as the ratio of the infant and under-five mortality rates derived using the Princeton North model life table divided by those implied by the life table that incorporates the impact of HIV. Table 4.8 presents the estimated bias in the summary birth history mortality estimates attributable to the use of a non-HIV model life table. The estimated bias is relatively small, suggesting that the age pattern of childhood mortality of the selected model life table (North family) is not very different from that of the model life table that incorporates the impact of HIV.

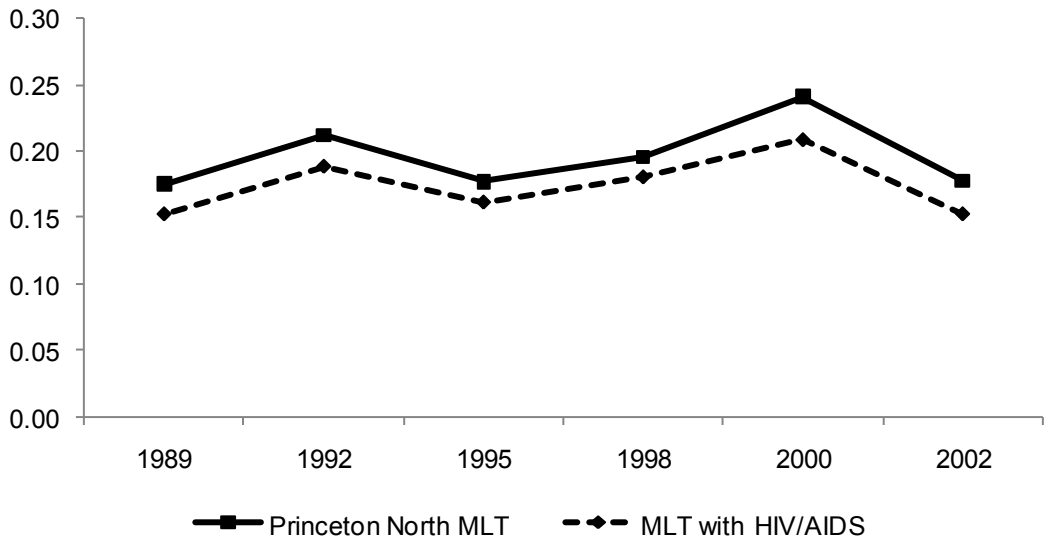
The direction of the bias indicates how the implied mortality trends derived by using the Princeton model life tables compare with those of the model life table with HIV. It is interesting to note that the direction of the bias varies with the age group of the mother; thus, one has to compare how the two standards fit the observed data in order to interpret them appropriately. The results suggests that the model that allows for the impact of HIV could increase the childhood mortality estimates further back in time and decrease the more recent estimates of mortality (relative to the Princeton North life table).

Figure 4.2 shows the plot of the mean absolute deviations of the fitted mortality rates from those observed over time. It shows that the model life table, which incorporates the impact of HIV, produces a better overall fit to the observed childhood mortality compared with the Princeton North model life table, as the mean absolute deviations are consistently lower. Therefore, the use of a model life table with the impact of HIV on the age pattern of mortality improves the conversion of the summary birth history mortality estimates, $q(x)$, to the common measures of childhood mortality.

Table 4.8 The bias in the summary birth history estimates due to the use of a non-HIV mortality life table

Age group of women	Reference date, t(x)	Princeton North model life table		Model Life table with HIV		Bias %	
		IMR	U5MR	IMR	U5MR	IMR	U5MR
20-24	2002.4	41.3	60.2	40.6	58.1	2	4
25-29	2000.4	47.1	68.4	46.7	66.7	1	3
30-34	1997.9	43.8	63.7	44.6	63.7	-2	0
35-39	1995.1	36.7	53.5	38.0	54.6	-4	-2

Figure 4.2 Mean absolute deviations between the fitted and the observed, $q(x)$



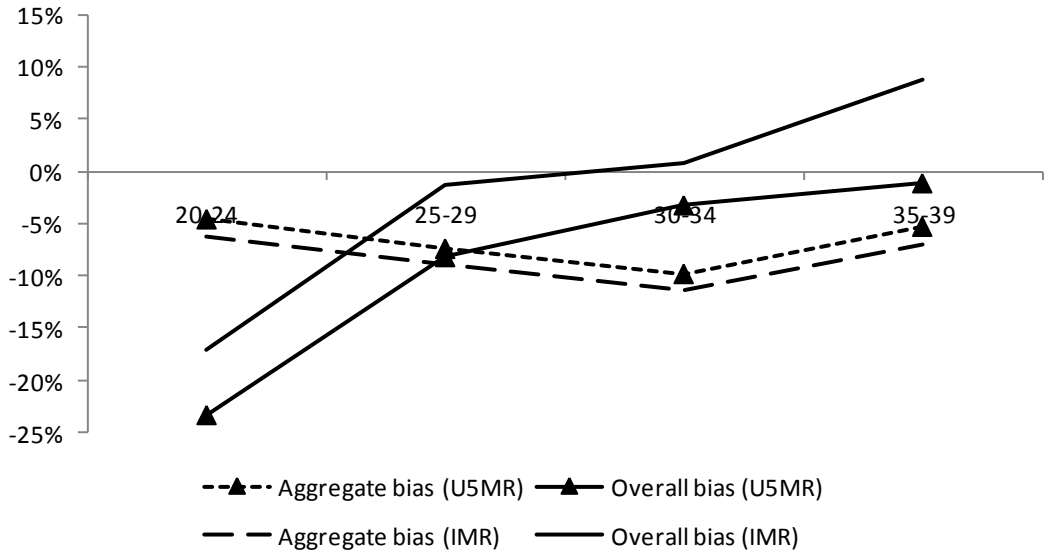
4.4.1 Aggregate vs overall bias

If, in the absence of HIV, the summary birth history method produced unbiased results, then the bias derived from the sum of the component biases, i.e. the bias due to the non-survival of mothers, the regression coefficients and the use of the non-HIV model life tables (labelled as Aggregate bias in Figure 4.3) would not be significantly different from the overall bias. Figure 4.3 shows that the two are significantly different, both in the levels and the by mother's age group.

Although the estimated biases in the under-five mortality rates are different, these tell the same story, namely, that the HIV epidemic results in the underestimation of childhood mortality rates derived from the summary birth history method. The estimates of the overall bias due to HIV could be unreliable because there are some biases inherent in the direct and the summary birth history method that have not been allowed for. In addition, the significant variation in the overall bias by five year age groups of the women, particularly the overall bias in the infant mortality rates, indicates

that this could be unreliable considering that the epidemic may have peaked somewhere around 1998; and hence, some gradual changes in the overall bias would be expected. While the sum of the biases suggests the need to increase the rates by between five per cent and 11 per cent for the impact of HIV, this bias appears to be counteracted by possible biases in the method. The average of the bias in the infant and under-five of these biases were compared with those derived from the Ward and Zaba model.

Figure 4.3 The overall and aggregate bias in the summary birth history mortality estimates



4.5 The bias in the summary birth history method using the Ward and Zaba model

The estimates of the bias in the summary birth history method derived from the model proposed by Ward and Zaba (2008) are shown in table Table 4.9. The results show that the bias increases with the age group of the mother and this is consistent with the expected cumulative effect of HIV, if the prevalence has remained constant over time. The model suggests high levels of bias due to HIV/AIDS. Although the bias in the summary birth history method in populations that have lower levels of background mortality and high HIV prevalence such as Zimbabwe is expected to be significant, the Ward and Zaba estimates in Table 4.9 appear to be implausible.

Table 4.9 Comparison of the bias in the summary birth history mortality estimates derived from the Ward and Zaba model and the aggregate and overall bias

Age group of women	Bias (%) using Ward & Zaba model	Aggregate bias (%) due to HIV	Overall bias (%) due to HIV
20-24	-32.2	-5	-20
25-29	-26.8	-8	-5
30-34	-38.4	-11	-1
35-39	-37.9	-6	4

The sum of the component biases due to HIV is much lower than that derived from the Ward and Zaba model. This indicates that the correction factors proposed by Ward and Zaba (2008) could possibly overestimate the adjustments that are required to correct the summary birth history estimates for the effect of a generalised HIV epidemic. In addition, the model may overestimate the extent of bias in the childhood mortality rates for the children born to women over 40 (results not shown) as the estimated bias consistently increases with the age group of the mother whereas the empirical estimates show the impact of HIV peaks at the children born to women 30-34, but declines thereafter.

In practice, with the exception of the estimate for women aged 20-24, the overall bias, i.e. after taking into account the bias in the method, is not very significant, indicating that the Ward and Zaba (2008) correction factors overestimates the adjustments that are required for the impact of HIV. This is because the model assumes that prevalence has been constant over time when in fact it has been changing. In addition, the prevalence among the older age groups is generally lower due to the effect of HIV related mortality.

5. DISCUSSION AND CONCLUSIONS

The principal objective of this research was to estimate the extent of the bias introduced by the HIV epidemic in the summary birth history method of estimating childhood mortality using the Manicaland longitudinal survey data. This chapter examines the extent to which the results obtained from the data analysis meet the set objectives, and it also identifies areas for possible future research.

5.1 Data quality

In order to attain the objectives of the research, the data on the birth histories of surviving and deceased women were used. Considerable difficulties were encountered in attempting to replicate the data sets that were used to derive the correction to the direct estimates for the impact of HIV by Hallett, Gregson, Kurwa *et al.* (2010), particularly the birth history data for the children born to deceased women. However, after much effort it was possible to reproduce the published results sufficiently accurately to be confident about both the datasets as well as the method used to produce the direct estimates.

The consistency of results between the summary and the full birth history data show that the reporting of women was fairly accurate. Although the methods employed to assess the quality of the birth history data on the children born to surviving women could not be applied to that of children born to women who had died, as the sample size is relatively small, it could be assumed that these were of reasonable quality. The assumption can be considered to be plausible because only a small proportion of the births to women who died were reported between the date of the last interview and the death of the mother. The greater proportion (97.2 per cent) of the birth history data collected in the verbal autopsy interviews could be verified with the data collected in the last interview with the women who had subsequently died.

As was pointed out in section 3.4.4, the proportion of children who died with unknown or unspecified year of death was relatively higher for the children born to deceased mothers than for those of surviving mothers. Given that the number of the children born to deceased women in the sample was small, these data could not be ignored, as to do so would result in underestimation of the childhood mortality produced by the direct method, and hence, the overall bias in the summary birth history method. Apportioning the date of death by using the distribution of those with reported date of death helped to minimise this error.

5.2 The bias in the summary birth history mortality estimates due to HIV/AIDS

As far as the impact of HIV on the summary birth history method the findings reveal that the summary birth history estimates derived from cross-sectional survey data (reports of surviving women only) could result in an underestimation of the childhood mortality. This could lead to the inappropriate assessment of the levels and trends in mortality among children.

The overall bias in the childhood mortality rates derived from the summary birth history method does not necessarily increase monotonically with the age of the mother, as would be the case if prevalence was constant over time (Ward and Zaba, 2008). This could be due to the fact that older women gave births when HIV prevalence was relatively low and hence more likely to be alive at the time of the survey to report on the survival of their children, who would not have had elevated mortality risks. In addition, the overall bias represents both the bias due to HIV as well as other biases in the method and the data. Thus, it is useful to discuss the main aspects of the method that contribute to the bias due to HIV.

The effect of HIV on the estimation of childhood mortality when using the summary birth history method has been attributed to the violation of the underlying assumptions described in section 2.4. The extent of bias induced by each of the assumptions has been evaluated and the results are discussed below.

The extent of bias in the summary birth history method due to the non-survival of mothers ranges from 3 per cent to 10 per cent. The estimated bias shows the increased correlation between the mortality of the mothers and that of their children in the presence of HIV. The impact of HIV/AIDS explains the bias, because a greater proportion of the cohort members died of HIV/AIDS (Gregson, Terceira, Kakowa *et al.*, 2002; Hallet, Gregson, Kurwa *et al.*, 2010). This means that the birth history data collected in the cross-sectional surveys and censuses are not a sufficient reflection of the survival of the births in the population.

The problem of the under-representation of children born to women who die before the survey due to HIV/AIDS has been studied in other populations using the full birth history data (direct estimates), although the estimated bias was found to be relatively low (Artzrouni and Zaba, 2002; Ng'weshemi, Urassa, Isingo *et al.*, 2002). This could be a reflection of the low HIV prevalence rates that were observed in the studied populations. Although Ng'weshemi, Urassa, Isingo *et al.* (2002) observed that maternal death negatively affects child survival, irrespective of the HIV status of the mother, the

estimated bias is attributed to the impact of HIV, as a considerable proportion of the maternal deaths were due to HIV/AIDS.

It is worth noting that the non-survival bias varies with the age of the mothers and is relatively high among younger women (excluding the youngest age group). This shows that childhood mortality is no longer independent of the age of the mother as was assumed by the summary birth history method. In a stable epidemic the children born to older women are more likely to be born when the mother is already infected and hence experience higher mortality risks. However, this may be counteracted in an expanding epidemic as the children born to recently infected women (the majority of them being younger women) could experience higher mortality risks associated with higher rates of vertical transmission when the mother's viral load is high.

The examination of the bias induced by HIV/AIDS through the deviations from the model fertility and mortality patterns employed to generate the regression coefficients used to convert the proportions of children dead among those ever born, $D(i)$, to childhood mortality rates, $q(x)$, and then to estimate the time point at which the estimates apply, is very small. This shows that the multipliers could be insensitive to changes in the pattern of fertility, and in particular, the mortality due to HIV. This could possibly suggest that it is not important to derive new regression coefficients to allow for the impact of HIV.

The changes in the levels and age patterns of mortality introduced by HIV have been a cause for concern with the standard application of the summary birth history method. This is because the model life tables generally used to convert the $q(x)$, to common measures of childhood mortality, $q(1)$ and $q(5)$, do not capture the impact of HIV (Mahy, 2003; Ward and Zaba, 2008). The results also show that the bias attributable to the use of non-HIV model life tables is relatively low. However, the extent of bias depends on the choice of the non-HIV model life tables; and substantial deviation from the observed mortality could increase this bias. In general, the use of the model life table that incorporates the impact of HIV improves the summary birth history mortality estimates, as suggested by Ward and Zaba (2008).

If, in the absence of HIV, the summary birth history method produces unbiased results, the bias derived from the sum of component biases discussed above would not be significantly different from the estimated overall bias. It is found that these differ in both the level and the pattern. While the sum of the biases suggests the need to increase childhood mortality rates by between 5 per cent and 11 per cent for the impact of HIV,

the bias appears to be counteracted by the possible biases in the summary birth history method. The comparison suggests the need to further investigate the other sources of bias in the summary birth history data and the method to ascertain the appropriate adjustments for the impact of HIV. This is because the data set could be used to reasonably estimate the bias due to HIV related mortality among women and not other biases because it allowed for the data for the children born to deceased women collected through the verbal autopsy interviews.

The results have shown that the Ward and Zaba (2008) adjustments for the underestimation of summary birth history estimates due to HIV are significantly higher than those implied by the sum of the component biases. Although, there is considerable uncertainty in the childhood mortality estimates and their bias, due to the small sample size, the difference between these adjustments is large, suggesting that the Ward and Zaba (2008) correction factors could be inappropriate for Manicaland. The overestimation of the extent of bias in the summary birth history method can be attributed to the violation of the assumptions underlying the Ward and Zaba (2008) correction factors, mainly the assumption that HIV prevalence has been constant over time. Since the epidemic is dynamic, the extent of bias in the mortality estimates of the children born to older women is lower than that predicted by the model. This is because the children born to older women would not have experienced higher mortality risks due to HIV as the majority of the children would have been born when HIV prevalence was relatively low. In addition, the model overestimates the extent of bias in an expanding epidemic as recently infected women would have had a majority of their births before HIV infection and hence would not have experienced higher mortality risks. Therefore, one can safely conclude that the correction factors proposed by Ward and Zaba (2008) are not appropriate for correcting the summary birth history method for the impact of HIV. Furthermore, the decline in HIV prevalence among women of reproductive age in Zimbabwe in the recent years further questions the usefulness of these correction factors for adjusting the summary birth history estimates over time.

5.3 Adjustment in practice

The results of the direct and summary birth history estimates before any adjustment for the impact of HIV show that childhood mortality has been increasing. This is consistent with the reversal in the decline in childhood mortality trends that has been observed in Zimbabwe, and hence, the Manicaland province, which has been mainly attributed to

the impact of HIV/AIDS (Central Statistical Office and Macro International Inc, 2007; Korenromp, Arnold, Williams *et al.*, 2004; Zaba, Marston and Floyd, 2003).

In order to evaluate the significance of the adjustments for the impact of HIV on the summary birth history method, the estimates are compared with the "true" level of mortality. Figure 5.1 and Figure 5.2 show the trends in childhood mortality derived from the summary birth history method before (uncorrected) and after (corrected) the adjustment for the impact of HIV using the aggregate bias and the Ward and Zaba correction factors. In addition, the direct estimates corrected for the impact of HIV that are regarded as the "true" childhood mortality estimates are shown. Generally, the results reveal that, with the exception of the most recent estimate, the adjustments for the bias due to HIV in the summary birth history method could possibly result in the overestimation of childhood mortality. However, given the uncertainty of the "true" mortality level, it is difficult to ascertain the appropriate adjustment for the impact of HIV. The most recent estimate could be unreliable, as the summary birth history method indicates a decline in childhood mortality in contrast to the "true" estimate. This could possibly suggest that the mortality risks represented by the proportion of children dead, born to women in the 20-24 age group, is lower than that experienced by the children in the five years before the survey (Hill, 1991). The adjustment for the aggregate bias due to HIV, improves the summary birth history estimate, although not adequately.

The uncorrected summary birth history infant mortality rates derived from the women aged 25-29 and 30-34, are close to the "true" estimates. This suggests that in the absence of HIV, the summary birth history method may produce estimates that are biased upwards, which in turn, cancels the downward bias due to HIV. Thus, excluding the most recent estimate, there is insufficient evidence of the need to adjust the infant mortality rates derived from the summary birth history method for the impact of HIV. On the other hand, the under-five mortality trend suggests the need for correcting summary birth history estimates for the impact of HIV as the uncorrected rates are relatively lower than the "true" level of childhood mortality, although even here the case is not strong. The Ward and Zaba adjustments results in higher estimates than the "true" childhood mortality estimates. The variation in the performance of the adjustments for the bias in the summary birth history method relative to the "true" estimates indicates that the extent of adjustment is not certain.

The longitudinal survey data have produced childhood mortality estimates that are lower than the provincial estimates, as observed in the 2005-6 Zimbabwe Demographic and Health survey. Hallett, Gregson, Kurwa *et al.* (2010) report that this could be a result of the selection criteria employed by the survey, which excluded the women who belonged to religious sects that do not utilise medical services. In addition, they point out that the province and hence the study population, is favoured in terms of food supplies, and health care services, which in turn results in lower childhood mortality rates than for the country as a whole. However, the lower childhood mortality rates could point to the study underestimating mortality.

Figure 5.1 Comparison of the infant mortality trends that are corrected for the impact of HIV

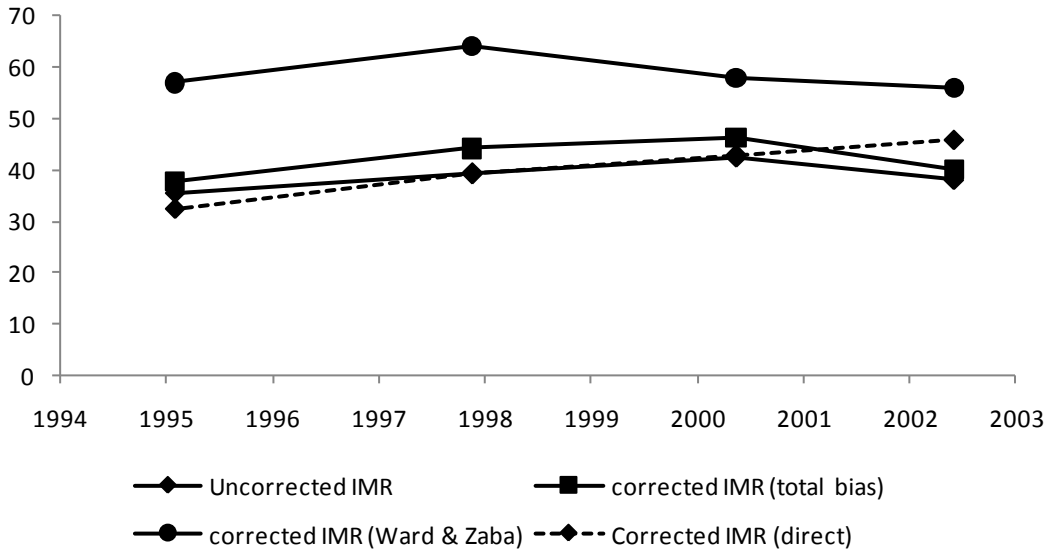
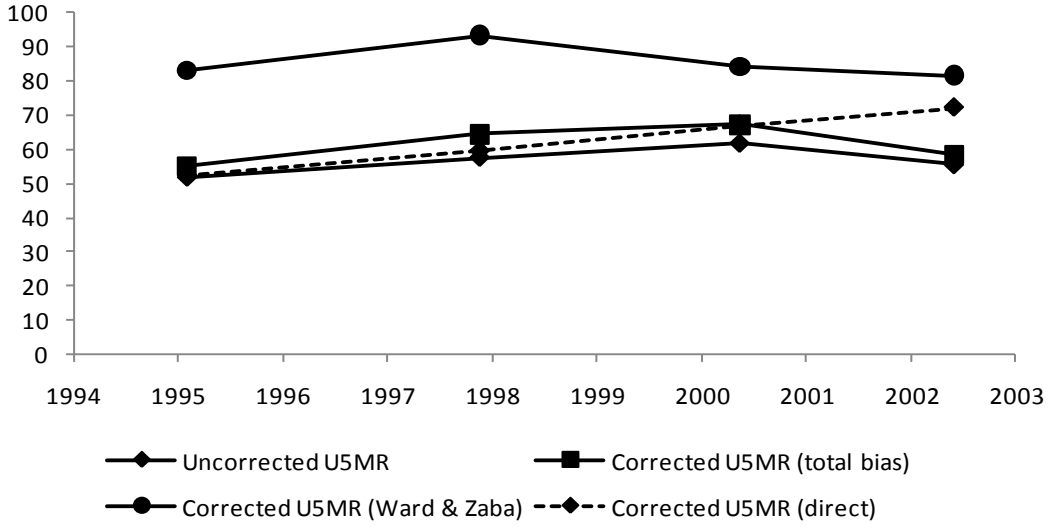


Figure 5.2 Comparison of the under-five mortality trends that are corrected for the impact of HIV



5.4 Limitations of the research

Although, the results from the longitudinal survey contributes to the understanding of the impact of HIV on the summary birth history method; the sample size is relatively small and of limited geographical coverage as the sites are in one province which does not necessarily represent other provinces in Zimbabwe. Thus, estimated biases may not be applicable to other populations affected by HIV. In addition, the small sample size may have caused fluctuations in the childhood mortality rates and their biases making them difficult to interpret.

Since the verbal autopsy interviews were not designed primarily to collect birth history data, these could not provide summary birth history data to estimate childhood mortality, as was done with the children born to surviving women. The research had to use the full birth history data to construct the summary birth history data. However, the background that the verbal autopsy interviews collected partial birth history data for the women who died posed a challenge to the reliability of the constructed summary birth history data. It was assumed that the partial birth history data (for children aged 16 years and below) is similar to the complete birth history. The assumption appears to be reasonable because the proportions of children surviving among those ever born to surviving women derived from their partial birth histories were not significantly different from those derived from the complete full birth histories.

It is important to note that the Manicaland data set is not a reliable source, "gold standard", for comparisons because it relies on verbal autopsy interviews to collect data on births and deaths to the women who have died. Further the survey is different from other demographic surveillance sites such as those in the ALPHA network that generally have fourth month reporting rounds, thereby obtain this information directly (London School of Hygiene & Tropical Medicine, 2011).

Another weakness of the research is the assumption that childhood mortality has been changing linearly between the point estimates derived using the direct method at the time reference points of the estimates derived from the summary birth history method. The changes in the childhood mortality in populations affected by the HIV epidemic could be different from linearity; and hence, could introduce slight errors in the estimated overall bias.

5.5 Further research

The birth history data of the children born to deceased cohort members from other demographic surveillance sites in countries affected by the generalised HIV epidemic

could be analysed to increase the body of evidence on the impact of HIV on the summary birth history method. These can be used possibly to provide adjustments to the Ward and Zaba (2008) correction factors. Further studies of the impact of HIV on the summary birth history method could be done to establish a micro-simulation model that could be used to correct the method for the populations affect by HIV.

The unavailability of the model life table systems, which allow for the impact of HIV required to convert the childhood mortality estimates to a common index, posed a challenge in this research. Although, the World Health Organisation and the INDEPTH network model life tables incorporate the impact of HIV, they only provide abridged life tables which do not provide mortality rates by single ages of children (INDEPTH Network, 2004; Lopez, Ahmad, Guillot *et al.*, 2001). Therefore, there is the need for further research into the development of model life table systems for populations affected by HIV. These could be used with the summary birth history method to reduce the bias due to the impact of HIV.

HIV prevalence has been declining in Zimbabwe among the women of reproductive age and the population as a whole in the recent past. In addition, the increasing access to PMTCT and antiretroviral therapy for both adults and children could result in the reduction of mortality due to HIV. Future research could examine the extent to which these changes affect childhood mortality and hence the extent of bias over time.

The overall bias in the summary birth history method attributable to the impact of HIV could be unreliable because it was based on corrected full birth histories at incorrect time points calculated using the regression coefficients and the small sample sizes by five year age groups of the women. There is room for further research into the impact of HIV on the summary birth history method, possibly by comparing the childhood mortality estimates, $q(x)$, that are derived from the standard application of the summary birth history method assuming that mortality has remained constant over time with corresponding mortality estimates that are derived directly from the full birth history data and corrected for the impact of HIV. This could allow for the estimation of the bias attributable to the differential in childhood mortality by the age of the mother due to HIV.

Further research into the impact of HIV could be performed through the comparison of the summary birth history estimates, $q(x)$ at the different points in time with the synthetic cohort childhood mortality estimates that pertain to the same point in

time. The full birth history data could be used to estimate the proportions of children surviving using the person-years of child exposure in the calendar year of interest (determined from the Trussell variant of the Brass's summary birth history method) as reported by all women to obtain the synthetic cohort mortality estimates.

5.6 Conclusions

Previous studies on child mortality in populations affected by HIV have questioned the extent of bias in the summary birth history method due to HIV/AIDS. It has been suggested that this could be substantial, as a result of the violation of the underlying assumptions of the method, principally the non-independence of maternal and child mortality (Ward and Zaba, 2008). Using the Manicaland longitudinal survey data, the current research has shown that indeed the increased correlation between the mortality of mothers and their children appears to be the major contributor to the aggregate bias due to HIV in the summary birth history method. On the basis of this observation, it is recommended that estimates of mortality in countries significantly affected by HIV require some adjustments for this bias. However, there is considerable uncertainty as to the extent of the adjustments for the non-survival of women due to HIV. These could not be derived with any certainty from the available data. This requires further research on bigger samples, and different populations to identify the possible correction factors.

The findings suggest that the bias due to the impact of HIV on the regression coefficients is negligible and can be ignored. Although, the bias due to the model life tables used to convert the rates to $q(1)$ and $q(5)$ is relatively low, this bias could be reduced by using a model life table that incorporates the impact of HIV in the population into the age pattern of mortality. However, this is subject to the availability of such model life table systems in countries affected by the generalised HIV epidemic.

The overall conclusion of this research is that, the impact of HIV on the summary birth history method does not appear to be so significant as to render the method unusable in low resource countries affected by HIV/AIDS. Clearly, further research into the development of appropriate adjustments for the impact of HIV would help to improve the accuracy of the summary birth history estimates in populations affected by HIV/AIDS.

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APPENDIX A: DERIVATION OF ALPHA AND BETA

The curve of the life table survivors, l_x, Blacker and Brass (2005) is given as follows:

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

where α is a constant representing the level of mortality and β, is the shape of mortality. Since the parameters of a life table are closely related, the following formula can be used to obtain the number of life table survivors, l_x, from L_x, the number of person-years lived between ages x and $x+1$.

$$L_x = \int_x^{x+1} l(a) d_a.$$

Substitute the $l(a)$ with the Blacker and Brass (2005) function and integrate to obtain L_x in terms of the α and β, as follows:

$$L_x = \int_x^{x+1} (1+\alpha a)^{-\beta} da$$

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

One can solve for α and β to best fit the L_x values derived from the survival ratios calculated using the population projection from the Spectrum suite. The α and β are then used to fit a life table which incorporate the impact of HIV, the l_x, values.

APPENDIX B: TABLES

Table B1 Summary birth history data of the children born to surviving women 15-49 years at the third round of the (July 2003 to August 2005)

Age group of women	Number of women	MCEB	FCEB	Total CEB	MCS	FCS	Total CS
15-19	1510	106	103	209	97	92	189
20-24	1218	658	644	1302	620	625	1245
25-29	958	992	1010	2001	931	951	1884
30-34	769	1036	1053	2089	975	988	1963
35-39	596	950	1014	1964	890	959	1849
40-44	599	1159	1184	2343	1090	1114	2204
45-49	559	1195	1209	2404	1106	1120	2226
Total	6208	6096	6217	12312	5709	5849	11560

Table B2 Summary birth history data of the children born to women who died aged 15-49 years in the five years before the third round of the survey

Age group of women	Number of women	MCEB	FCEB	Total CEB	MCS	FCS	Total CS
15-19	7	1	0	1	1	0	1
20-24	19	10	14	24	6	12	18
25-29	45	28	40	68	21	30	51
30-34	62	66	66	132	54	56	110
35-39	46	73	59	133	70	51	121
40-44	52	77	65	142	71	56	127
45-49	86	55	43	98	46	42	88
Total	316	311	287	598	268	246	515

Table B3 Generated life tables for Zimbabwe incorporating the impact of HIV on the age pattern of mortality

	Lx													
Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9455	0.9427	0.9393	0.9344	0.9290	0.9243	0.9213	0.9216	0.9223	0.9211	0.9202	0.9204	0.9238	0.9284
2	0.9361	0.9337	0.9301	0.9244	0.9181	0.9127	0.9091	0.9087	0.9086	0.9067	0.9051	0.9049	0.9081	0.9130
3	0.9306	0.9285	0.9247	0.9185	0.9118	0.9060	0.9020	0.9012	0.9006	0.8983	0.8964	0.8959	0.8990	0.9040
4	0.9267	0.9248	0.9209	0.9144	0.9074	0.9012	0.8970	0.8958	0.8949	0.8923	0.8902	0.8895	0.8925	0.8976
5	0.9237	0.9219	0.9179	0.9112	0.9039	0.8976	0.8932	0.8917	0.8905	0.8878	0.8854	0.8845	0.8875	0.8927
6	0.9213	0.9195	0.9155	0.9086	0.9011	0.8946	0.8900	0.8884	0.8870	0.8840	0.8815	0.8805	0.8834	0.8887
7	0.9192	0.9176	0.9135	0.9064	0.8987	0.8921	0.8874	0.8856	0.8840	0.8809	0.8783	0.8771	0.8800	0.8853
8	0.9174	0.9159	0.9117	0.9045	0.8967	0.8899	0.8851	0.8831	0.8814	0.8781	0.8754	0.8742	0.8770	0.8823
9	0.9158	0.9144	0.9102	0.9028	0.8949	0.8880	0.8830	0.8810	0.8791	0.8757	0.8729	0.8716	0.8744	0.8798
10	0.9153	0.9142	0.9103	0.9029	0.8951	0.8882	0.8832	0.8805	0.8779	0.8740	0.8707	0.8688	0.8709	0.8758
11	0.9131	0.9120	0.9083	0.9012	0.8933	0.8863	0.8811	0.8787	0.8763	0.8721	0.8682	0.8659	0.8680	0.8728
12	0.9126	0.9117	0.9079	0.9005	0.8926	0.8856	0.8804	0.8776	0.8746	0.8703	0.8664	0.8638	0.8653	0.8696
13	0.9104	0.9096	0.9060	0.8988	0.8909	0.8838	0.8785	0.8760	0.8733	0.8687	0.8644	0.8616	0.8631	0.8673
14	0.9100	0.9093	0.9056	0.8982	0.8903	0.8833	0.8780	0.8750	0.8718	0.8672	0.8630	0.8600	0.8611	0.8648
15	0.9079	0.9072	0.9037	0.8966	0.8886	0.8815	0.8762	0.8735	0.8707	0.8659	0.8614	0.8582	0.8593	0.8631
16	0.9074	0.9070	0.9033	0.8959	0.8880	0.8810	0.8757	0.8727	0.8694	0.8647	0.8603	0.8572	0.8582	0.8619
17	0.9049	0.9045	0.9010	0.8938	0.8859	0.8788	0.8735	0.8708	0.8679	0.8630	0.8584	0.8551	0.8562	0.8599
18	0.9036	0.9032	0.8994	0.8919	0.8841	0.8772	0.8720	0.8690	0.8658	0.8611	0.8567	0.8535	0.8544	0.8581
19	0.8998	0.8991	0.8953	0.8878	0.8798	0.8729	0.8679	0.8655	0.8628	0.8581	0.8536	0.8503	0.8514	0.8552
20	0.8971	0.8960	0.8915	0.8833	0.8751	0.8682	0.8635	0.8610	0.8583	0.8541	0.8501	0.8472	0.8483	0.8523