MEASURING ADULT MORTALITY IN THE ERA OF HIV/AIDS: ESTIMATES FROM CENSUS AGE DISTRIBUTION

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ABSTRACT

In resource-poor settings, researchers apply various techniques to estimate mortality and other demographic outcomes. Estimation methods and outputs depend on the quality of input data, assumptions made about the data and choice of standard model patterns. We employ Preston-Bennett technique to illustrate how one can estimate levels of adult mortality in the era of HIV/AIDS. We use data on population age distribution from two consecutive censuses in the United Republic of Tanzania. This method indirectly takes into account the impact of HIV/AIDS on the population that would not be captured by other estimation techniques based on model life tables.

We find very high adult mortality between ages 15 and 60 in the intercensal period. The timing and age-patterns of mortality strongly suggest a major demographic impact of HIV/AIDS. We also find significant sex differentials on the levels on adult mortality in Tanzania, with younger women more affected than men. In the absence of a vital statistics system that produces good quality data on mortality levels and causes of death, census-based methods that use population age distributions can be used to examine the impact of HIV/AIDS on mortality in the intercensal period and provide robust estimates of the mortality levels.

INTRODUCTION

Since the 1980s, HIV/AIDS has taken a devastating toll on Sub-Saharan African populations. Yet direct measurement of the demographic impact of the epidemic are scarce. Of all the countries with high levels of HIV/AIDS in sub-Saharan Africa, only South Africa has good sources of vital registration data or mortality statistics that records deaths and their causes, and the demographic characteristics of the deceased. This hinders measuring the impact of HIV/AIDS on mortality, particularly among adults (Blacker 2004; Timaeus and Jasseh 2004). In this context, demographers and researchers use direct and indirect estimation methods to estimate mortality. Such methods make use of model life tables, in combination with sophisticated modeling techniques based on survey estimates of child mortality, and assumptions about levels of HIV and adult mortality (Blacker 2004; Brass and Coale 1968; Heuveline 2003). A major concern about applying model life tables to measure estimates of mortality in 21st-century sub-Saharan Africa, however, stems from the fact that existing models were derived almost entirely from the western countries and that they do not take into account the changes in the disease burden and do not consider environment in which new diseases are emerging (Zuberi, Bawah and Noumbissi 2003). With high levels of HIV in southern Africa, the existing life table models may no longer be appropriate. In addition, survey-derived mortality data may not always be available for many of these countries, or if available, they may come from selected geographically defined populations usually not representative of the entire country.

Recent studies at the sub-national level that mortality—particularly among adults—is increasing at alarming rates in Africa (Blacker 2004; Feeney 2001; INDEPTH 2002; Kitange et al. 1996; MEASURE et al. 2001; Ministry of Health 2004a, 2004b; Ngom and Clark 2003; United Nations 1998, United Republic of Tanzania 1997; Zaba, Whiteside and Boerma 2004).

The sharp increase is largely attributable to the impact of HIV/AIDS (Clark et al. 2003; Ng'weshemi et al. 2003; Nicoll et al. 1994; Porter and Zaba 2004; Stanecki 2000). Indeed, improvements in life expectancy observed in the late seventies and early eighties in many of these countries are stagnating and in many cases reversed (Timaeus 1998, 1999; Tollman et al. 1999; United Nations 1998; UNAIDS 2004). However, because of their localized nature, some concern remains that findings from these studies may not be representative of the situation in the entire country or region.

Although nearly all African countries lack reliable sources of mortality data including causes of death, almost all sub-Saharan countries conduct population and housing censuses. These censuses, with some degree of variation, follow a ten-year cycle. In addition to information on age distribution of population, most censuses report information on mortality.[1] Particularly in light of alternative sources, censuses have been an under-utilized source of mortality data at national level that are available in many countries affected by the AIDS pandemic. One reason for the under-utilization of census data is a general concern that they are likely to be of poor quality. Mortality statistics, in particular, have not always been reliable and usable. Fortunately, however, data on population age distributions are believed to be of much better quality than information on deaths, and techniques exist to make use of these data to estimate mortality.

One such approach for measuring the impact of HIV/AIDS on mortality is to compare age distributions from two censuses: the first would be from some point before onset of high levels of AIDS mortality; the second would be from a time point after the demographic effects of

[1] Some variables collect information on deaths in the past 12 months prior to census, some collect information on children ever born and children surviving and others collect information on survival of parents from which estimates of mortality can be produced.

a generalized epidemic have become manifest. In sub-Saharan Africa, at least 20 countries have: a generalized AIDS epidemic (defined as a national HIV prevalence rate of greater than 3%); a census conducted prior to 1990 (i.e. before the presumed wide-scale impact of AIDS); and have had or will have a census between 2000 and 2010 (i.e. after the impact of AIDS is likely to show up strongly in levels of adult mortality). For this set of countries, application of census-based methods to estimate the impact of HIV/AIDS on population and health in these countries is possible.

OBJECTIVES

This paper has two main objectives. First, we employ the reported age-distribution data to estimate levels of adult mortality in the 1988–2002 intercensal period in the United Republic of Tanzania. Our aim is to examine whether mortality, particularly among adults, has increased in the country in line with the predictions of the impact of HIV/AIDS on adult mortality. Using appropriate adjustments to the census-based method described below, we estimate the levels adult mortality and construct life table for the intercensal period. Second, we apply indirect demographic techniques to test the applicability of existing model patterns to our estimates of mortality in Tanzania. This kind of analysis will allow us to identify and select an appropriate model life table to use for comparing and assessing the magnitude of our estimates of the mortality levels.

Tanzania serves as good case for the application of methods. The country is among the most hard-hit by HIV/AIDS in sub-Saharan Africa. Current estimates of HIV prevalence among adults aged 15–49 years are 6.5%, with about 1.4 million people living with the virus. Deaths from AIDS are estimated to be high, and the proportion of reported orphans has increased dramatically due to AIDS (UNAIDS 2006). Many diseases, which seemed to have been under control in the period just before the epidemic, have returned to higher levels due to HIV/AIDS. Currently, HIV/AIDS is probably the leading cause of adult mortality in many parts of the country (http://www.tanzania.go.tz/hiv_aids.html; United Republic of Tanzania 1997; Ministry of Health 2004a, 2004b).

DATA AND METHODS

Population and housing censuses in Tanzania

In this paper we employ the Preston-Bennett method (Preston and Bennett 1983). This technique makes use of two successive national census age distributions to estimates adult mortality. Age distribution data come from the two most recent Tanzania population and housing censuses: 1988 and 2002. We consider 1988 as representing a period of low impact of HIV/AIDS mortality and 2002 as a period of much higher mortality as a result of HIV/AIDS. Previous published national census reports indicate declining mortality rates across all ages and for both men and women between 1978 and 1988 (United Republic of Tanzania 1994). Although the first cases of AIDS were reported in Tanzania in 1983, given the apparently low prevalence at the time, and the relatively slow progression of the disease from infection to death, it is unlikely that the mortality impact of HIV would have been detectable on the crude death rates measured in the 1988 census.

The accuracy of age reporting in the 1988 census and in the 2002 census have been discussed elsewhere (http://www.nbs.go.tz/; http://www.tanzania.go.tz/census/; United Republic of Tanzania 1988, 1994). Briefly, the age structure of the 2002 census shows a tendency towards age heaping and “age/digital preference”, particularly in the years adjacent to those ending with

"0", "2", "4", "5" and "8". It was observed that the digital preference is higher among the female populations compare to male populations. These tendencies were similar to those found in the 1978 and 1988 censuses. While there is some evidence of single-year misreporting of ages, the overall age-structure is as expected, and reports for the 1988 and 2002 censuses suggest that, on average, age reporting in Tanzania was fairly accurate (United Republic of Tanzania 1994). Therefore, age and sex distribution of the population from the two censuses are employed in our analyses without further adjustment.

The Preston-Bennett Method and application to Tanzania census data

Traditional intercensal survival methods (United Nations 2002) cannot easily be applied to the 1988 and 2002 Tanzania censuses because of the wide intercensal interval (14 years). The availability of data on population size by age from the 1988 and 2002 population and housing censuses is, however, appropriate for the Preston-Bennett method, which relies on two successive census age distributions and age-specific growth rates to make inferences about adult mortality. The Preston-Bennett method uses age-specific growth rates for an intercensal period to convert a non-stable age distribution into the corresponding stationary or life-table population from which life expectancies at each age are obtained. This method does not require assumptions of stability, and is more appropriate for Tanzanian data because the method can be applied even when the intercensal period is not a multiple of five years. While the method is best suited for use in populations closed to migration, Preston and Bennett indicate that their method can be used in situations where migration is taking place, as long as observed growth rates are adjusted. In order to estimate a closed population during the intercensal period, we adjusted for the impact of migration on population growth rates using simple techniques that employ an adaptation of the cohort component approach. During the 1988–2002 intercensal period, Tanzania experienced inflow of migrants from the neighboring countries as well as migrants from overseas. For example the Rwanda-Burundi genocide of 1994, the Mozambican civil wars of 1987, and the 1997 civil wars in Congo forced a number of survivors and other individuals to flee their home countries and enter Tanzania. In this context, we take into account the possibility of effects of net migration on population growth rates in Tanzania.

The Preston-Bennett method is based on the discrete approximation of the general equation for the age distribution of a closed population suggested by Bennett and Horiuchi (1981). Therefore, the approximation for estimating mortality from the census data is deduced from the following relationship:

$$N(x) = N(0)\exp\left(-\int_0^x r(a)da\right)p(x) \qquad (1)$$

where *N(x)* is the number of persons aged *x*, *N(0)* is the number of births (persons at age 0), *r(a)* is the age-specific growth rates of persons aged *a*, and *p(x)* is the probability of survival from birth to age *x*.

And if we make *p(x)* the subject in equation (1), we get:

$$p(x) = \frac{N(x)\exp\left(\int_0^x r(a)da\right)}{N(0)}$$

In a conventional life-table notation $p(x) = l_x/l_0$, it means that *N(0)* is directly analogous to l_0 (the radix) and $N(x)\exp\left(\int_0^x r(a)da\right)$ is directly analogous to l_x (the number surviving to age *x*). Therefore it follows that:

$$ {}_nL_y = \int_y^{y+n} N(x)\exp\left(\int_0^x r(a)da\right) \qquad (2) $$

whose discrete approximation to five-year age groups becomes:

$$ {}_5L_y = {}_5N_y \times \exp\left(2.5 \times {}_5r_y + 5 \times \sum_{x=0}^{y-5} {}_5r_x)\right) \qquad (3) $$

And therefore other life table estimates can be calculated as follows:

$$ T_j = \sum_{y=j}^{\infty} {}_5L_y \qquad (4) $$

Also, $$ l_j = \frac{{}_5L_j + {}_5L_{j-5}}{10} \qquad (5) $$

And $$ e_j = \frac{T_j}{l_j} \qquad (6) $$

The geometric mean of the two census age distributions provides values for the mid-interval age distributions (the set of ${}_5N_y$'s and the intercensal growth rates (the set of ${}_5r_x$'s). Detailed description of methodology and calculation of complete life table estimates are described elsewhere (Preston, Hueveline and Guillot 2001). The computed abridged life-table will lack l_0 and e_0 since the value of $N(0)$ has to be obtained from registered births.

If there had not been a dramatic increase in mortality in the mid-1990s to early 2000 in Tanzania, we would expect a sequence of life expectancies at age x among adults in the intercensal period to decline regularly (small difference in the estimates from one age to the next). Otherwise, a large difference in the estimates of life expectancies between two successive ages would indicate a sharp increase in adult mortality in the time period. Ratios of life expectancies derived from the application of Preston-Bennett method to the estimates from the standard model life-table will provide some indication of the mortality experience for Tanzania. The ratio estimates will also provide an assessment of whether the intercensal age pattern of mortality reflects a pattern implied by the impact of HIV/AIDS as suggested from the analysis of data from Tanzanian demographic surveillance sites (Mswia 2006).

Adjustments for migration

While the Preston-Bennett has the advantage of being convenient for census intervals that are not multiples of five, and is relatively robust to local age misreporting patterns, it is sensitive to age distortions resulting from age misreporting and the presence of intercensal migration (Preston, Elo and Stewart 1999). Therefore, it is necessary to adjust for migration. In order to do so, we first estimate the annual net migration rates using the intercensal cohort-component estimation technique (see Appendix A for description of this method). The estimates of net annual migration rates are then subtracted from the annual age-specific growth rates before applying the Preston-Bennett method to estimate age-specific life expectancies for adult males and females. It should be noted that the age distributions and the estimates of age-specific growth rates are computed from the available data on population sizes by age; we do not engage in any further evaluation of completeness of enumeration coverage of the 1988 and the 2002 censuses and smoothing of age distribution other than what has already been done using the *Hill-Zlotnick*-Durch polynomial procedures and grouping of populations into five-year age intervals (United Republic of Tanzania 1994).

Comparison with standard model life tables

We apply ordinary least squares (OLS) regression to the Brass logit transformation of the estimates of intercensal survival probabilities (lx) estimated from Preston-Bennett method. We test the fit of the models for males and females using existing model life-table systems. Intercensal survival probabilities (lx) employed in the modeling range from l5 to l55. This regression technique allows us to select an appropriate model life table to use for comparing and assessing the magnitude of mortality for the 1988–2002 intercensal period. The model life table patterns we test include standard patterns are from Preston (1976) populations with life expectancy between 45 and 54 years), the Coale and Demeny (1966, 1983) with mortality level 15 (e_0 about 55 years for females and about 52 years for males), the INDEPTH (2004) patterns with e_0 between 50 and 56 years, the United Nations (1982) with e_0 of about 55 years for females and about 52 years for males, and the WHO (2002) models (AfrD with e_0 about 52 years for females and 50 years for males and AfrE with e_0 about 45 years for females and 44 years for males, together with WHO's estimates for the United Republic of Tanzania with e_0 about 47 years for females and 46 years for males).

In addition, we estimate probability of dying between ages 15 and 60 years (${}_{45}Q_{15}$) and compare our estimates with estimates from model life tables commonly used to estimate mortality. We also compare our estimates of life expectancy from our model with estimates from the INDEPTH pattern 2 (standard model) and with estimates from closely monitored populations with stable mortality rates during large portion of the intercensal period. Our objective in this exercise is to assess the degree to which Preston-Bennett are consistent with other data sources from Tanzania. Specifically, we compare the results of this indirect estimation procedure based on national census data to direct measurement from three demographic surveillance sites. The comparison this cannot be taken as a 'validation' or verification, but can help diagnose the presence of errors, if any, in the set of our population growth rates that we used as inputs into the Preston-Bennett model.

RESULTS

Mortality ratios in 1988 and 2002

Between 1988 and 2002, mortality levels increased dramatically among adults of both sexes. The probability of dying between ages 15 and 60 years increased by about 26% among men and about 39% during this time period. Ratios of age-specific death rates the two censuses for males (Figure 1) and for females (Figure 2) indicate a variation in the age patterns of mortality. Among males, age-specific ratios indicate that mortality increased markedly between 20 and 60, while rates between the ages 0–15 have declined. Similarly, the figure for females indicates that mortality increased dramatically between ages between 15 and 50, peaking among 30 to 40-year olds. Again, estimates of female mortality rates for infant and children were lower in 2002 compared to the estimates in the late 1980's.

(Figures 1 and 2 about here)

Estimates of levels of mortality in the intercensal period, 1988–2002

Estimates of mortality levels and life expectancies for the intercensal period after the application of the Preston-Bennett method are presented in Table 1 for females and Table 2 for males. These estimates take account of the net affects of migration (analysis not shown). The age-specific estimates of the life expectancies for the 1988–2002 intercensal period are much lower than those estimated for 1988, and somewhat lower than those for 2002 derived using life table techniques (results not shown). We observe a large decline in life expectancy with age among adults, indicating a sharp increase in adult mortality in the mid-1990s. Overall, the probability of dying between ages 15 and 60 years in the intercensal period was 0.50 for men and 0.55 for women. This is in line with the expectation of the impact of HIV/AIDS on mortality during that period.

(Tables 2 and 3 about here)

Sex differentials in life expectancy were also observed. Between the ages of 15 and 50 years, age-specific life expectancies were consistently lower in females. In the absence of the impact of HIV/AIDS on mortality, one would expect to see the reverse. This is consistent with findings from demographic surveillance work in Tanzania during the 1990s that showed considerably higher AIDS mortality in women.[2]

We also compared The PB estimates of life expectancies in Tanzania to the life expectancies derived from the INDEPTH pattern 2 model life tables (INDEPTH 2004), and from estimates of the life expectancies for the 1998–2002 period from the three community-based demographic surveillance sites in Tanzania (Mswia 2006). Both of these sources exhibit the impact of HIV/AIDS in death rates. Ratios of the estimated of intercensal life expectancies in Tanzania to the estimates of life expectancies from the INDEPTH pattern 2 and estimates from the DSS sites for ages 5–55 are plotted in the Figure 3 for females and Figure 4 for males.

(Figures 3 and 4 about here)

Taking the INDEPTH pattern as the standard model, we can indirectly assess the extent of the differentials in completeness of census coverage between the two censuses from the observed variation in the derived ratios for both males and females in the intercensal period relative to our standard. Usually, the ratios of the age-sequence of estimates of life expectancy are expected to decline regularly. In our case, the mean ratio for females for the first five ages

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[2] [1] Adult Morbidity and Mortality Project, National Sentinel Surveillance Teams (Tanzanian Ministry of Health). Monitoring community-level trends in HIV/AIDS/TB mortality in Tanzania: an equity perspective. Second Multisectoral AIDS Conference in Tanzania; 2002 December 16-20; Arusha, Tanzania; 2002.

(5–25) is 0.766 and for the last six is 0.626, giving an overall mean of 0.696. Similarly, the mean ratio for males for the ages 5–25 years is 0.861 and for the ages 30–55 is 0.759, giving an overall mean of 0.810. We observe a systematic decline in the overall pattern–lower ages associated with higher estimate of the ratio, and higher ages associated with lower estimate of the ratio for males and females.

Figure 3 for females show that the PB estimates are consistently lower than the estimates derived from the INDEPTH pattern 2 model life table and those derived from the demographic surveillance sites, indicating that mortality in these age range was very high. However, the life expectancy estimates for females in Dar es Salaam—a district in Tanzania considered to be heavily affected by HIV/AIDS pandemic—were closer to the our estimates of intecensal life expectancies, indicating that the impact of HIV/AIDS on mortality in Tanzania in the mid 1990's was severe, in the levels comparable to recent estimates for urban areas in the country. Ratios of estimates of the intercensal period to estimates from an affluent rural district in Tanzania suggest that although impact of HIV/AIDS is severe, there is wide variation within the country.

The plot of life expectancy estimates in males in the ages 5–55 (Figure 4) depicts a slightly different pattern. For males in the intercensal period are somewhat irregular but the ratios of intercensal life expectancy to the estimates of life expectancy in the demographic surveillance sites and in the INDEPTH pattern 2 shown some similarity in the age pattern. The pattern indicate a sharp increase in the ratios between the ages 15 and 25 among males before they begin to drop. The pattern tells us that in the ages where the ratios were increasing correspond to increase in mortality in the selected standard pattern and in the demographic surveillance sites to the levels similar to what was observed in the intercensal period. Sex differentials are also apparent when comparing the figures for males and females. Overall mortality among adult females in the intercensal period, as summarized by life expectancy estimates, was higher than among males in 1988–2002 period. The findings suggest that in the intercensal period, HIV/AIDS impact is largely responsible for recent increase in adult mortality, and the impact of the disease was more severe among women than among men.

Tanzanian congruency with model life tables

The OLS regression results of the Brass logit transformation for testing of applicability of model life table patterns to Tanzania are summarized in Table 4 for the 1988–2002 intercensal period. From the table, with the exception of AfrE model for males, it is observed that all the values of α for both female and male models are above zero (α>0), with p-values of less than 0.001. The parameter estimate indicate that that on average mortality in the intercensal period appears to have been significantly higher relative to all of the standard model life tables. In addition, majority of values of the β coefficients for both males and females are above unity (β<1), indicating that in the intercensal period in Tanzania, the overall mortality schedules for females and for males were more concentrated at older ages, relative to the standard model, than at younger ages. This is clearly an indication that adult mortality has dramatically increased in the 1990s. The best-fitting model for females in the intercensal period are the INDEPTH pattern 2 and the afrD models (R^2 = 0.988). High levels of infant mortality and very high levels of adult mortality characterize these two standard patterns. The INDEPTH pattern 2 model has an effect of HIV/AIDS mortality. The observed levels of mortality correspond to life expectancy of birth for females of approximately 50 years. For males, the best-fitting model for the intercensal period appears to be the Coale-Demeny models with mortality level 15, particularly the North model (R^2 = 0.956). The pattern corresponds to life expectancy at birth of about 52 years. The overall levels of mortality for both males and females are similar to the levels of mortality estimated for the three demographic surveillance sites in Tanzania (Clark et al. 2003; Mswia 2006). In summary, the findings suggest that overall mortality in the intercensal period (1988–2002) in Tanzania are consistent with what is predicted to be the moderate to severe impact of HIV/AIDS pandemic on mortality in sub-Saharan African in general and in Tanzania in particular.

(Table 4 about here)

DISCUSSION AND CONCLUSION

It is very likely that the observed variation in the age curves is a result of the impact of HIV/AIDS on mortality in Tanzania. Although it is anticipated that effects of HIV/AIDS pandemic will be experienced across all age ranges—from birth through mother-to-child transmission to adults mainly through sexual contacts—we do not observe increase in infant and child mortality in the time period of our analysis. One possible explanation for this is that Tanzania is yet to experience the full impact of the epidemic among children. Alternative explanation is that infant and child mortality is indeed decreasing in Tanzania despite the impact of HIV/AIDS on mortality. The improvements in child mortality are a result of local and international efforts aimed at promoting and improving maternal and child health through provision of ante-natal care, cost-effective interventions and access to heath care.

In this paper, we set out to examine adult mortality in the era of HIV/AIDS in Tanzania using census age data. Our approach is different to other studies that have looked at the impact of AIDS on mortality in Africa in the fact that we exclusively employ distribution of population by age from two consecutive censuses to produce our estimates—a method that may be useful in settings with poorly functioning vital registration systems and absence of reliable mortality statistics. Although the situation in few African countries is changing with respect to availability and accessibility of other mortality data from other sources, other than censuses, population censuses largely remains the major contributor of data sources that are periodically updated, although not as frequent. With appropriate adjustments and reasonable assumptions, methods that take into account age distributions such as the Preston-Bennett, are more appropriate in providing estimates of mortality and trends in mortality over time at national levels in resource poor countries. Moreover, it is possible to tease out an impact of a particular cause of death on the overall patterns of mortality, without necessarily having cause of death information, which is largely lacking at national level in many countries in sub-Saharan Africa.

It is argued that estimates of mortality from census data alone, especially in the era of HIV/AIDS, do not provide useful information for short term planning because of a range of uncertainty around these estimates (Stover, Ghys and Walker 2004). For accurate estimates of the impact of HIV/AIDS on the levels and rates of mortality, one needs to take into account both the demographic inputs (population distribution by age and sex) and the HIV-related inputs (including HIV prevalence, distribution of HIV infection by age and sex, and progression rates from HIV to AIDS) in modeling. Consequently, UNAIDS/WHO is promoting the use of Spectrum computer models (www.constellafutures.com) based on the above inputs to estimate the impact of AIDS on health and well-being of populations. While cause-specific inputs are desirable, they are not always available for inclusion in the model for majority of countries in sub-Saharan Africa. In countries where such data are available, they are usually estimated from a segment of population[3], vary within country and across time depending on the estimation

[3] For example: estimates of adult HIV prevalence based on data from pregnant women attending ante-natal clinics

methods used and assumptions employed in the analysis, and probably due to impact of country efforts and programmatic actions to combat diseases. In our application of Preston-Bennett method to Tanzanian data, we attempt to show that even with minimum set of data like census age distribution, it is possible to produce reliable estimates of adult mortality that are consistent with our expectations and which are within the ranges of estimates produced from sophisticated modeling techniques that require more data and assumptions on the level and trends in cause-specific mortality conditions.

The major concern of censuses conducted in sub-Saharan African countries is in the reliability of information collected and in the coverage (Dorrington et al. 2005). In this context, the Preston-Bennett technique becomes a useful alternative tool in estimating the changes in the adult mortality in the period between two censuses despite its inability to effectively represent mortality during the first five years of life, its sensitivity to completeness of census coverage, and its sensitivity to the impact of net migration to estimates of growth rates. With appropriate adjustments to the growth rates and age reporting, the Preston-Bennett method has many advantages over other intercensal procedures in counties with deficient vital registration systems and problematic census enumeration. The main focus of our paper was to investigate the changes in adult mortality in Tanzania during the 1988–2002 intercensal period, and whether HIV/AIDS epidemic plays a significant role in the observed changes. However, when reliable estimates of birth rates are available, it is possible to estimate mortality conditions of the under five using similar approach.

One disadvantage of the Preston-Bennett method mentioned earlier is that we cannot estimate life expectancy at birth—a measure that would have been useful in examining the changes in overall mortality in the period between the two national censuses. However, separate analysis using the 1988 census and using the 2002 census indicate that life expectancy at birth in Tanzania has declined between the two time points. In 1988, before impact of HIV/AIDS was considered severe, the estimate of life expectancy at birth was about 57 years for females and about 53 years for males. In 2002, life expectancy at birth for female was estimated at 56 and it was about 52 for males. In our estimation for the intercensal period, which is considered severely impacted by HIV/AIDS pandemic, we make use of standard model patterns and other sources of information available for a segment of population in Tanzania. With the choice of our model patterns, and the estimates from the demographic surveillance sites, we estimate the implied levels of life expectancy at birth in the intercensal period to be about 50 years for females and 52 years for males, a significant reduction when compared to the pre-AIDS era.

If there is any difference in the coverage completeness, errors may likely be introduced in our adjusted growth rates applied in the Preston-Bennett model. Presence of any errors might have some implications to our estimates of levels of adult mortality and life expectancies. However, if the difference in census completeness does not vary with age, then the intercensal growth rates will be in error by the same amount. We suspect that high estimates of growth rates are due to systematic error originating from the raw data on population sizes, particularly at older ages in the 1988 and in the 2002 censuses. The difference in the total populations by age in the 1988 and the 2002 censuses at these oldest ages were large. The systematic errors in the age distributions at older ages were either due to the change in census coverage between 1988 and 2002, or were due to age misreporting in the censuses. Both these explanations may introduce errors in the estimates resulting into the bias in the estimates of population sizes and growth rates. In our analysis, the population sizes by age groups from 1988 and from 2002 censuses were taken at face values.

In general, errors due to misclassification of growth rates result into under-estimation or over-estimation of mortality in the intercensal period, depending on the direction of misclassification. If growth rates are misclassified to higher rates or lower rates than what they should be, estimates of life expectancies become too high or too low. In our analysis, we employ Preston-Bennett technique to two censuses that are 14 years apart. Very long intervals are likely to give poor results. If age-specific growth rates change substantially from one five-year age group to another , the growth rates of the number of persons at different ages within each age group will also not be constant, hence introducing errors in the estimates of survival ratios. An illustration of a complete calculation and results of the application of cohort-component method for estimating net migration rates for females is presented in the Appendix A, with a table of results in Table 5.

In this paper, we have shown that adult mortality has indeed increased in Tanzania in the mid-1990s; several years after the first cases of HIV/AIDS were identified in the country. Sharp increase in mortality was observed in the ages between 15 and 50, affecting adults in the most productive and reproductive ages. Given the timing of the infection, age pattern of mortality and magnitude of the changes in mortality during the intercensal period, HIV/AIDS epidemic provides a credible explanation on the recent changes in adult mortality in Tanzania. Our findings are consistent other recent studies on the impact of HIV/AIDS on health and well-being of populations in sub-Saharan Africa (Blacker 2004; Sanders et al. 2003; Timaeus 1998). Our estimates of life expectancy for ages between 15 and 50 for both females and males show an age trend. The trend is more apparent for females, where the ratios decrease with increasing age, indicating that in the time period under study, young women are more affected than men. Additionally, the results for the 1988–2002 intercensal period in Tanzania show lower life expectancies among males and females compared to the standard model patterns and when compared to the recent estimates from demographic surveillance in three communities of differing socio-economic and demographic background. The results are in line with our expectations and what was considered the likely HIV/AIDS situation in Tanzania in the mid 1990s—that the epidemic is largely responsible for the high increase in morbidity and mortality among adults in their most productive years.

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APPENDIX A

Method for estimating net migration rates for the 1988–2002 intercensal period by 5-year age[4].

This method is based on the intercensal cohort component method. The method involves calculation of estimates by age group for males and females separately. Estimates of fifteen-year cumulative life table survival ratio between 'ages *x and above*' and 'ages *x+15 and above*' (T_{x+15} / T_x) were calculated to use in the estimation of annual net migration rates (Lahiri 2004). We generated life tables for 1988 and 2002 to obtain estimates of $T_x^{(1988)}$ and $T_x^{(2002)}$ to apply in the calculation of intercensal survival ratios (T_{x+15} / T_x). The ratios measure survivorship over a span of time represented by the differences between age groups reflecting the differences in years between two census periods. Because the 1988–2002 intercensal interval is 14 years and the cohort-component method requires intercensal period that are divisible by 5, we assumed a 15-year interval (from 1988–2003) in order to estimate life table survival ratios. This means that individuals who were 0–4 age group in 1988, they would be in the 15–19 age group in 2003. We also assumed that the 2002 population is very close to the 2003 population, and hence used the 2002 census data to represent 2003 in our application of cohort-component method. Our inputs for the cohort component method are:

1. Population sizes in 1988 and in 2002 by 5 year age groups, smoothed for age reporting, obtained from the 1988 and the 2002 national censuses, respectively.
2. Estimates of survivor ratios by 5-year age groups calculated from the estimates of life table from 1988 and 2002 census data.

We apply these inputs into an Excel spreadsheet to calculate estimates of annual net migration rates using the 'forward' and 'reverse' methods described below:

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[4] *Source:* Siegel and Swanson (2004)

Forward Method:

a) Survivors in 2002 by age groups are obtained by multiplying intercensal survival ratio with population size by age in 1988.

b) Net migration is then calcul

c) ated from subtracting survivors in the intercensal period (1988 to 2002) from the size of the population in 2002.

Reverse Method:

a) 'Younged' population in 2002 is obtained by taking population by age in 2002 divided by intercensal survival ratio for that age group.

b) Net migration is then obtained by subtracting population size in 1988 from the 'younged' population in 2002.

3. Average estimate of intercensal net migration (1988–2002) is obtained by averaging the sum of net migrations estimates derived from the 'forward' and 'reverse' methods described in (3) above.

Finally, the average annual estimates of net intercensal migration rates (1988–2002) are then obtained by taking the average estimates (obtained in step 4) divided by *Person-years lived in the 1988 to 2002 interval*. The estimate of the *person-years lived in the 1988 to 2002 period* is obtained by taking the geometric average of the 1988 and 2002 populations multiplied by the intercensal interval in years.

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Table 1: Average annual net migration rates, unadjusted and adjusted annual growth rates for Tanzanian females and males, 1988–2002

Start of age interval	Females: Average estimate of annual net migration rate	Females: Unadjusted average annual growth rate	Females: Adjusted average annual growth rate	Males: Average estimate of annual net migration rate	Males: Unadjusted average annual growth rate	Males: Adjusted average annual growth rate
0	0.00280	0.02067	0.01788	0.00300	0.02438	0.02138
5	0.00379	0.03292	0.02913	0.00334	0.02768	0.02433
10	0.00346	0.02617	0.02271	0.00355	0.02821	0.02466
15	0.00346	0.02360	0.02015	0.00373	0.02806	0.02433
20	0.00428	0.03219	0.02791	0.00402	0.02901	0.02498
25	0.00473	0.03533	0.03060	0.00511	0.04000	0.03489
30	0.00486	0.03391	0.02904	0.00549	0.04091	0.03542
35	0.00495	0.03145	0.02649	0.00553	0.03689	0.03136
40	0.00532	0.03185	0.02652	0.00597	0.03711	0.03114
45	0.00508	0.02335	0.01827	0.00551	0.02513	0.01962
50	0.00598	0.02802	0.02203	0.00642	0.02832	0.02190
55	0.00540	0.01249	0.00709	0.00596	0.01282	0.00687
60	0.00807	0.03225	0.02418	0.00826	0.02576	0.01750
65+	0.00896	0.02571	0.01675	0.00942	0.01971	0.01030
All ages	*0.00412*	*0.02817*	*0.02405*	*0.00425*	*0.02918*	*0.02493*

Note: Average estimates of annual net migration rates were calculated by the cohort component method. The method is outlined in the appendix A and in Table for appendix A

Table 2: Application of census-based Preston-Bennett method to Tanzanian females, 1988–2002

Start of age interval	Geometric mean of two populations (1988–2002)	Adjusted average annual growth rate	Sum of age-specific growth rates to midpoint of interval	Stationary Population in interval	Stationary population above age *x*	Number of surviving to age *x* *L_0 is empty*	Estimate of life expectancy at age *x* *e_0 is empty*
X	${}_nN_x^*$	${}_nr_x$	S_x	${}_nL_x$	T_x	l_x	e_x
0	2,452,514	0.01788	0.044689	2,564,601	25,596,774	-	-
5	2,030,307	0.02913	0.162211	2,387,861	23,032,173	495,246	46.51
10	1,839,976	0.02271	0.291811	2,463,453	20,644,312	485,131	42.55
15	1,555,026	0.02015	0.398949	2,317,389	18,180,859	478,084	38.03
20	1,394,096	0.02791	0.519092	2,342,779	15,863,469	466,017	34.04
25	1,165,298	0.03060	0.665371	2,266,753	13,520,690	460,953	29.33
30	900,275	0.02904	0.814483	2,032,830	11,253,938	429,958	26.17
35	678,473	0.02649	0.953322	1,760,172	9,221,108	379,300	24.31
40	543,282	0.02652	1.085865	1,609,200	7,460,936	336,937	22.14
45	429,968	0.01827	1.197851	1,424,479	5,851,736	303,368	19.29
50	374,232	0.02203	1.298611	1,371,260	4,427,257	279,574	15.84
55	275,383	0.00709	1.371428	1,085,276	3,055,997	245,654	12.44
60	253,299	0.02418	1.449609	1,079,422	1,970,720	216,470	9.10
65	188,813	0.01675	1.551921	891,298	891,298	197,072	4.52
70+	369,686	-	-	-	-	-	-

Note: Average annual growth rates are adjusted by subtracting average annual net migration from observed growth rates
Source: From authors' calculation of 1988 and 2002 Tanzanian census data

Table 3. Application of census-based Preston-Bennett method to Tanzanian males, 1988–2002

Start of age interval	Geometric mean of two populations (1988–2002)	Adjusted average annual growth rate	Sum of age-specific growth rates to midpoint of interval	Stationary Population in interval	Stationary population above age *x*	Number of surviving to age *x* *L_0 is empty*	Estimate of life expectancy at age *x* *e_0 is empty*
X	${}_nN_x^*$	${}_nr_x$	S_x	${}_nL_x$	T_x	l_x	e_x
0	2,386,461	0.02138	0.053455	2,517,501	25,162,641	-	-
5	2,120,645	0.02433	0.167742	2,507,942	22,645,140	502,544	45.06
10	1,833,203	0.02466	0.290229	2,450,503	20,137,198	495,844	40.61
15	1,447,235	0.02433	0.412702	2,186,619	17,686,695	463,712	38.14
20	1,144,432	0.02498	0.535975	1,955,963	15,500,076	414,258	37.42
25	989,820	0.03489	0.685651	1,964,856	13,544,112	392,082	34.54
30	816,785	0.03542	0.861417	1,932,931	11,579,256	389,779	29.71
35	636,716	0.03136	1.028366	1,780,571	9,646,325	371,350	25.98
40	516,363	0.03114	1.184625	1,688,227	7,865,754	346,880	22.68
45	401,324	0.01962	1.311528	1,489,650	6,177,526	317,788	19.44
50	351,435	0.02190	1.415336	1,447,162	4,687,876	293,681	15.96
55	265,215	0.00687	1.487258	1,173,561	3,240,714	262,072	12.37
60	240,058	0.01750	1.548173	1,128,963	2,067,153	230,252	8.98
65	186,101	0.01030	1.617664	938,189	938,189	206,715	4.54
70+	372,840	-	-	-	-	-	-

Note: Average annual growth rates are adjusted by subtracting average annual net migration from estimates of growth rates
Source: From authors' calculation of 1988 and 2002 Tanzanian census data

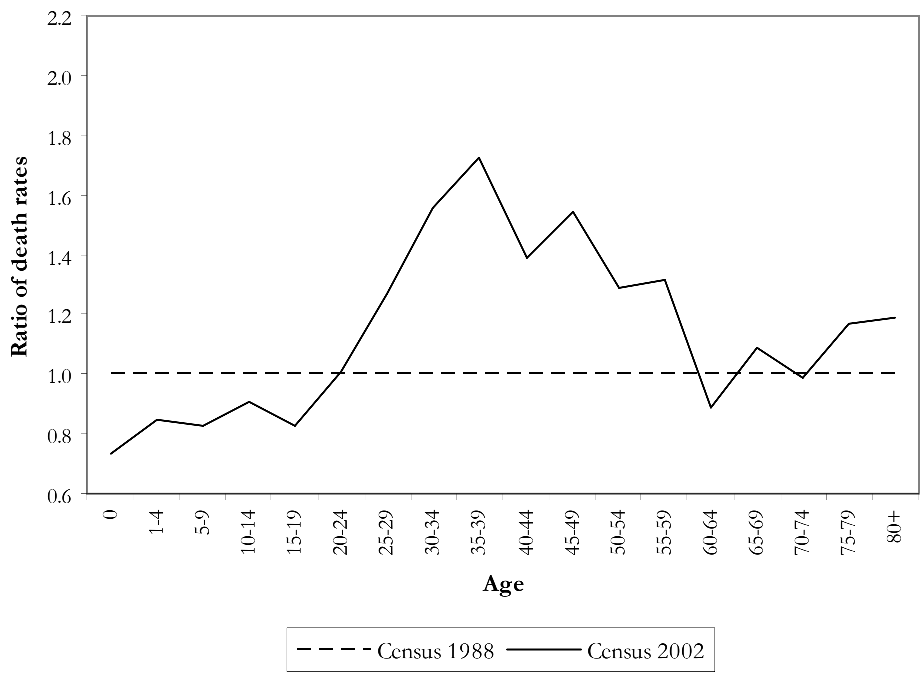
Table 4: Simple linear regression (OLS) of logit transformations of intercensal survival probabilities on model life table values

Standard Model Table	Females			Males		
	R^2	α	β	R^2	α	β
Preston's National Populations[1]	0.977	0.559	1.802	0.927	0.327	1.427
Coale-Demeny Models[2]						
North	0.963	0.631	1.571	0.956	0.400	1.301
West	0.976	0.637	1.505	0.932	0.443	1.261
South	0.975	0.929	2.167	0.928	0.595	1.675
East	0.978	0.845	1.881	0.919	0.540	1.533
INDEPTH Models[3]						
Pattern 1	0.976	0.734	1.742	0.902	0.350	1.171
Pattern 2	0.988	0.303	1.023	0.900	0.192	0.810
United Nations Models[4]						
Latin America	0.980	0.720	1.718	0.925	0.469	1.390
Chile	0.983	0.714	1.640	0.896	0.421	1.177
South Asia	0.962	1.132	2.448	0.875	0.733	1.916
Far Eastern	0.980	0.520	1.147	0.917	0.369	0.927
General Pattern	0.979	0.666	1.521	0.918	0.455	1.242
WHO 2000[5]						
AfrD	0.988	0.400	1.301	0.882	0.295	1.062
AfrE	0.978	0.010	0.839	0.880	-0.004	0.702
United Rep. of Tanzania	0.980	0.075	0.852	0.887	0.057	0.716

Notes: Standard patterns are from 1) Preston 1976 (Table 5.1: Populations with life expectancy between 45 and 54 years); 2) Coale and Demeny 1983-mortality level 15, e_0 is 55 for females and about 52 for males; 3) INDEPTH 2004, e_0 between 50 and 56; 4) United Nations 1982, e_0 = 55 for females and 52 for males; 5) WHO 2002 - AfrD (e_0=52 for females and 50 for males) and AfrE (e_0=45 for females and 44 for males) and WHO's estimates for the United Republic of Tanzania (e_0=47 for females and 46 for males.

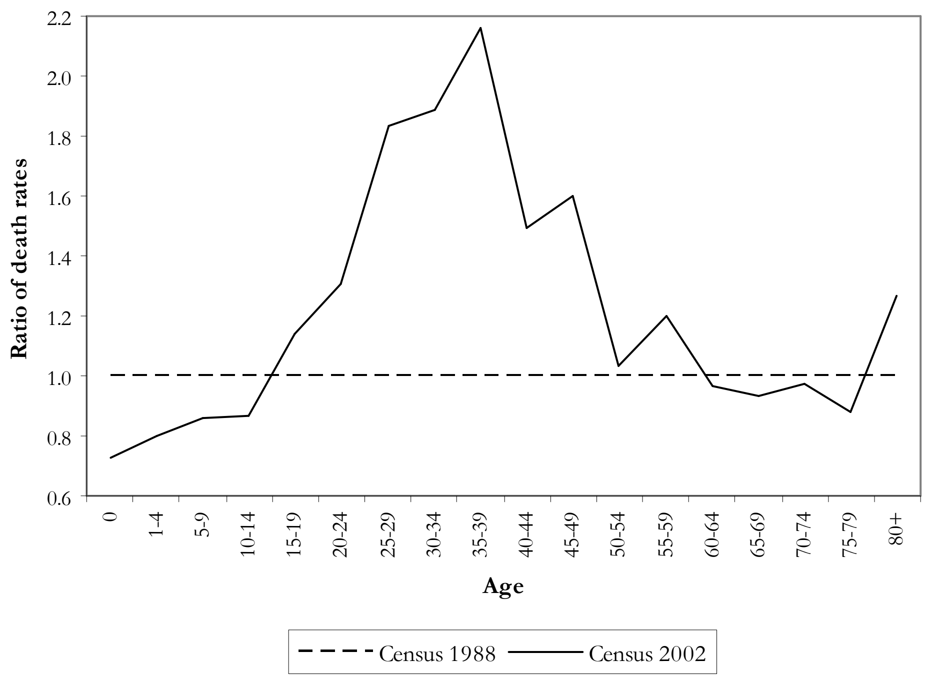
Source: From authors' calculations of Tanzanian intercensal (1988–2002) data using different standard model life tables.

Figure 1. Ratio of age-specific death rates for males from the 2002 census to the age-specific death rates from the 1988 census in Tanzania



Source: From authors' calculation of death rates from Tanzanian censuses of 1988 and 2002.

Figure 2. **Ratio of age-specific death rates for females from the 2002 census to the age-specific death rates from the 1988 census in Tanzania**



Source: From authors' calculation of death rates from Tanzanian censuses of 1988 and 2002.

Figure 3: **Ratio of intercensal life expectancy for females in Tanzania (1988–2002) derived using Preston-Bennett method to the estimates of life expectancy from the INDEPTH Pattern 2 and from the three DSS sites.**

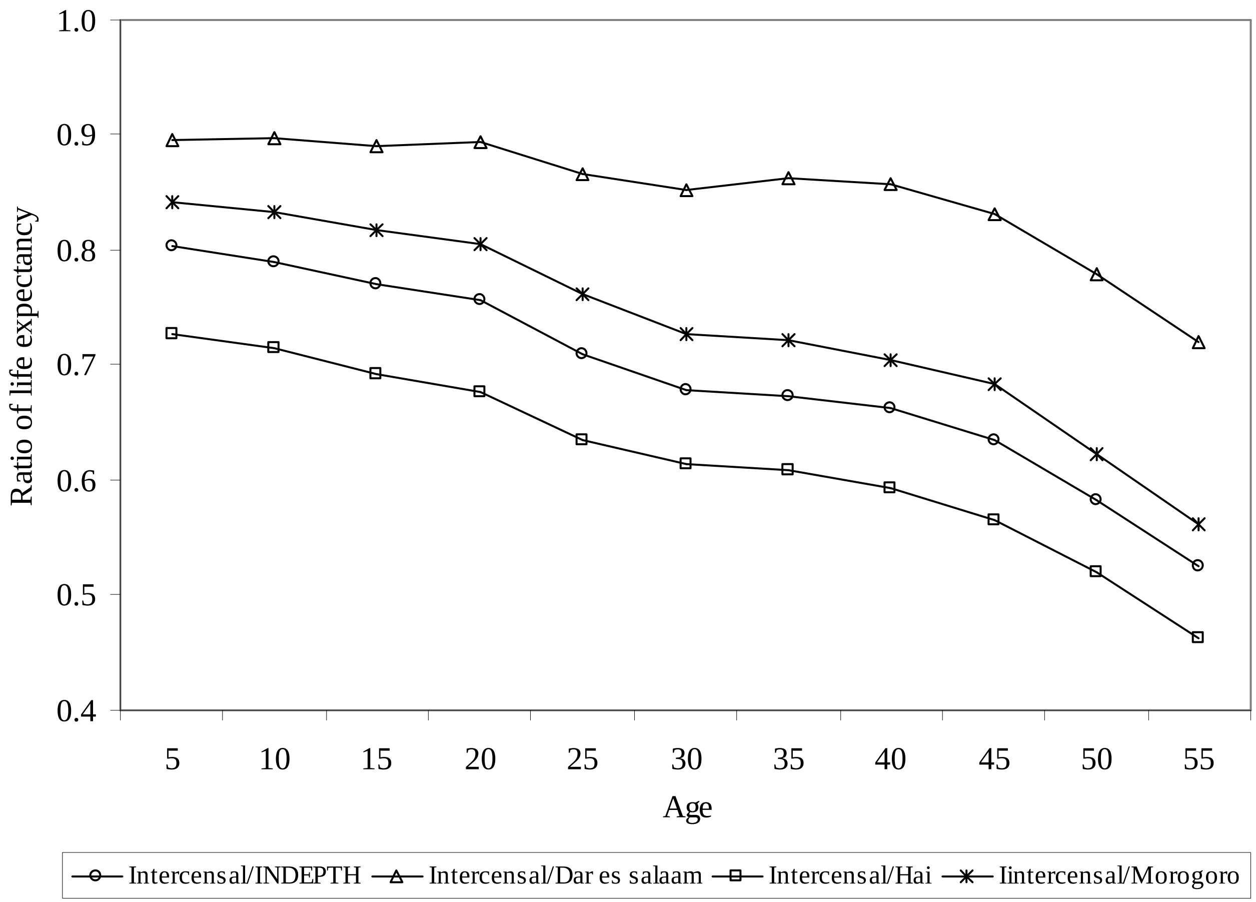


Figure 4: **Ratio of intercensal life expectancy for males in Tanzania (1988–2002) derived using Preston-Bennett method to the estimates of life expectancy from the INDEPTH Pattern 2 and from the three DSS sites**

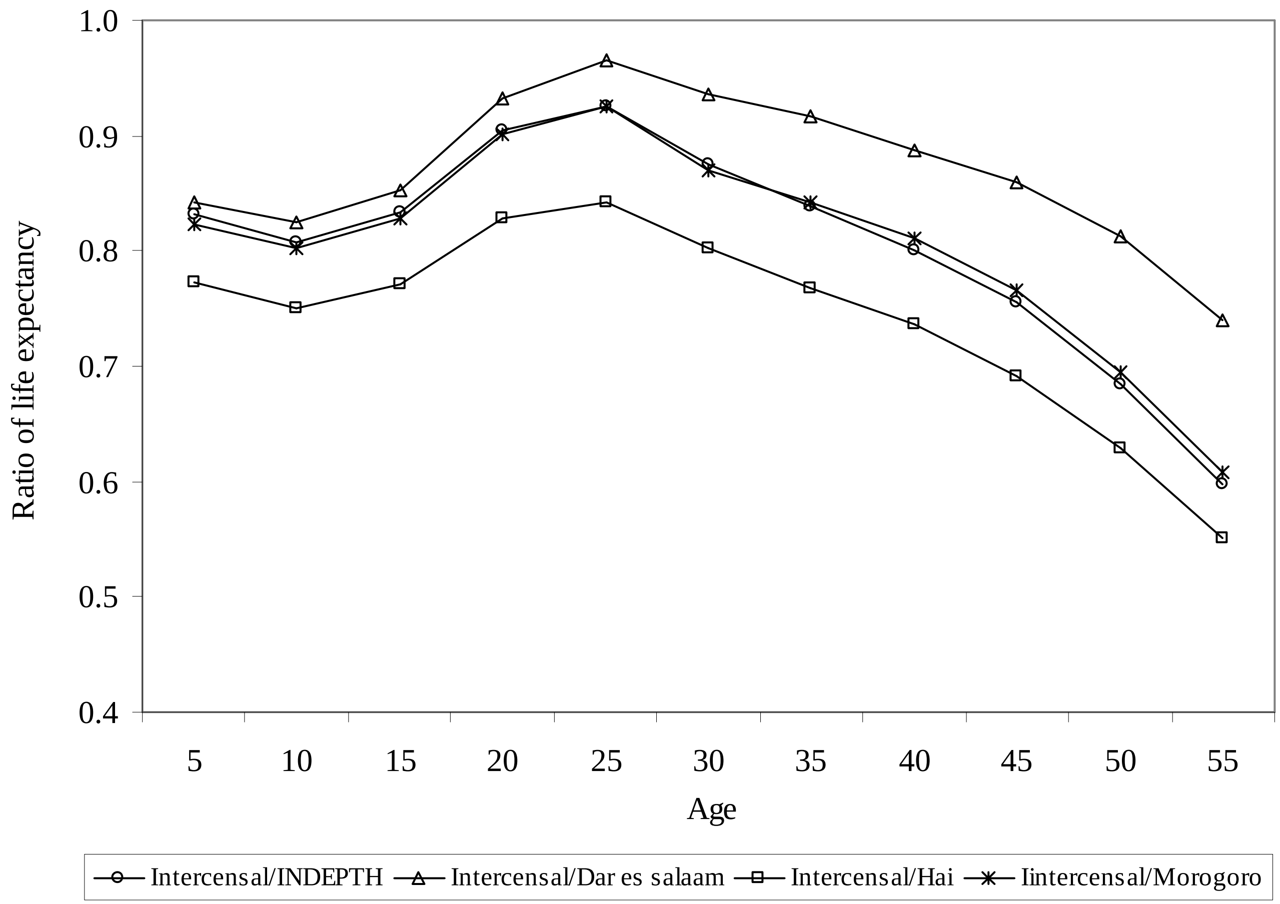


Table 5 for Appendix A: Calculation of estimates of net intercensal migration rates of females by age cohorts, Tanzania 1988–2002

Age in 1988	Population in 1988	Population in 2002	Life table survival ratio	Forward Method: Survivors (1) x (3) =	Forward Method: Net Migration (2) – (4) =	Reverse Method: 'Younged Population (2) / (3) =	Reverse Method: Net migration (6) – (1) =	Average estimate of net migration [(5)+(7)]/2=	Person-years lived in the intercensal period SQRT[(1)x(2)] / interval =	Annual Net migration rate (8) / [(9) x interval] =
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Total	*11,873,448*	*17,613,742*		*7,703,234*	*9,442,186*	*26,519,242*	*14,937,618*	*12,189,902*	*197,133,205*	*0.0618*
0-4	2,122,109	2,834,362	0.7528	1,597,422	1,236,940	3,765,333	1,643,224	1,440,082	34,335,197	*0.0419*
5-9	1,612,447	2,556,455	0.7363	1,187,259	1,369,196	3,471,987	1,859,540	1,614,368	28,424,304	*0.0568*
10-14	1,532,006	2,209,856	0.7148	1,095,111	1,114,745	3,091,478	1,559,472	1,337,108	25,759,668	*0.0519*
15-19	1,318,196	1,834,406	0.6915	911,548	922,858	2,652,747	1,334,551	1,128,704	21,770,368	*0.0518*
20-24	1,112,840	1,746,436	0.6677	742,993	1,003,443	2,615,778	1,502,938	1,253,191	19,517,345	*0.0642*
25-29	909,949	1,492,304	0.6434	585,459	906,845	2,319,411	1,409,462	1,158,154	16,314,179	*0.0710*
30-34	710,060	1,141,447	0.6181	438,862	702,585	1,846,811	1,136,751	919,668	12,603,856	*0.0730*
35-39	544,419	845,535	0.5905	321,466	524,069	1,431,958	887,539	705,804	9,498,619	*0.0743*
40-44	434,717	678,959	0.5594	243,198	435,761	1,213,641	778,924	607,343	7,605,944	*0.0799*
45-49	365,143	506,301	0.5238	191,251	315,050	966,646	601,503	458,277	6,019,549	*0.0761*
50-54	307,585	455,319	0.4836	148,738	306,581	941,584	633,999	470,290	5,239,242	*0.0898*
55-59	252,323	300,550	0.4376	110,429	190,121	686,737	434,414	312,268	3,855,359	*0.0810*
60-64	202,110	317,454	0.3864	78,097	239,357	821,553	619,443	429,400	3,546,193	*0.1211*
65-69	157,720	226,036	0.3259	51,401	174,635	693,579	535,859	355,247	2,643,384	*0.1344*
70+	291,824	468,322								

Note: This table was produced following a method to calculate the annual net migration rates outlined in Appendix A. The annual net migration rates are then used to adjust observed estimates of annual growth rates in the application of the Preston-Bennett method.