Original Research Article

Revised Fixed-base Model for Estimation of Adult Mortality in Developing Countries

Abstract

This paper presents a revised Fixed-base model (RFBM) for the estimation of adult mortality in developing countries. The RFBM also derives estimates of adult mortality from the age distributions of two censuses by 5-year age-groups. Unlike the original version, RFBM does not depend on person – years lived between exact ages 0 and 5 years ($_5L_0$) and the mid-point population of those aged 0 – 4 years ($_5\overline{N}_0$). Both $_5L_0$ and $_5\overline{N}_0$ are known to be affected by under-reporting in most developing countries. The estimates of the RFBM appear to have improved and compare favourably with estimates from other methods. We recommend the use of the model, especially when there is insufficient data for direct estimation of adult mortality in developing countries, among others.

Key words: Adult mortality, census, expectation of life, fixed-base model, developing countries.

1. Introduction

Mortality serves as a gauge of a nation's extent of socio-economic and health development. As the level of demographic parameters (especially mortality) of a country improves; the ranking of the country on health issues increases among the committee of nations. Among the components of population change, mortality stands out because it affects some age distributions directly and others indirectly Nwogu and Okoro [1]. The focus of this present study is on mortality at age five years and above (denoted as adult mortality in most intercensal methods).

The direct estimation of adult mortality in many developing countries is difficult due to unreliable or incomplete civil registration systems. In most developing countries, because of the limitations of civil registration systems, demographic parameters are derived from censuses and survey data ─ these two sources are often defective, Nwogu and Okoro, [1]; Okoro [2]; Okoro and Nwogu [3]. Hence, the dependence on indirect techniques for the estimation of adult mortality in developing countries.

Derivation of adult mortality from two census age distributions is an alternative means explored by most developing countries to overcome or augment her ineffective civil registration systems. The intercensal survival methods still relevant are those that assume arbitrary intercensal period such as Preston integrated method [4], Preston-Bennett method [5], United Nations Synthetic Survival Ratio [6], Fixed-base model proposed by Nwogu and Okoro [1], etc. The Fixed-base model and Preston-Bennett method [5] are similar and do not make reference to life tables.

The Fixed-base model is considered for revision because it adopted a more conservative approach in the estimation of person-years lived (${}_nL_x$) and expectation of life at age x (e_x) but not without a limitation. The probability of surviving to exact age one (l_1) an index for infant mortality is known to produce poor results according to many authors (UN [7]; kpedekpo [8]; Nwogu [9]; Okoro et al.[10]. In deriving ${}_5L_0$ used in the estimation of ${}_nL_x$, l_1 is one of the components used. However, it has been shown that l_1 is affected by under reporting. If it is possible to obtain an estimate that does not depend on both ${}_5L_0$ and ${}_5\overline{N}_0$ (that is, the mid-point population of those aged 0 – 4 years), improved estimates of adult mortality may be derived especially estimates of the life expectancy at age x which is an index for measuring adult mortality in most census-based methods.

Moreover, the ultimate objective of this study is to derive a model for estimation of adult mortality which does not depend on ${}_5L_0$ and ${}_5\overline{N}_0$. The specific objectives are to (i) derive the revised fixed-base model, (ii) obtain estimates of adult mortality (expectation of life at age x), and (iii) assess the performance of the revised model using empirical examples.

There are six sections to the paper. The first section contains an introduction; the second section contains a review of the Fixed-base model; the third section contains the derivation of the revised Fixed-base model; the fourth section contains empirical examples; the fifth section contains discussion; and the final section contains the conclusion.

2. Fixed-base Model

Nwogu and Okoro [1] proposed a Fixed-base model for estimation of adult mortality in developing countries based on the concept of variable-r method. The model proposed by Nwogu and Okoro [1] for estimation of expectation of life at age x (e_x) an index for measuring adult mortality is

$$e_x = \sum_{x=5}^{\omega-5} {}_5L_0 \frac{{}_5\overline{N}_x}{{}_5\overline{N}_0} \exp[5\sum_{i=0}^{x-5} {}_5r_i] + L_{\omega+}, \qquad x = 5, 10, 15, \ldots \qquad (2.1)$$

where,

$${}_5L_x = {}_5L_{x-5} \frac{{}_5\overline{N}_x}{{}_5\overline{N}_{x-5}} \exp[5({}_5r_{x-5})], \qquad x = 5, 10, 15, \ldots \omega - 5 \qquad (2.2)$$

$${}_5L_0 = 0.3 + 2l_1 + 2.7l_5 \qquad (2.3)$$

is the total of person- years lived between exact ages 0 and 5 years, and

$${}_5\overline{N}_x = \frac{[{}_5N_x^{(2)} - {}_5N_x^{(1)}]}{t\ {}_5r_x} \qquad (2.4)$$

is the mid-point population, and

$${}_5r_x = \frac{1}{t} Ln\left(\frac{{}_5N_x^{(2)}}{{}_5N_x^{(1)}}\right) \qquad (2.5)$$

is the age-specific growth rate, Ln is log base e . For the open age interval ($\omega+$), Nwogu and Okoro [1] applied an expression by Kpedekpo [8] for the estimate of the number of person-years lived from ω years and above as

$$L_{\omega+} = l_\omega \times \log_{10}(l_\omega) \qquad (2.6)$$

and ω is the beginning of the open interval.

3. Revised Fixed-base Model

Thus, if ${}_5\overline{N}_5$ and ${}_5L_5$ are assumed to be more accurate or robust than ${}_5\overline{N}_0$ and ${}_5L_0$ (which is often the case in most developing countries), the estimate of ${}_5L_x$, for x = 10, 15, $\ldots \omega - 5$ from equation (2.2) can be expressed as

$$ {}_5L_{10} = {}_5L_5\left(\frac{{}_5\overline{N}_{10}}{{}_5\overline{N}_5}\right)\exp[5({}_5r_5)] $$

$$ {}_5L_{15} = {}_5L_5\left(\frac{{}_5\overline{N}_{15}}{{}_5\overline{N}_5}\right)\exp[5({}_5r_5 + {}_5r_{10})] $$

$$ \vdots \qquad\qquad \vdots $$

$$ {}_5L_x = {}_5L_5\left(\frac{{}_5\overline{N}_x}{{}_5\overline{N}_5}\right)\exp[5\sum_{i=5}^{x-5}{}_5r_i], \qquad x = 5, 10, 15, \ldots \omega - 5 \qquad (3.1) $$

where ${}_5L_5$ (total Person-years lived between exact ages 5 and 10) quoted by Siegel & Swanson [11] according to Reed and Merell

$$ {}_5L_5 = -0.003l_0 + 2.242l_5 + 2.761l_{10} \qquad (3.2) $$

where,

l_0 is the radix (equal to one) while l_5 and l_{10} are the probabilities of surviving to exact ages 5 and 10 respectively, and other elements are as defined in the original Fixed-base model.

3.1 Estimation of open ended interval life table function (L_{w+})

For the open age interval ($\omega+$) in this revised version, we adopted an approach by Preston-Bennett [5] for the estimate of the number of person-years lived from ω years and above

$$ \mathrm{L}(\omega+) = \mathrm{N}(\omega+)\exp[\mathrm{R}(\omega+)] \qquad (3.3) $$

where $\mathrm{R}(\omega)$ is the cumulated growth rate defined by Preston-Bennett [5] as

$$ R(\omega) = a(\omega) + b(\omega).r(10+) + c(\omega).Ln\left[N(45+)/N(10+)\right] + 5\sum_{y=0}^{\omega-5}{}_5r_y \qquad (3.4) $$

$N(10+)$ is the mid-period population aged 10 years and above and $r(10+)$ is the corresponding inter-censal growth rate; $N(45+)$ is the mid-period population aged 45 years and above while $\mathrm{a}(\omega)$, $\mathrm{b}(\omega)$, and $\mathrm{c}(\omega)$ are given constants.

Specifically,

$$ e_x = \sum_{x=5}^{\omega-5}{}_5L_5\frac{{}_5\overline{N}_x}{{}_5\overline{N}_5}\exp[5\sum_{i=5}^{x-5}{}_5r_i] + L_{\omega+} \qquad x = 10, 15, \ldots \qquad (3.5) $$

where the components of equation (3.5) are defined in equations (2.4, 2.5, 3.1, 3.2, and 3.3) respectively.

3.2 Algorithm for Estimation of Adult Mortality using the revised fixed-base model

The measure of adult mortality adopted in this study is the expectation of life at age x (e_x) for $x = 10, 15, \dots$ From equation (3.5)

$$ {}_5L_x = {}_5L_5 \left(\frac{{}_5\overline{N}_x}{{}_5\overline{N}_5} \right) \exp[5\sum_{i=5}^{x-5} {}_5r_i], \quad x = 10, 15, \dots \ \omega - 5 \tag{3.6} $$

where,

$$ {}_5\overline{N}_x = \frac{[{}_5N_x^{(2)} - {}_5N_x^{(1)}]}{t \ {}_5r_x} \tag{3.7} $$

is the 5- year age distribution derived from the two census ${}_5N_x^{(1)}$ *and* ${}_5N_x^{(2)}$ and refer to the midpoint of the intercensal period while ${}_5L_5$ is defined in equation (3.2).

$$ {}_5r_x = \frac{1}{t} In\left(\frac{{}_nN_x^{(2)}}{{}_nN_x^{(1)}} \right) \tag{3.8} $$

is the average intercensal growth rate. From the relationship among life table functions

$$ l_x = \frac{1}{10}\left[{}_5L_{x-5} + {}_5L_x \right] \tag{3.9} $$

Hence,

$$ l_5 = \frac{1}{10}\left[{}_5L_0 + {}_5L_5 \right] $$

$$ l_{10} = \frac{1}{10}\left[{}_5L_5 + {}_5L_{10} \right] $$

$$ \vdots \qquad\qquad \vdots $$

$$ l_{\omega-5} = \frac{1}{10}\left[{}_5L_{\omega-2(5)} + {}_5L_{\omega-5} \right] $$

$$ T_x = \sum_{i=x}^{\omega-5} {}_5L_i + L_{w+} \tag{3.10} $$

where L_{w+} is given in (3.3).

$$e_x = \sum_{x=5}^{\omega-5} {}_5L_5 \frac{{}_5\overline{N}_x}{{}_5\overline{N}_5} \exp[5\sum_{i=5}^{x-5} {}_5r_i] + L_{\omega+}, \qquad x = 10, 15, \ldots \qquad (3.11)$$

4. Empirical examples

The revised model with other related models were applied to selected developing countries in this section. Section 4.1 deals with application to Nigeria Female Populations, 1991 – 2006, while Section 4.2 deals with the application to Zambia Female Populations, 2000 – 2010.

4.1 Application to Nigeria Female Populations: 1991 – 2006

The revised model was applied to census age distributions of the Nigerian female populations, from 1991 to 2006. Equations (3.6) through (3.11) were applied to the female populations to obtain the expectation of life at age *x*. Table 1 (details in appendix A), show that at age 5, a female in Nigeria from 1991 to 2006 was expected to live approximately 60 years which is below the estimate of Preston-Bennett method, relatively above the fixed-base model and 6-years higher than the estimate of World Health Organization (WHO) for Nigeria in 2006.

Table 1: Estimates of expectation of life at age x (e_x) from the Revised Fixed-base Model (RFBM) for Nigeria Females and other related methods

Age	RFBM	FBM	PBM	WHO 2006
5	59.8	59.0	63.8	54.1
10	55.6	54.1	60.8	50.3
15	52.0	49.9	58.4	45.9
20	48.2	45.6	48.8	41.8
25	44.0	40.7	39.4	38.1
30	39.5	35.4	34.3	34.6
35	35.3	30.6	33.9	31.3
40	31.9	26.7	31.2	28.0
45	28.2	22.4	28.8	24.5
50	25.5	19.3	25.7	20.7
55	22.1	15.3	24.0	17.1
60	20.3	13.3	22.3	13.4
65	17.2	9.7	16.9	10.4
70	15.6	7.9	17.4	7.7
75	13.7	5.6	14.4	5.6
80	12.7	4.5	12.7	4.0

4.2 Application to Zambia Female Populations: 2000 – 2010

The revised model was also applied to Zambia Female Populations, 2000 – 2010. Table 2 (details in appendix B), show that the results obtained by applying the model. Just like most developing countries, Zambia has the challenge of age misreporting such as digit preference, under-reporting of certain ages, etc. It equally has the problem of unreliable and incomplete civil registration systems hence the use of indirect techniques for the estimation of most demographic parameters. The poor quality of data in such countries may affect especially the estimates of all demographic indicators from direct approaches. Table 2 shows that at age 5 (adult mortality), a female in Zambia from 2000 to 2010 was expected to live approximately 62 years for both revised version and the original fixed-base model but one year above the WHO estimate for Zambia in 2010 while the Preston-Bennett method estimate is about 63 years.

Table 2: Estimates of expectation of life at age x (e_x) from the Revised Fixed-base Model (RFBM) for Zambia Females and other related methods

Age	RFBM	FBM	PBM	WHO 2006
5	61.9	61.9	63.0	59.3
10	57.4	57.5	56.9	55.2
15	52.9	53.0	48.9	50.7
20	48.1	48.6	42.4	46.4
25	43.1	44.0	38.3	42.3
30	38.5	39.7	35.8	38.5
35	34.4	35.4	33.4	34.9
40	30.4	31.2	31.3	31.5
45	26.9	27.1	29.7	28.1
50	23.7	23.2	25.7	24.6
55	20.5	19.5	23.3	21.0
60	17.9	16.0	20.6	17.4
65	15.1	13.1	16.3	14.0
70	12.8	10.2	14.0	10.9
75	10.9	7.7	11.5	8.3
80	9.5	5.8	9.5	6.1

5. Discussion

The RFBM was applied to census age distributions of the Nigeria female populations, from 1991 and 2006, and Zambia female census populations from 2000 and 2010 to obtain estimates of adult mortality for the respective countries. The RFBM also derives estimates of adult mortality from the age distributions of two censuses by 5-year age-groups. Unlike the original version, RFBM does not depend on person – years lived between exact ages 0 and 5 years (${}_5L_0$) and the mid-point population of those aged 0 – 4 years (${}_5\overline{N}_0$). Both ${}_5L_0$ and ${}_5\overline{N}_0$ are known to be affected by under-reporting error in most developing countries. The RFBM depends on person – years lived between exact ages 5 and 10 years (${}_5L_5$) and the mid-point population of those aged 5 – 9 years (${}_5\overline{N}_5$).

For Nigeria, the probability of surviving to exact age five (l_5 = 0.8519) and the probability of surviving to exact age ten (l_{10} = 0.8267) was derived from 2013 Nigeria Demographic Health Survey, National Population Commission [15] using the Trussell variant of the Brass method. Equation (3.2) was used to compute to ${}_5L_5$ = 4.1895. The estimates of both (l_5 =0.9050 and l_{10} = 0.8741) for Zambia were derived from the Zambia 2013-14 DHS [16] and the estimate of ${}_5L_5$ is 4.4394. The RFBM uses both estimates of ${}_5L_5$ and ${}_5\overline{N}_5$ as key components in obtaining estimates of adult mortality.

At age 5, a female in Nigeria from 1991 to 2006 was expected to live approximately 60 years which indicates that people are likely to die while in service. The retirement age in Nigeria for most establishments are between 60 and 65 years, and in rare cases 70 years especially for Professors and supreme court Judges. The result suggests that socio-economic and health development in Nigeria are still poor. Furthermore, the age-specific estimates of the expectation of life of the RFBM are consistently higher than the WHO estimates and slightly lower than Preston-Bennett estimates from ages 45 to 75. The observed differences in the estimates of life expectancy for Nigeria among the methods are not ease to explain. It may be due to poor census data or differences in data sources and methodology. World Health Organization estimates are used for assessment in this study not as a direct comparison of results because the data sources and methodology are not the same. WHO derives its estimates from existing model life tables such as United Nations Model life tables, WHO [12]; Okoro and Nwogu [13]. The data used in preparing or simulating such life tables are not from developing countries. They are mere interpolated values that put question marks on such estimates.

For Zambia, the age-specific estimates of the expectation of life of the RFBM appear very consistent with the WHO estimates from ages 5 to 20. Then, from age 35 and above, the WHO and Preston-Bennett method estimates were consistently higher than the RFBM estimates. The observed differences among the methods may be due to reasons mentioned above. It may also be that both the World Health Organization and Preston-Bennett method overestimated the life expectancy for that age range. Even at that, WHO estimates are interpolated values from existing model life tables which makes it susceptible to errors while the RFBM, FBM, and Preston-Bennett method derive their estimates directly from reported census data which may be affected by age-misreporting. Just like other inter-censal survival methods, the RFBM may be biased by net-migration, completeness of the two censuses, etc., UN [6]; UN [7]; ECA [14].

6. Conclusion

This paper revised the Fixed-base model for the estimation of adult mortality in developing countries. The model can derive estimates of adult mortality from the age distributions of two censuses. The estimates from the RFBM compared favourably well with estimates from other methods. World Health Organization estimates are used for assessment in this study not as a direct comparison of results because the data sources and methodology are not the same. The RFBM appear more consistent with the original version and the WHO estimates. The RFBM is a good alternative for the estimation of adult mortality in developing countries. The use of indirect techniques for estimation of most demographic parameters and socio-economic indicators should not obstruct the need to improve the civil registration systems so that mortality estimates can be derived directly from death records without going through the rigorous processes of indirect techniques.

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Appendix A

Table 1: Revised Fixed-base Model applied to Nigeria, Females: 1991-2006

Age	$_5\bar{N}_x$	$_5r_x$	$5(_5r_x)$	$5\sum_{x=5}^{x-5} {}_5r_x$	$Exp[5\sum_{x=5}^{x-5} {}_5r_x]$	$\frac{_5N_x}{_5N_5}\exp[5\sum_{x=5}^{x-5} {}_5r_x]$	$_nL_x$	l_x	e_x	FBM	WHO 2006	PBM
0	8,860,650	0.0317	0.1587	-	-	-	-	-	-	-	-	-
5	8,309,338	0.0209	0.1047	-	-	1.0000	4.1895	-	59.8	59.0	54.1	63.8
10	6,415,589	0.0250	0.1250	0.1047	1.1104	0.8573	3.5918	0.7781	55.6	54.1	50.3	60.8
15	5,994,389	0.0298	0.1490	0.2297	1.2582	0.9077	3.8028	0.7395	52.0	49.9	45.9	58.4
20	5,659,102	0.0351	0.1753	0.3787	1.4603	0.9946	4.1668	0.7970	48.2	45.6	41.8	48.8
25	5,228,822	0.0357	0.1784	0.5540	1.7402	1.0951	4.5878	0.8755	44.0	40.7	38.1	39.4
30	3,961,545	0.0328	0.1638	0.7324	2.0801	0.9917	4.1547	0.8743	39.5	35.4	34.6	34.3
35	2,756,163	0.0422	0.2108	0.8962	2.4502	0.8127	3.4049	0.7560	35.3	30.6	31.3	33.9
40	2,419,578	0.0343	0.1713	1.1069	3.0251	0.8809	3.6904	0.7095	31.9	26.7	28.0	31.2
45	1,493,585	0.0453	0.2265	1.2782	3.5902	0.6453	2.7036	0.6394	28.2	22.4	24.5	28.8
50	1,506,466	0.0326	0.1631	1.5047	4.5030	0.8164	3.4202	0.6124	25.5	19.3	20.7	25.7
55	659,324	0.0419	0.2093	1.6678	5.3005	0.4206	1.7620	0.5182	22.1	15.3	17.1	24.0
60	931,522	0.0222	0.1108	1.8771	6.5348	0.7326	3.0692	0.4831	20.3	13.3	13.4	22.3
65	434,787	0.0266	0.1328	1.9880	7.3007	0.3820	1.6004	0.4670	17.2	9.7	10.4	16.9
70	474,266	0.0251	0.1256	2.1207	8.3371	0.4759	1.9936	0.3594	15.6	7.9	7.7	17.4
75	200,576	0.0335	0.1673	2.2463	9.4528	0.2282	0.9559	0.2950	13.7	5.6	5.6	14.4
80	282,121	0.0319	0.1594	2.4136	11.1742	0.3794	1.5895	0.2545	12.7	4.5	4.0	12.7
85	248,241	0.0329	0.1644	-	-	-	-	-	-	-	-	-

Note: $_5L_5$ = 4.1895, l_5 = 0.8519, l_{10} = 0.8267 (derived from 2013 Nigeria DHS). Life expectancy estimates for fixed-base model and Preston-Bennett Method was extracted from the study by Nwogu and Okoro [1]. WHO life expectancy estimates retrieved from WHO Global Health Observatory Data Repository.

Appendix B

Table 2: Revised Fixed-base Model applied to Zambia, Females: 2000-2010

Age	$_5\bar{N}_x$	$_5r_x$	$5(_5r_x)$	$5\sum_{x=5}^{x-5} {_5r_x}$	$Exp[5\sum_{x=5}^{x-5} {_5r_x}]$	$\frac{_5N_x}{_5N_5}\exp[5\sum_{x=5}^{x-5} {_5r_x}]$	$_nL_x$	l_x	e_x	FBM	WHO 2010	PBM
0	973,395	0.0309	0.1543	-	-	-	-	-	-	-	-	-
5	841,695	0.0273	0.1367	-	-	1.0000	4.4394	-	61.9	61.9	59.3	63.0
10	740,446	0.0393	0.1966	0.1367	1.1464	1.0085	4.4773	0.8917	57.4	57.5	55.2	56.9
15	663,192	0.0341	0.1703	0.3333	1.3956	1.0996	4.8815	0.9359	52.9	53.0	50.7	48.9
20	563,713	0.0264	0.1320	0.5036	1.6546	1.1081	4.9195	0.9801	48.1	48.6	46.4	42.4
25	463,460	0.0389	0.1943	0.6355	1.8880	1.0396	4.6151	0.9535	43.1	44.0	42.3	38.3
30	340,498	0.0410	0.2051	0.8298	2.2928	0.9275	4.1177	0.8733	38.5	39.7	38.5	35.8
35	268,673	0.0399	0.1995	1.0348	2.8146	0.8984	3.9886	0.8106	34.4	35.4	34.9	33.4
40	192,243	0.0303	0.1514	1.2343	3.4360	0.7848	3.4840	0.7473	30.4	31.2	31.5	31.3
45	152,727	0.0421	0.2105	1.3858	3.9979	0.7254	3.2204	0.6704	26.9	27.1	28.1	29.7
50	124,847	0.0323	0.1616	1.5962	4.9343	0.7319	3.2492	0.6470	23.7	23.2	24.6	25.7
55	84,598	0.0290	0.1449	1.7578	5.7994	0.5829	2.5877	0.5837	20.5	19.5	21.0	23.3
60	79,044	0.0272	0.1358	1.9026	6.7035	0.6295	2.7947	0.5382	17.9	16.0	17.4	20.6
65	56,573	0.0320	0.1602	2.0384	7.6784	0.5161	2.2911	0.5086	15.1	13.1	14.0	16.3
70	39,997	0.0438	0.2192	2.1986	9.0122	0.4283	1.9012	0.4192	12.8	10.2	10.9	14.0
75	23,573	0.0585	0.2924	2.4178	11.2208	0.3143	1.3951	0.3296	10.9	7.7	8.3	11.5
80	13,755	0.0443	0.2217	2.7102	15.0320	0.2457	1.0906	0.2486	9.5	5.8	6.1	9.5
85	13,669	0.0543	0.2713	-	-	-	-	-	-	-	-	-

Note: $_5L_5$ = 4.4394, l_5 = 0.9050, l_{10} = 0.8741 (derived from 2013-14 Zambia DHS). Life expectancy estimates for fixed-base model and Preston-Bennett Method was extracted from the study by Nwogu and Okoro [1]. WHO life expectancy estimates retrieved from WHO Global Health Observatory Data Repository.