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Explanatory and technical notes

BY MID-2000 THE POPULATION OF SOUTH AFRICA IS ESTIMATED TO BE 43,68 MILLION (WITHOUT TAKING INTO ACCOUNT ADDITIONAL DEATHS DUE TO HIV/AIDS) AND 43,29 MILLION WHEN SUCH ADDITIONAL DEATHS ARE CONSIDERED. THESE ESTIMATES HAVE BEEN ARRIVED AT USING THE 1996 CENSUS FIGURES AS THE BASE POPULATION AND MAKING CERTAIN ASSUMPTIONS IN THE ESTIMATION OF FERTILITY AND MORTALITY.

Summary of methods used in preparing population estimates for mid-2000

Refinements and improvements in the methods used in population projections are on-going activities in several statistical agencies. In the previous statistical release on mid-year estimates, it was stated that population projections prepared by Stats SA would be revised to take AIDS as well as internal migration into account. This statistical release reflects such improvements.

Introduction

When fertility reaches low levels, the role of mortality in population projections becomes increasingly important. This is even more so when mortality starts showing signs of increasing. This phenomenon of fertility decline in South Africa has been confirmed through analyses done at Stats SA (Stats SA, 1999a and Udjo, 1999) and elsewhere. The observation about the rise in mortality was alluded to in Stats SA's statistical release on recorded deaths for 1996 (Stats SA, 1999b). A possible contributor to the rise in mortality is HIV/AIDS. In the 1999 sero-prevalence survey conducted by the Department of Health among pregnant women visiting antenatal clinics, HIV prevalence was estimated at 22,4% (Department of Health, 2000). This means that population projections for South Africa will be more realistic if special attention is paid to obtaining accurate mortality estimates (summarised as survivorship rates obtained from life tables). In addition, when projections are required at provincial level, the other dimension of regional population growth, namely, inter-regional migration has to be taken into account. For these reasons, Stats SA has revised its projection methodology to incorporate what it sees as more realistic life tables and to take into account inter-regional migration and additional deaths due to HIV/AIDS. These and other issues are discussed briefly below and at length in the explanatory and technical notes.

More realistic life tables

A life table is the demographer's way of representing the effects of mortality. Life tables are realistic when they adequately reflect the age pattern and level of mortality of the population under study. When death registration is complete, life tables (centered around census year) can be computed directly using the registered deaths and the population figures obtained from the census. The population figures are normally adjusted to bring the census population to mid-year (when the census date is different from mid-year). In cases where recorded deaths are not complete, the main challenge faced by the analyst is in estimating the degree(s) of completeness of death registration (either by age or globally). Thereafter, adjustment factor(s) are obtained which are applied to the recorded death rates before using them for subsequent construction of life tables. When recorded deaths are at a sufficiently high level, they still provide a good basis for constructing life tables. There are different views on what level can be described as 'sufficiently high'. Hill (1984) puts it at 75% while Preston (1984) puts it (as a rough rule of thumb) at about 60%. When the proportion of recorded deaths is above this threshold value, the data can be utilised for constructing life tables. Several demographic techniques have been devised for estimating the level of completeness of recorded deaths. Once the levels have been estimated, they can be used to adjust the

recorded death rates, which are subsequently used in the construction of life tables through standard demographic methods. In passing, it must be mentioned that there is the possibility of analysing census or survey data obtained in response to questions asked on 'deaths in the past year'. As Hill (1984) has noted, cases exist where responses to such questions have been so poor as to be uninterpretable. Hence, in this report, deaths registered through the civil registration system are analysed rather than deaths reported by respondents in a survey or census.

For South Africa as whole, one can safely say that registration of deaths is above 50% but less than 100% complete. A life table constructed on the assumption that death registration is 100% complete would give the lowest mortality or the maximum calculable life expectancy at birth. On the other hand, a life table constructed on the assumption that death registration is only 50% complete would give the highest mortality or the lowest life expectancy at birth. This reciprocal relationship between mortality and life expectancy is common knowledge. However, as pointed out by Pollard (1982), the exact mathematical connection between the two is rather complicated.

When recorded deaths are low (below the threshold level of 60%-75%), they still serve some purpose but generally are not of much use in the construction of life tables. For such populations, life tables could be constructed using other means such as analysis of survivorship of kin data (sons, daughters, sisters, mother or spouse). In the preparation of the last two mid-year population estimates (Stats SA 1998 and Stats SA 1999c), the life tables used were based on survivorship of kin since at the time of writing the data on recorded deaths for 1996 were not yet available. There are two serious problems with the survivorship of kin methods. The mortality estimates (for adults) refer to some distant past and extrapolations invariably have to be used to obtain estimates for the more current period. When mortality has increased in ways contrary to what the trends show, the life tables obtained as a result of such extrapolations could under-estimate mortality. A second serious problem is in their failure to adequately capture the prevailing age patterns of mortality. The methods compute life table measures at selected ages and then using standard life tables (and with the aid of parametric models of two or more parameters), estimate the age patterns of mortality at all other ages. Recorded deaths on the other hand give the mortality rates for the current period and reflect the underlying age pattern of mortality. However, in cases where recorded deaths are not available or of very poor quality, there is hardly any alternative to deriving life tables based on survivorship of kin, as described above.

In preparing the life tables for this report, both methods of construction were used. In the case of the provinces and urban and non-urban projections, life tables were based on recorded deaths adjusted for incompleteness. Since the recorded deaths do not have population group identifiers, life tables for population groups were constructed using survivorship of kin data obtained from the 1996 census. Further details are given in the explanatory and technical notes.

Additional deaths due to HIV/AIDS

In this report, the number of new AIDS cases in a given year has been estimated from the Department of

Health's sero-prevalence data (with provincial level breakdowns). The method used is covered in the explanatory and technical notes. Several assumptions are needed to translate new AIDS cases to 'additional deaths due to HIV/AIDS'. First, it is assumed that the period from new AIDS cases to death is a year. Second it is assumed that all the new AIDS cases in 1995 which led to deaths in 1996 have been included in the life tables constructed for 1996 (adjusted for under-registration of deaths). In short, those AIDS deaths have become part of 'normal mortality' and are not part of 'additional deaths due to HIV/AIDS'. By October 2001, the additional deaths due to HIV/AIDS that would have occurred to the population alive in 1996 are taken as the deaths occurring between January 1997 to October 2001 less the AIDS deaths that would occur over this period as part of 'normal mortality'. These deaths are subtracted from the projected 2001 population to obtain the estimated population with 'additional deaths due to HIV/AIDS'. *Taking account of inter-regional migration*

From the 1996 census, it is possible to obtain figures for all the migration streams into, and out of, any province for the five-year period prior to the census, 1991-1996. The figures are used to obtain age-specific migration rates used in the projection model. Further details are given in the explanatory and technical notes.

Materials/software used

Several software programs were used in the course of preparing this report. Specifically, the following have been used:

1. Population Analysis System (PAS) from the US Census Bureau. The product is shareware and can be downloaded from the following site: <http://www.census.gov/ipc/www/pas.html>.
2. AIDSProj from Futures Group International. The product is shareware and can be downloaded from the following site: <http://www.tfgi.com/aidsproj.asp>.
3. The United Nations Software Package for Mortality Measurement (MORTPAK-LITE) and QFIVE. Both products have copyrights and can be purchased from the United Nations at the following address: Department of International and Economic and Social Affairs, United Nations, New York, New York 10017, USA.
4. Several linked Excel programs and FORTRAN programs developed at Stats SA.

Way forward

Stats SA has acquired several programs for estimating/projecting the prevalence of HIV/AIDS as well as software for doing full multiregional population projections. Stats SA will continue its research efforts in assessing these programs and seeing how best some of them can be utilised in producing more accurate population projections. Readers will be updated on any progress/breakthroughs in subsequent releases on mid-year estimates. At the same time, Stats SA is working towards including uncertainty in its forthcoming detailed population projection report. One approach for doing so is the Bayesian Demographic approach. Some experts are assisting Stats SA in this regard and the preliminary findings

on the feasibility of this for South Africa have been outlined in a consultancy report (Daponte and Wolfson, 2000).

Summary of population estimates for mid-2000

The report presents results at 16 levels of aggregation/disaggregation, namely: RSA; urban and non-urban areas; 5 population groups (including 'other/unspecified'); and 9 provinces. The results of the mid-year estimates are shown in Table 1.1 through 1.3. By mid-2000 the population of South Africa is estimated to be 43,68 million (without taking into account additional deaths due to HIV/AIDS) and 43,29 million when such additional deaths are considered. These estimates have been arrived at using the 1996 census figures as the base population and making certain assumptions in the estimation of fertility and mortality. The growth rates that underlie these estimates are summarised in Table E. These growth rates are 'inferred' growth rates, which differ from actual growth rates obtained from two consecutive censuses.

Mid-year population estimates for 2000

RSA, urban and non-urban, without additional deaths due to HIV/AIDS

		Population estimates for Mid-2000
RSA	Male	21 016 530
	Female	22 669 169
	Total	43 685 699
Urban	Male	11 273 108
	Female	11 852 086
	Total	23 125 194
Non-urban	Male	9 743 422
	Female	10 817 083
	Total	20 560 505

1. Mid-year population estimates for 2000

2. RSA, population groups, without additional deaths due to HIV/AIDS

		Population estimates for Mid-2000
RSA	Male	21 016 530
	Female	22 669 169
	Total	43 685 699
African/Black	Male	16 245 538
	Female	17 634 314
	Total	33 879 852
Coloured	Male	1 841 970
	Female	1 954 888
	Total	3 796 858
Indian/Asian	Male	534 390
	Female	558 132
	Total	1 092 522
White	Male	2 200 000
	Female	2 321 663
	Total	4 521 664
Other and Unspecified	Male	194 632
	Female	200 171
	Total	394 803

1 Mid-year population estimates for 2000

3. RSA, provinces, with and without additional deaths due to HIV/AIDS

	Population estimate with additional deaths due to HIV/AIDS	Population estimate without additional deaths due to

			HIV/AIDS
RSA	Male	20 819 156	21 016 530
	Female	22 472 285	22 669 169
	Total	43 291 441	43 685 699
Western Cape	Male	2 036 917	2 042 963
	Female	2 141 681	2 147 693
	Total	4 178 598	4 190 656
Eastern Cape	Male	3 160 441	3 178 318
	Female	3 650 932	3 668 844
	Total	6 811 373	6 847 162
Northern Cape	Male	424 897	426 710
	Female	444 351	446 155
	Total	869 248	872 866
Free State	Male	1 358 083	1 373 193
	Female	1 402 475	1 417 540
	Total	2 760 558	2 790 733
KwaZulu-Natal	Male	4 154 070	4 218 749
	Female	4 703 545	4 768 109
	Total	8 857 615	8 986 857
North West	Male	1 734 108	1 751 111
	Female	1 798 716	1 815 666
	Total	3 532 824	3 566 777
Gauteng	Male	3 948 551	3 994 974
	Female	3 832 079	3 878 231
	Total	7 780 631	7 873 205
Mpumalanga	Male	1 460 214	1 479 104
	Female	1 544 702	1 563 534
	Total	3 004 916	3 042 637

Northern Province	Male	2 541 874	2 551 409
	Female	2 953 805	2 963 398
	Total	5 495 679	5 514 807

Explanatory and technical notes

In a departure from the last mid-year estimates that made use of only the 1996 census data, this report makes use of the 1996 census data, registered births and deaths and data on documented immigration and self-declared emigration. Further details are given below.

1. Base population

For the purpose of computing central death rates, it was necessary to use the mid-1996 population. In order to bring the population to mid-year ('younging'), the total population had to be multiplied by a factor. An estimate of the mid-year population was obtained by using a modified form of the balancing equation. This is the balancing equation with adjustments for undercount on the terms dealing with death, births and migration. The ratio of this estimate to the 1996 census population gives an adjustment factor used to 'young' the population.

For the projections, the base population used was the actual 1996 census data adjusted for undercount by the post-enumeration survey. The reported ages of the population were used as they were without any adjustments made to them. A small proportion of the population had unstated ages. This proportion was distributed among the population of known ages through a standard procedure explained below. Projections were done on the population with known ages and an adjustment factor for pro-rating the population of unknown ages, k , was calculated and applied to the projected population. The adjustment factor, k , is calculated as follows:

$$k = P_T / (P_T - P_u)$$

where

P_T is the total population over all ages (including those with unknown ages), and

P_u is the population of unknown ages.

The adjustment factors obtained are given in Table A.

2. Estimation of population aged 0-4

From the census data, reported fertility (births in the past twelve months) per woman and parity (average number of children ever born per woman) were obtained. However, due to the misunderstanding of the reference period, reported fertility often underestimates true fertility. There is therefore the need to adjust the reported fertility estimates. The method opted for is that of Arriaga (1983). In that method, the reported parities are transformed into age-specific fertility rates and are subsequently cumulated. These cumulated rates are compared with another set of cumulated rates obtained from the reported fertility to obtain adjustment factors. Adjustment factors could be based on age groups 20-24, 25-29 or 20-29.

Adjustment factors based on women in the age group of 20-29 years have been used, as they usually give estimates that lie between those obtained from the 20-24 age group and the 25-29 age group. The program used for doing this is FERTPF in the United Nations Software Package for Mortality Measurement (MORTPAK). Note that there are other methods for indirectly estimating fertility which would not necessarily give the same results. With direct techniques, it is possible to arrive at a fixed value, but with indirect methods, the values and variances vary slightly within an acceptable range.

The adjusted age-specific fertility rates are used to obtain an estimate of the average annual number of births. This is multiplied by five to obtain average number of births for five years. This number is separated into males and females using an assumed sex ratio at birth (1,03). For each pair of male and female life tables, the respective number of five-year births is multiplied by the five-year survivorship ratio from birth to obtain an estimate of the population aged 0-4.

Table A. Adjustment factors for unknown ages in the 1996 census data

Broad category	Unit	Gender	Adjustment factor for unknown ages, <i>k</i>
Total	South Africa	Male	1.013249
		Female	1.011280
Urban/non-urban	Urban	Male	1.013399
		Female	1.010921
	Non-urban	Male	1,013069
		Female	1,011682
Population group	Africans/Blacks	Male	1,012713
		Female	1,011033
	Coloureds	Male	1,008511
		Female	1,007423
	Indians/Asians	Male	1,009092

		Female	1,008806
	Whites	Male	1,016343
		Female	1,013680
	Others and	Male	1,081407
	Unstated	Female	1,049809
Province	Western Cape	Male	1,012425
		Female	1,008996
	Eastern Cape	Male	1,009130
		Female	1,007416
	Northern Cape	Male	1,012227
		Female	1,009987
	Free State	Male	1,011974
		Female	1,010441
	KwaZulu-Natal	Male	1,015138
		Female	1,013524
	North West	Male	1,009349
		Female	1,007395
	Gauteng	Male	1,014680
		Female	1,012884
	Mpumalanga	Male	1,019284
		Female	1,016576
	Northern Province	Male	1,013774
		Female	1,012319

Note: The categories used in the first column are non-overlapping since the provinces totals add up to RSA, the five population groups add up to the RSA and the urban/non-urban locations also add up to the RSA.

3. Incorporation of internal migration into the projections

3.1 Background

When projections for all the regions of a country are required and the appropriate data are available, a multiregional approach should be considered (United Nations, 1992). The method combines the cohort-component perspective of demographic projection with matrices of inter-area migration rates (Rees, 1994). In this approach, regional population projections are generated simultaneously for a system of several interacting regional populations and it guarantees that the total migration flows between regions will sum to zero (or to the assumed level of international migration). The required mathematics for doing so (known variously as multistate demography, multiregional mathematical demography and multidimensional mathematical demography) has been developed through the works of Rogers (1973, 1975), Willekens and Rogers (1978) and Ledent (1980) among others. In the case of migration, the data come in different forms. Research in multiregional demography has seen the emergence of different techniques to handle different data types. First is the distinction between migration data recorded as relocation events (as in the case of migration information derived from a Population Register) and migration data derived by a comparison of place of residence in two points in time (as in the case of retrospective questions asked in censuses and surveys). The former is known as the 'movement approach' or 'movement perspective' and the latter as 'transition approach' or 'transition perspective' (Rees, 1997; Ledent, 1980). Unlike births and deaths, each type of migration data has its own peculiar twist. For migration data that come in the form of 'place of previous residence', the application of multiregional demography has been outlined by Philipov and Rogers (1981). For migration data that comes in the form of 'lifetime migration', the application of multiregional demography has been outlined by Ledent (1981) while for 'last-move' migration data, the topic has been covered by Schmertmann (1999).

The prerequisite for a full-scale multiregional population projection is the multiregional life table model. Developments in multistate demography have seen the vector generalisation of ordinary life table functions to suit the multiregional context. In particular, works on multiregional life tables from within the transition perspective have been investigated by Rogers (1975), Willekens and Rogers (1978), Ledent and Rees (1980), and Ledent (1982) among others. The estimation of the full multiregional life table requires age-specific flows among the various states considered in the analysis. For the internal migration component, all elements of the 'migration cube' (age, origin and destination) need to be provided (Rees and Kupiszewski, 1999). For the mortality component, age-specific mortality rates have to relate not only to the state of residence at age x but also to the state in which the deaths actually occur (Ledent, 1982). Naturally, the data requirements for the application of the full multiregional population projection model are quite demanding and in many cases the data are not available. To overcome these data shortcomings, the estimation of missing data has been addressed by Willekens (1982). Another work has investigated the extent to which the full internal migration matrix can be simplified without seriously affecting the performance of the resulting multiregional model (van Imhoff *et al.*, 1997). Lastly, another work has developed model multistate migration schedules for use in situations where the available migration data are inadequate or inaccurate (Rogers and Castro, 1982).

3.2 Application of multiregional demography to relatively 'data-poor' countries

Attempts at applying multiregional demography to relatively 'data-poor' countries have been undertaken by only a few researchers. An early attempt was by Doeve (1984) in which he used Thailand's data. In that study, Doeve made the following remarks:

The operationalization of something as sophisticated as multistate demography in developing countries is not necessarily a 'dirty job'. (Doeve, 1984)

Some aspects of this operationalisation have been addressed by Bah (1990). In that paper, the following remarks were made about Doeve's work:

What could ... be learnt from Doeve's exercise is the lesson that data which suffers from underenumeration and omissions should not be dismissed as being unfit for the purpose of construction of multiregional life tables. Or to phrase this in other words, we cannot say that because African data is beset by problems of underenumeration [,] omission and misreporting, we should not attempt [to use them] to construct multiregional life tables. (Bah, 1990:15)

In another attempt, the United Nations (1992) applied a modified multiregional projection model to Indonesian data. This method has been adopted in this report. Details are given in the next section..

3.3 United Nations' modified multiregional migration model

In attempting to reduce the data needs for doing a full multiregional population projection model, the United Nations (1992) developed a spreadsheet program based on a simplification of the multiregional approach of Rogers (1985). From the methodological steps outlined in the example, one can mathematically describe the simplification procedure as follows:

In a single region (with no migration considered), one has that,

$${}_5P_{x+n,t+n} = {}_5P_{x,t} * \frac{{}_5L_{x+n}}{{}_5L_x}$$

where

${}_5P_x$ is the population aged x to $x+4$ at time t

${}_5P_{x+n}$ is the population aged $x+n$ to $x+n+4$ at time $t+n$

and

${}_5L_{x+n}/{}_5L_x$ is the life table survivorship ratio from age $x+4$ to age $x+n+4$

With the inclusion of migration, the survivors in region j (5 years later), out of the original population in region i , is given by:

$${}_5L_{x+n,t+n}^{ij} = {}_5L_{x,t}^i * \frac{{}_5L_{x+n}^i}{{}_5L_x^i} * [{}_5M_{x+n,t+n}^{ij}]$$

The non-migrant population in region i is given by:

$${}_5L_{x+n,t+n}^{ii} = {}_5L_{x,t}^i * \frac{{}_5L_{x+n}^i}{{}_5L_x^i} * \left[1 - \sum_{j \neq i} {}_5M_{x+n,t+n}^{ij} \right]$$

where ${}_5M_{x+n,t+n}^{ij}$ is a conditional probability (also known as conditional migration proportion). It denotes the probability of being in region j at time $t+n$, conditional on survival to time $t+n$. It is loosely called 'migration rate' but is different from the usual age-specific mortality and fertility rates. It expresses the number of migrants as a fraction of the population of region i , aged x to $x+n$ at the beginning of the period.

Mathematically, ${}_5M_{x+n,t+n}^{ij}$ is defined as:

$${}_5M_{x+n,t+n}^{ij} = \frac{{}_5M_{x+n,t+n}^{ij}}{[{}_5L_{x+n,t+n}^i - [{}_5M_{x+n,t+n}^{i1} + \dots + {}_5M_{x+n,t+n}^{in}]]}$$

where

${}_5M_{x+n,t+n}^{ij}$ is the age-specific migration stream from province i to province j , over the previous five-year period. This refers to persons whose last moves occurred within the specified interval, originating in i and terminating in j ,

${}_5M_{x+n,t+n}^i$ is the sum of all age-specific migration streams into province i , over the previous five-year period, and

${}_5M_{x+n,t+n}^i$ is the sum of all age-specific migration streams out of province i , over the previous five-year period.

This formula is similar to the version suggested in United Nations (1970). However, further clarification on the formula was offered by van Imhoff (2000) and Ledent (2000). In this expression, the denominator is composed of persons who resided in i throughout the entire interval plus all persons whose last move (made after time t) originated in i , regardless of where they resided between time t and time of last move. Other formulae for estimating age-specific migration rates have been suggested in the literature (Ledent, 1982). Note that in the United Nations document where the modified multiregional method was outlined, the migration rates were obtained from the Rogers and Castro model. However, in this case, migration rates have been estimated, since the census data provide figures on migration for the five years prior to the census.

This UN model is simplified in that survival, migration and births are calculated independently. Whereas in the full multiregional migration model, all the demographic rates are applied simultaneously, in some modified models (as in this case), it is done sequentially (van Imhoff *et al.*, 1993). The model uses fertility and mortality rates for the region at the start of the interval, irrespective of whether a migration occurred. This could probably lead to some distortion, especially if the migration is from a region of lower mortality to a region of higher mortality (van Imhoff, 2000).

The method described above was applied to the nine provinces of South Africa, using data from the 1996 census. The spreadsheet file used for doing so was developed at Stats SA. This is the first stage towards applying a near-full multiregional migration model. As the migration propensities from the 1996 census are low, the modified model is probably sufficient at this stage.

4. Incorporation of deaths due to HIV/AIDS

This section reviews Stats SA's attempt to incorporate additional deaths due to HIV/AIDS into the mid-year estimates. Earlier on, a workplan had been set out in which the exercise would start with a literature review on HIV/AIDS models. This was completed and the as yet unpublished document resulting from the review is titled: "A supplementary review of existing HIV/AIDS models with the view of adopting/adapting one or more models for national and provincial population projections in South Africa". In that report, the following was suggested as the way forward:

In making selection of models for projecting HIV/AIDS prevalence, the preference has to be for models that maximise the available data in South Africa. A model, no matter how elegant or realistic, cannot be utilised if the necessary input parameters are not available. In view of the discussion above, Stats SA could use three strategies: short run, medium term and long run. In the short run, at least two issues could be addressed. First is the construction of life tables reflecting both pre-AIDS mortality and mortality during the AIDS era. Here, some of the works of Ian Timaeus could be drawn upon as well other

indirect demographic estimation techniques. Second, AIDSproj could be made use of to obtain projections of HIV/AIDS prevalence and these rates could be fed other projection software/programs to prepare projections that incorporate HIV/AIDS. The different ways of preparing population projections incorporating HIV/AIDS have been discussed in Stover and Way (1998). In the medium term, programs could be written to use the model of Mariotto and Verdecchia and adapt it where necessary. In the long term, the model of Mariotto and Verdecchia could be reformulated within a Bayesian framework to allow for uncertainties in all of the input parameters. This would fit in quite well with the Bayesian population projections that Stats SA would be preparing for its detailed population projections.

The first aspect was completed and the results are to be published as a Stats SA life table report (Report No. 02-06-04 (1985-1994 and 1996)). The AIDSProj spreadsheet model was modified to handle South Africa's nine provinces. The main input data needed for the application of the model are base populations, annual growth rates and sero-prevalence data from antenatal clinic surveys. The user has the option of accepting the sero-prevalence data as reported or make some adjustments to them (taking account of male HIV infections, women of all ages and lower fertility among HIV+ women) using the data supplied in the model or otherwise. The user is also expected to fit a gamma curve to the sero-prevalence data (by changing the parameters of the model, α and β), chosen from one of three incubation distribution functions (fast, medium or slow) and choose the reference year (usually the last year for which surveillance data is available).

The sero-prevalence data used were those reported by the Department of Health based on the ongoing national antenatal clinic surveys that have been conducted since 1990. The gamma functions were successfully fitted to the available sero-prevalence data (1990 to 1999). Appropriate selections of parameters were made with expert advice (Stover, 2000).

5. Estimation of under-registration of death registration and the subsequent construction of life tables

5.1 Background and overview

Before selecting methods for estimating the degree of completeness of death registration, it is possible to obtain a reasonable range estimate within which calculated values should lie. In the case of South Africa, the disparity between urban and non-urban areas bears heavily on estimates of completeness of death registration. To get an idea of what this means, we take an example using the 1996 deaths data and figures from the 1996 census. The 1996 census reports 54% of the population living in urban areas and 46% in non-urban areas. The 1996 death data however reports 76% of deaths occurring to residents of urban areas and 24% to residents of non-urban areas. If we calculate the crude death rates, this gives 11,4 per thousand for the urban areas and 4,1 per thousand for the non-urban areas. This does not seem plausible. It could only mean that the deaths in the non-urban areas are considerably under-reported

compared to deaths in the urban areas.

Since the population of South Africa is 46% non-urban, the average for South Africa as a whole would be lowered even if the completeness in the urban areas were high. If, for illustrative purpose, we apply the death rate in the urban areas to the non-urban areas, this would yield a figure of 248 313 for deaths in non-urban areas instead of the recorded 77 330. This would mean that deaths in non-urban areas are under-recorded by just over 3,2 times. So for South Africa as whole, the level of completeness of death registration as at 1996 would be 71% at the maximum. It is hard to see how it can be greater than this when births registered in 1996 was only about 50% complete at the maximum (based on comparison of currently registered births with population register figures which are continuously updated for late registrations).

To continue along the same lines of reasoning, if the death rate in the non-urban areas is higher than that in urban areas (a phenomenon that should not be taken for granted) the level of completeness of death registration in South Africa would even be lower. While there are techniques for estimating completeness of death registration, as mentioned earlier, these are only usable when registration of deaths is sufficiently high. When registration of deaths is lower than the suggested threshold figure, the techniques have to be used with great caution. Stats SA has devised a way of going around this. The method, however, would need estimates of completeness for RSA as a whole and for urban areas. These would have to be obtained by one of the existing methods for estimating the level of completeness of death registration.

Preston (1984) provides a comprehensive review of direct and indirect techniques for estimating the completeness of death registration. Each of the techniques was developed based on one of three assumptions, namely: the assumption of population stability, the assumption of quasi-stability and the assumption that registered deaths represent a constant proportion of true deaths at each age within the age range considered.

While there are many indirect methods proposed for estimating the completeness of death registration, four of them stand out as being most widely applied. These are the Brass method (Brass, 1975), the Preston and Coale method (Preston *et al.*, 1980), the Preston and Hill method (Preston and Hill, 1980) and the Bennet and Horiuchi method (Bennet and Horiuchi, 1981). In his review of techniques available for estimating the completeness of death registration, Preston (1984) also gave more attention to these four techniques. The first two methods were widely applied in the model life table construction project of the United Nations and in that of the Organisation for Economic Co-operation and Development (OECD) (Preston, 1984).

5.2 The method adopted and justification for doing so.

There is some confusion on the application of the Preston-Coale and the Bennet-Horiuchi methods with regards to the registered deaths used. The equation on which the method is based requires that all data refer to a 'population' - so if the growth rates are intercensal, so should be all other data (Preston, 2000).

In his 1984 review, Preston had noted the following:

Note, however that if intercensal growth rates are used, the Bennet and Horiuchi (and the Preston and Coale) procedures should also be used with intercensal deaths not simply with deaths centred on one of the two censuses. (Preston, 1984:69-70)

In the paper by Preston *et al.* (1980) where this method was outlined, the method was applied to Korean data and regarding the deaths, $D(a)$, and the population, ${}_5N_a$ used in the calculation, the following footnote was written:

$D(a)$ is deaths over the intercensal period 1970-1975; ${}_5N_a$ is five times the average of the population in the two censuses. (Preston *et al.*, 1980:197)

However it is possible to use data at one census to estimate what the intercensal data would be. Obviously, some error can creep into this substitution (Preston, 2000).

Similarly, Bennet and Horiuchi define the deaths term ${}_5D_{a-5}$ used in their formula as,

the number of deaths occurring in the cohort (or the stationary population age group) in the intervening period. (Bennet and Horiuchi, 1981:210)

Indeed, in the BENHR program included in MORTPAK for applying the Bennet-Horiuchi method, the deaths data stated are clearly written as 'intercensal deaths'. The Preston and Hill method also requires intercensal deaths and two censuses.

In short, in their original formulation, three of the four methods mentioned above require intercensal deaths and two censuses. In the South African context, going the route of using the 1991 census and intercensal deaths is not a very appealing option and is beset by many problems. Some of the problems deal with the changing demarcation of provincial and national boundaries over this period. The 1991 and 1996 censuses were referring to different geographic entities. A related more serious problem is the exclusion of death statistics from the former TBVC states. If for example the Preston and Coale method is to be used, one would have to 'experiment' with different growth rates if one does not want to use the intercensal growth rates. While this procedure has worked well in at least one case, the caution from one of the authors of the technique is that, in general, it may not be satisfactory (Preston, 1984). The route of using deaths centered on one year (instead of the intercensal deaths) and 'experimenting' with different growth rates, it seems, is an exercise in futility. The situation is even more serious in the case of the Bennett and Horiuchi technique, where the 'experimentation' has to be done for all five-year age groups. A golden rule in indirect techniques is that one cannot force the application of a technique just because of its more solid theoretical basis. Indeed, where the data are available, the choice has to be for the technique with the more solid theoretical basis. This was the case in the Island of Mauritius. Census data

were available for 1972 and 1983 and registered deaths for the intervening years. Since the intercensal period was 11 years (not a multiple of five), the Preston-Hill method was not suitable. As Mauritius had a full set of uninterrupted intercensal deaths and had the advantage of being a small island (without changes in national boundaries), the Bennet and Horuichi method was applied and yielded good results (Bah, 1995).

If one has to use data from only one census (1996) and deaths for that year and one does not want to use either intercensal growth rates or intercensal deaths, then one's options are very limited. One would have to resort to the Brass method or employ direct methods, to estimate the degree of incompleteness of death registration. While the Brass method is more appropriate under conditions of stability, it has been found to work adequately in quasi-stable conditions. As Preston (1984:69) observed,

When errors in the data are abundant, the analyst may wish to impose the stability assumption in order to 'discipline' the data

And United Nations (1983:132) has noted that,

A history of declining mortality causes a departure from the stable age distribution but usually a rather limited departure

Beside the advantage of having lesser data requirements, another advantage that the Brass method has over the Preston and Coale method is the flexibility of eliminating data points believed to be faulty. Clearly more research is needed to modify the Brass method in such a way that the modification does not involve circularity or the need for additional data. In the interim, the Brass method has been used for the national figures and for the urban areas. For the other population sub-groupings, a weighting method has been used which takes into account the urban/non-urban disparity in South Africa.

In estimating completeness in death registration, there are some in-built checks for assessing the validity of the results and for safeguarding against having unrealistic life tables. For countries known to have incomplete recording of deaths, an estimate of completeness of 100% or more would be unacceptable. When the completeness of recording is very low and the estimated level of completeness is far higher than the actual level (a case of serious underestimation), the life expectancy derived from the life table would be very high. A comparison of the results with those of countries with accurate life tables could easily show the problem. On the other hand, when completeness of death registration is fairly high, to err in the exact level of incompleteness does not affect the life expectancy much. The mathematics show that if one comes to within 10 per cent of the true value in the corrected estimates of age-specific death rates, one should be within 1-4 per cent in the corresponding estimates of life expectancy at birth. For example, at life expectancy at birth of 55 years, the error introduced by a 10 per cent error in the estimate of the completeness translate to 0,5 to 2,2 years (Preston, 1984).

5.3 Outline of the Brass method

In general, for any closed population, the following equation applies:

$$r_{x+}^I = b_{x+}^I - d_{x+}^I$$

where,

r_{x+}^I is the true partial growth rate for age x .

b_{x+}^I is the true partial birth rate for age x and is given as:

$$b_{x+}^I = \frac{{}_5N_x + {}_5N_{x-5}}{10 * N_{x+}}$$

where

${}_5N_x$ is the number of persons recorded in the age interval from x to $x + 5$, and

d_{x+}^I is the true partial death rate for age x .

The growth balance method makes two major assumptions: a) the assumption of population stability and b) the assumption that the completeness of death registration is invariant to age within the range specified.

This means that

$$r_{x+}^I = r^I$$

and

$$d_{x+}^I = C * d_{x+}^I$$

where C is the completeness of death recording and d_{x+} is the partial death rate for age x based on recorded deaths.

Using these two assumptions, the closed population equation could be written as follows:

$$b_{x+}^T = r^T + \frac{1}{C} d_{x+}$$

This is a linear equation with the parameters r^T as intercept and $1/C$ as the slope. The reciprocal of the slope therefore gives the proportion of completeness of death recording.

The GRBAL program in PAS was used to fit the growth balance method to the data. The resulting correction factors were used to adjust the age specific death rates.

These adjusted age specific death rates were used as input into the LIFTB program of MORTPAK. Note that the Brass method is not seen as a perfect tool. It is however one of the very few tools available given the constraints outlined earlier. As a way out, it has been used only for South Africa as a whole and for urban areas. A weighting method is used for obtaining estimates for non-urban areas and the provinces. This method is elaborated upon below.

5.4 Method for incorporating the relative distribution of deaths and population in urban and non-urban areas

Upon applying the Brass method to all the population sub-groupings (urban and non-urban, provinces and RSA), it emerged that there were cases where the plots of the partial birth and partial death rates were clearly aberrant. The most aberrant cases were the following: non-urban males and females, Eastern Cape males and females and Northern Province males and females. According to the 1996 census, Eastern Cape and Northern Province are largely non-urban in their population composition, Eastern Cape being 63,4% non-urban and Northern Province being 89,0% non-urban. As such, it can be reasoned that because of the largely non-urban character of these provinces, registration of deaths becomes close to, or lower than, the minimum level required for application of these methods.

The strategies adopted for estimating the level of completeness of death registration for non-urban areas and for all the provinces are given in what follows.

1. For non-urban population

Given that the true number of deaths in South Africa is the sum of the deaths in the urban and non-urban areas, one has the following:

$$D_{RSA}^T = D_{ur}^T + D_{nur}^T$$

where D^T stands for the true number of deaths and the subscripts ur and nur stand for urban and non-urban respectively.

As the true number of death, D^T , is a multiple, k or $1/C$, of the registered deaths, D , one has that:

$$D^T = k * D$$

Hence,

$$k_{nur} = \frac{k_{RSA} * D_{RSA} - k_{ur} * D_{ur}}{D_{nur}}$$

or,

$$k_{nur} = \left(\frac{D_{RSA}}{D_{nur}} \right) * k_{RSA} + \left(\frac{D_{ur}}{D_{nur}} \right) * k_{ur}$$

In short, having obtained the more reliable correction factors for the RSA and for the urban population, the additive relationship between the number of the deaths in the sub-components and the whole, allows one to estimate the correction factors for the less reliable, or highly incomplete, non-urban data.

2. For all provinces

Similarly, for any given province, i , the total number of deaths in the province is a sum of the deaths in the urban and non-urban areas of that province.

$$D_i^T = D_{ur,i}^T + D_{nur,i}^T$$

Hence, in terms of reported deaths, one has:

$$k_i * D_i = k_{ur,i} * D_{ur,i} + k_{nur,i} * D_{nur,i}$$

or,

$$k_i = \left(\frac{D_{ur,i}}{D_i} \right) * k_{ur,i} + \left(\frac{D_{nur,i}}{D_i} \right) * k_{nur,i}$$

Assuming that $k_{ur,i} = k_{ur}$ and that $k_{nur,i} = k_{nur}$

one has,

$$k_i = \alpha_i * k_{ur} + (1 - \alpha_i) * k_{nur}$$

where

$$\alpha_i = \frac{D_{ur,i}}{D_i}$$

5.5 The life tables obtained and their plausibility

For the pre-1996 life tables (1985-1994), the summary of the life expectancies at birth obtained for the different population groups are shown in Table B. For the sake of brevity, the methodology used is not outlined here. The reader is referred to the above-mentioned Stats SA life table report for further details. Research on South African life tables has shown that death registration was incomplete (at varying degrees) for all population groups (Bah, 2000). As such, previously published life tables cannot be used to assess the plausibility of the life tables derived for this work. Instead, we have constructed life tables at two extremes, the assumption of 100% completeness and the assumption of 50% completeness. The summary of the life expectancies at birth obtained are shown in Table C. For most of the provinces (with the exception of the largely non-urban provinces), the life expectancies of these two levels of completeness should bracket the life table obtained. Table D gives the summary of the life expectancies at birth using the estimated level of completeness.

Table B: Life expectancy at birth as derived from the 1985-1994 life tables, for South Africa as a whole and population groups

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Population groups	Male	Female
RSA	54,12	65,38
African/Black	52,51	64,62
Coloured	57,36	65,02
Asian/Indian	60,95	68,90
White	65,22	73,08
Other and unspecified	59,75	66,04

Table C: Implied life expectancy at birth at two given levels of completeness of death registration, for South Africa as a whole, provinces and urban/non-urban residence, 1996

	Male		Female	
	100%	50%	100%	50%
	completeness	completeness	completeness	completeness
RSA	59,543	47,112	68,952	57,031
Western Cape	60,084	48,217	69,296	58,270
Eastern Cape	62,128	49,905	72,716	61,834
Northern Cape	56,083	43,335	64,538	51,893
Free State	56,126	43,121	62,885	49,552
KwaZulu Natal	56,154	43,186	67,388	54,745
North West	60,152	47,916	67,906	55,382
Gauteng	59,538	47,165	67,036	55,508
Mpumalanga	59,062	46,919	67,253	55,250
Northern Province	65,970	54,412	76,524	66,770
Urban	54,241	41,631	65,455	52,526

Non-urban	69,772	57,185	77,326	68,908
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Table D: Life expectancies at birth as derived from the 1996 life tables, for South Africa as a whole, provinces and urban/non-urban residence.

	Male		Female	
	Percentage completeness of death registration	Life expectancy at birth e(0)	Percentage completeness of death registration	Life expectancy at birth e(0)
RSA	66,90	52,11	65,40	61,60
Western Cape	79,55	55,75	81,34	65,68
Eastern Cape	64,43	54,16	64,18	65,76
Northern Cape	76,54	51,17	77,51	59,92
Free State	70,25	49,34	70,44	56,11
KwaZulu Natal	62,43	47,16	60,29	58,13
North West	56,51	50,00	53,30	56,47
Gauteng	81,26	55,54	83,83	63,87
Mpumalanga	58,65	49,56	56,12	57,20
Northern Province	49,26	54,10	45,06	65,14
Urban	84,30	50,85	86,7	62,58
Non-urban	39,10	52,76	35,7	63,92

Perhaps a surprising feature of Table D is the high sex differential in life expectancies at birth. This is comparable to experiences elsewhere. In Poland in 1990, Trovato and Lulu (1996) report that the

male-female difference in life expectancy at birth was 9,14 years. For the same year, the male-female difference in life expectancy at birth was 8,89 years in Hungary and 8,41 years in France. In that study, Trovato and Lalu offered possible reasons for these differences as well as the differences observed in 27 other industrialised countries.

Another surprising feature is the slightly higher life expectancy in non-urban as compared to urban areas and the relatively high life expectancy at birth in some predominantly non-urban provinces. This can be situated within the experience of another Southern African country. In Zimbabwe, it has been found that mortality in the predominantly non-urban province of Matabeleland South was lower than that in other some predominantly urban provinces. Root (1997) further investigated this in a study and singled out population density as the possible reason for this differential. In the case of South Africa, more research is needed to fully establish the reality of this phenomenon.

6. Growth rates and interpolation

6.1 Overview

If population estimates are desired for quinquennial years, they can be produced by standard cohort-components method (with population and demographic rates grouped into five-year age groups) without need for population growth rates. If population estimates are desired for each year, they can be obtained by one of two approaches: first, by grouping population and demographic rates into single years and doing yearly projections; or second, by interpolating between successive quinquennial age distributions. The first approach is feasible in 'data-rich' countries and is utilised more in the context of projections produced by microsimulation. The latter is more widely used and is often done in the context of projections produced by macrosimulation (van Imhoff, 1998) The interpolation referred to is, in essence, making use of a growth rate (either linear, geometric, compound or exponential).

Using the census totals for 1996 and the projected totals for 2001, exponential growth of the population was assumed and the 'inferred' growth rate, r , was obtained as follows:

$$P_{t2} = P_{t1} * \exp (r * (t2 - t1))$$

where $t1$ is the initial time and $t2$ is the final time.

$$\text{Hence, } r = 0.2 * \log_e (P_{2001} / P_{1996})$$

Regarding the population estimates for the period 1991-1996, one could either use growth rates derived for that period (using backward projection of the 1996 census to 1991 and inferring the growth rate from the totals) or assume that the growth rates for the period 1996-2001 would be applicable for the earlier period as well. Both methods were attempted but the latter procedure gave more plausible results and

hence has been adopted.

For any given date, tx , either prior to 1996 or after 1996, the mid-year population estimate is obtained as follows:

$$P_{tx} = P_{1996.775} \cdot \exp(r \cdot (tx - 1996.775))$$

where 1996.775 is the decimalised equivalent of the Census night, 10 October 1996.

Note that the 'inferred' growth rates should not be confused with intercensal growth rates obtained from data from two censuses. However, the more realistic the population projection model, the closer the two rates become. In passing, it must be noted that demographic literature also mentions another growth rate, the intrinsic growth rate (the rate that is achieved when the population becomes stable). Such a growth rate also becomes closer to the intercensal growth rate the closer the population is to stability. The growth rates calculated are shown in Table E. These inferred growth rates differ from the previously published ones since internal migration has now been taken into account and the life tables used are based on reported deaths, adjusted for under-registration.

6.2 Short proof of why male inferred rate of growth could be greater than that of female even though the female population may be higher

Using the same symbols as above, and adding the m superscript to indicate males and f for females, one has the following:

$$P_{t2}^m = P_{t1}^m \exp(r^m \cdot (t2 - t1))$$

$$P_{t2}^f = P_{t1}^f \exp(r^f \cdot (t2 - t1))$$

$$r^m - r^f = \frac{1}{(t2 - t1)} * \left[\log_e \left(\frac{P_{t2}^m}{P_{t2}^f} \right) + \log_e \left(\frac{P_{t1}^f}{P_{t1}^m} \right) \right]$$

$$r^m - r^f = \frac{1}{(t2 - t1)} * [\log_e SR_{t2} - \log_e SR_{t1}] = \Delta$$

where SR is the overall sex ratio in the population.

If $\Delta > 0$ then $r^m > r^f$

In short, it is the relative size of the male and female population at two points in time that determine whether the male or female rate of growth would be greater, not the absolute sizes of the male and females population at both time points.

As an illustrative example, KwaZulu-Natal has higher female population in both 1996 and in the projected figures for 2001. The value for Δ works out to be positive (0,00009217) and hence $r^m > r^f$.

7. Reconciling the totals with the sum of the components

In preparing mid-year estimates for the total population and for some of its components, one could either use a 'bottom-up' approach, a 'top-down' approach or a 'hybrid' approach. In the bottom-up approach, the national figures are obtained by aggregating the sub-national estimates. In this case, the problem of reconciling discrepancies does not arise. However, when the estimates for the national and the sub-national populations are obtained independently, there is often some discrepancy between the sum of the initial estimates of the components and the total population. There is need then to adjust for the differences to arrive at final estimates. This gives rise to the top-down approach, wherein the sub-national totals are forced to sum up to the national. This approach is also appropriate when the national figures are seen to be more reliable than the sub-national ones. The procedure for controlling is known variously as iterative proportional fitting, raking and rim-weighting. The hybrid approach attempts to combine the advantages of the top-down approach and the bottom-up approach.

In this report, a hybrid (bottom-up/top-down) approach has been used in arriving at the totals. Where internal migration has been included in the projection, a bottom-up approach was seen as more appropriate than a top-down approach and was therefore used. However in the case of the population groups and urban/non-urban estimates, a top-down approach was used.

In the case where reconciliation was done, it was done separately for males and females. The program used for doing this is CTBL32 in Population Analysis Software (PAS) by the US Bureau of Census. The urban and non-urban projections as well as the projections for the population groups were constrained to the RSA projection obtained by adding up the provinces. Note that the constraining of the population group totals to the RSA ensures the population group projection has not been overestimated (by virtues of using life tables with lighter mortality).

8. Estimation of economically active population

The reader is referred to statistical releases of the October Household Survey (P0317) and the forthcoming statistical releases of the Labour Force Survey. Those surveys provide up-to-date estimates

of the economically active population.

9. Note to users who would like to prepare special population estimates

A) If a user needs to estimate the population of a given population group at the provincial level for a non-census date, one option is as follows. Make the assumption that the national growth rate for that population group applies at the provincial level and proceed with applying that rate on the provincial total of that population group. Other options are possible.

B) If a user needs to estimate the population at sub-provincial level for a non-census date, one option is as follows. Estimate the ratio of that sub-provincial total to the province total and apply that ratio on the provincial estimate at the desired date. Other options are possible.

Table E. Exponential growth rates inferred from the projected population, with and without taking into account additional deaths due to HIV/AIDS

Broad category	Unit	Gender	Exponential growth rates, r , for 1996-2001	
			Taking into account additional deaths due to HIV/AIDS	Without taking into account additional deaths due to HIV/AIDS
Total	RSA	Male	-	0,019841
		Female	-	0,019738
Urban/Non-urban	Urban	Male	-	0,014981
		Female	-	0,018439
	Non-urban	Male	-	0,025898
		Female	-	0,023638
Population group	African/Black	Male	-	0,028497
		Female	-	0,028660
	Coloured	Male	-	0,020119

		Female	-	0,020070
	Asian/Indian	Male	-	0,016957
		Female	-	0,018251
	White	Male	-	0,010179
		Female	-	0,011871
	Other and Unspecified	Male	-	0,020193
		Female	-	0,018828
Province	Western Cape	Male	0,013711	0,014507
		Female	0,015519	0,016272
	Eastern Cape	Male	0,022343	0,023857
		Female	0,019553	0,020867
	Northern Cape	Male	0,007831	0,008974
		Female	0,010291	0,011379
	Free State	Male	0,012076	0,015046
		Female	0,013205	0,016074
	KwaZulu-Natal	Male	0,013487	0,017635
		Female	0,013883	0,017543
	North West	Male	0,013374	0,015993
		Female	0,014366	0,016884
	Gauteng	Male	0,013790	0,016928
		Female	0,016952	0,020166
	Mpumalanga	Male	0,018687	0,022137
		Female	0,019088	0,022341
	Northern Province	Male	0,032378	0,033383
		Female	0,026486	0,027356

Note: The categories used in the first column are non-overlapping since the provinces totals add up to the RSA, the five population groups add up to the RSA and the urban/non-urban locations also add up to the RSA.

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