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Estimation of Adult Mortality in Developing Countries Using an Application Based on the Variable-r Method

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Abstract

This paper proposes another approach to estimation of adult mortality in developing countries based on the variable-r method. The method derives estimates of adult mortality from the age distributions of two censuses. It is similar to Preston-Bennett method, but uses a slightly different approach to obtain estimates of person-years lived and expectation of life at age x. The proposed method is very simple and estimates from it compare favorably well with estimates from other related methods.

Keywords

Adult mortality, census, life expectancy, intercensal, variable-r method

1. Introduction

Mortality levels have become one of the most important indices for measuring the level of advancement of any nation in health care delivery. Mortality is an agent of population change that affects directly all age-segments of a population while migration and fertility affect some segments of a population directly and others indirectly. The effects of fertility and migration can be checked to a large extent through human know-how while mortality is above human expertise, especially beyond 5 years and above.

Mortality is popularly grouped into infant, childhood and adult mortality. The complications and preventive measures linked to infant and childhood mortality are well known, but similar measures on adult mortality are not totally clear. The determinants of adult mortality in developing countries have been widely discussed by several authors (Rogers et al. 2000; Gakidou et al. 2004; Nwogu, 2004; Chukwu and Oladipupo, 2012; Masquelier et al. 2013; Nwogu and Nweke, 2016; Lancet, 2017). Adult mortality may increase the financial burden of the family and influence issues such as girl-child marriage, orphan-hood burden, and out-of-school children in developing countries (Beegle and Krutikova, 2008).

Adult mortality is poorly estimated in developing countries (Hill, 2001) because of poor data quality. Different authors have written extensively on the weak civil registration systems and poor census and sample survey data in developing countries, hence, the recourse to indirect techniques for the estimation of adult mortality and other demographic parameters (Ekanem, 1972; Hill 2001; Nwogu, 2006, 2011; Ohaegbulem, 2015; Nwogu and Okoro, 2017; Okoro, 2019; Okoro and Nwogu, 2019, 2020).

Estimation of adult mortality from two census age distributions appears very popular in most developing countries because of (i) paucity of an accurate record of deaths and (ii) census data are readily available. The two census-based methods that are still in use are those that require that the censuses are five or ten years apart, including the United Nations (2002) Five-Year interval Method and United Nations (2002) Ten-Year interval method. However, the Preston integrated (1983) method, the Preston-Bennett (1983) method and United Nations (2002) Synthetic Survival Ratio do not assume that the intercensal interval must be five or ten years apart. The Preston integrated (1983) method requires a standard life table for its implementation. For most developing countries, those standard life tables may not exist or even when available may not be a true representation of mortality patterns. The Preston-Bennett (1983) method does not require a standard life table to determine estimates of adult mortality.

Furthermore, the Preston-Bennett measure for estimating adult mortality is the expectation of life at age y

$$e_y = \frac{T_y}{l_y} = \frac{\sum_{y=x}^{\omega} {}_5L_y + L(\omega+)}{l_y} \quad , \quad y = 10, 15, \ldots \omega - 5 \tag{1}$$

where,

$${}_5L_y = {}_5\overline{N}_y \exp[5\sum_{x=0}^{y-5} {}_5r_x + 2.5{}_5r_y] \tag{2}$$

is the number of person- years lived between ages y and $y+5$ years, and

$$l_y = \frac{1}{10}\left[{}_5\overline{N}_y \exp[2.5({}_5r_y)] + {}_5\overline{N}_{y-5} \exp[-2.5({}_5r_{y-5})]\right] \tag{3}$$

is the survivor to exact age *y*,

$${}_5\overline{N}_y = \frac{[{}_5N_y^{(2)} - {}_5N_y^{(1)}]}{t \; {}_5r_y} \tag{4}$$

is the mid-point population, and

$${}_5r_y = \frac{1}{t} Ln\left(\frac{{}_5N_y^{(2)}}{{}_5N_y^{(1)}}\right) \tag{5}$$

is the age-specific growth rate, Ln is log base e and ω is the beginning of the open interval. For the open age interval ($\omega+$), Preston-Bennett (1983) gave an expression for the estimate of the number of person-years lived from ω years and above as

$$L(\omega+) = N(\omega+)\exp[R(\omega+)] \tag{6}$$

where $R(\omega)$ is the cumulated growth rate defined by Preston-Bennett (1983) as

$$R(\omega+) = a(\omega) + b(\omega)r(10+) + c(\omega)Ln\left[N(45+)/N(10+)\right] + 5\sum_{y=0}^{\omega-5} {}_5r_y \tag{7}$$

$N(10+)$ 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.

From the relationship among life table functions, the denominator of e_y in Preston-Bennett (from equation (1)) is $l_y = \frac{1}{10}\left({}_5L_y + {}_5L_{y-5}\right)$. From (2) this equivalent is

$$= \frac{\exp[5\sum_{x=0}^{(y-5)} {}_5r_x]}{10} \left\{ {}_5\overline{N}_y \exp\left(+2.5_5 r_y\right) + {}_5\overline{N}_{y-5} \exp\left(-2.5_5 r_{y-5}\right)\right\} \qquad (8)$$

$\neq \frac{1}{10}\left\{ {}_5\overline{N}_y \exp\left(+2.5_5 r_y\right) + {}_5\overline{N}_{y-5} \exp\left(-2.5_5 r_{y-5}\right)\right\}$ as claimed by Preston-Bennett (1983) unless $\exp[5\sum_{x=0}^{(y-5)} {}_5r_x] = 1$.

To this extent, estimate of adult mortality from Preston-Bennett may be affected by this factor ignored

$$B = \exp[5\sum_{x=0}^{(y-5)} {}_5r_x] \quad , \mathrm{y} = 10, 15, \ldots \qquad (9)$$

The slow improvement in the estimate of the life expectancy of most developing countries even with the massive interventions and programs by multinational agencies such as World Health Organization, United Nations, World Bank etc. may be more due to the use of a wrong model and not some risk factors (Malaria, HIV/AIDS etc.) as is often claimed.

Therefore, the ultimate objective of the present study is to develop a model for estimation of adult mortality based entirely on age-sex distributions of two population at two points in time with an arbitrary intercensal period, which may address the bias observed in the Preston-Bennett method. The specific objectives are to (i) derive a model that relates characteristics of the observed population to life table functions, (ii) express the life table functions in terms of the observed population characteristics, (iii) obtain estimates of adult mortality from the life table functions, and (iv) assess the performance of the new model using empirical examples.

2. Proposed Method

By analogy to the derivation made by Preston and Coale (1982) for discrete age in single years, the population aged (*x* , *x+5*) at time *t*, ${}_5N_x(t)$ may be derived from population aged (*x-5*, *x*) at time *t-5*, ${}_5N_{x-5}(t-5)$ as

$$ {}_5\mathrm{N}_\mathrm{x}(\mathrm{t}) = {}_5\mathrm{N}_{\mathrm{x}-5}(\mathrm{t}-5)\,{}_5\mathrm{P}^{(5)}_{\mathrm{x}-5} \qquad (10) $$

where

$$ {}_5\mathrm{P}^{(5)}_{\mathrm{x}-5} = \frac{{}_5\mathrm{L}_\mathrm{x}}{{}_5\mathrm{L}_{\mathrm{x}-5}} \qquad (11) $$

is the survival ratio from age group (*x-5*, *x*) to age group (*x* , *x+5*). Similarly, given the average age-specific growth rate (${}_5r_x$), for the age group (*x* , *x+5*), the population aged (*x* , *x+5*) at time t, can be derived from the corresponding population aged (*x* , *x+5*) at time *t-5* as

$$ {}_5\mathrm{N}_\mathrm{x}(\mathrm{t}) = {}_5\mathrm{N}_\mathrm{x}(\mathrm{t}-5)\exp[5({}_5\mathrm{r}_\mathrm{x})] \qquad (12) $$

For the age group (*x-5, x*),

$$ {}_5N_{x-5}(t) = {}_5N_{x-5}(t-5)\ \exp[5({}_5r_{x-5})] \qquad (13) $$

Hence,

$$ {}_5N_{x-5}(t-5) = {}_5N_{x-5}(t)\ \exp[-5({}_5r_{x-5})] \qquad (14) $$

Substituting (14) into (10), we have

$$ \begin{aligned} {}_5\mathrm{N}_\mathrm{x}(\mathrm{t}) &= {}_5\mathrm{N}_{\mathrm{x}-5}(\mathrm{t})\ \exp[-5({}_5\mathrm{r}_{\mathrm{x}-5})]\,{}_5\mathrm{P}^{(5)}_{\mathrm{x}-5} \\ &= {}_5\mathrm{N}_{\mathrm{x}-5}(\mathrm{t})\ \exp[-5({}_5\mathrm{r}_{\mathrm{x}-5})]\frac{{}_5\mathrm{L}_\mathrm{x}}{{}_5\mathrm{L}_{\mathrm{x}-5}} \end{aligned} \qquad (15a) $$

Specifically, for

x = 5 $\qquad {}_5N_5(t) = {}_5N_0(t)\ \exp[-5({}_5r_0)]\frac{{}_5L_5}{{}_5L_0}$

$x = 10$ $\qquad {}_5N_{10}(t) = {}_5N_5(t)\ \exp[-5({}_5r_5)]\dfrac{{}_5L_{10}}{{}_5L_5}$

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$$x = \omega - 5 \qquad {}_5N_{\omega-5}(t) = {}_5N_{\omega-2(5)}(t)\ \exp[-5({}_5r_{\omega-2(5)})]\frac{{}_5L_{\omega-5}}{{}_5L_{\omega-2(5)}} \tag{15b}$$

Hence, the new approach derives the expression for adult mortality from ${}_5L_x$ (the life table population aged (x , $x+5$). From (15)

$$\frac{{}_5\mathrm{L}_\mathrm{x}}{{}_5\mathrm{L}_{\mathrm{x}-5}} = \frac{{}_5\mathrm{N}_\mathrm{x}}{{}_5\mathrm{N}_{\mathrm{x}-5}}\ \exp[5({}_5\mathrm{r}_{\mathrm{x}-5})] \tag{16}$$

and

$${}_5L_x = {}_5L_{x-5}\ \frac{{}_5N_x}{{}_5N_{x-5}}\exp[5({}_5r_{x-5})],\ x = 5,\ 10 \ldots \omega - 5 \tag{17}$$

Specifically,

$${}_5\mathrm{L}_5 = {}_5\mathrm{L}_0\left(\frac{{}_5\mathrm{N}_5}{{}_5\mathrm{N}_0}\right)\exp[5({}_5\mathrm{r}_0)]$$

$${}_5L_{10} = {}_5L_5\left(\frac{{}_5N_{10}}{{}_5N_5}\right)\exp[5({}_5r_5)]$$

$$= {}_5L_0\left(\frac{{}_5N_5}{{}_5N_0}\right)\left(\frac{{}_5N_{10}}{{}_5N_5}\right)\exp[5({}_5r_0) + 5({}_5r_5)]$$

$$= {}_5L_0\left(\frac{{}_5N_{10}}{{}_5N_0}\right)\exp[5({}_5r_0 + {}_5r_5)]$$

$$\vdots \qquad \vdots$$

$${}_5L_x = {}_5L_0\left(\frac{{}_5N_x}{{}_5N_0}\right)\exp[5\sum_{i=0}^{x-5}{}_5r_i] \tag{18}$$

$$\vdots \qquad \vdots$$

$${}_5L_{\omega-5} = {}_5L_0\left(\frac{{}_5N_{\omega-5}}{{}_5N_0}\right)\exp[5\sum_{x=0}^{\omega-2(5)}{}_5r_x]$$

(a) **Estimation of open-ended interval life table function (L_{w+})**

According to the United Nations (1956), by a mere coincidence, most available life table expectations of life at age 85 very nearly equals the common logarithm of l_{85} when expressed for 100,000 birth i.e. for $l_0 = 100000$, $e_{85} \cong \log_{10} l_{85}$. Therefore,

$$L_{85+} = T_{85} \cong l_{85} \log_{10} l_{85} \tag{19}$$

Kpedekpo (1982) tried to generalize this by giving ${}_{\infty}L_{75}$ as

$${}_{\infty}L_{75} = l_{75} \times \log_{10}(l_{75}) \tag{20}$$

By this generalization we have

$$L_{w+} = l_w \times \log_{10}(l_w) \tag{21}$$

(b) **Estimation of total Person-years lived between exact ages 0 and 5 (${}_5L_0$)**

For ages under 10 years, Shyock and Siegel (1976) quoted Reed and Merrel as noting that ${}_5L_x$ may be determined from $l_0, l_1, and\ l_5$ as

$${}_1L_0 = 0.276l_0 + 0.724l_1 \tag{22}$$

$${}_4L_1 = 0.034l_0 + 1.184l_1 + 2.782l_5 \tag{23}$$

where $l_0 = 1$

$${}_5L_0 = 0.31 + 1.908l_1 + 2.782l_5 \tag{24}$$

On the other hand, Kpedekpo (1982) derived ${}_5L_0$ from $l_0, l_1, and\ l_5$ as

$${}_1L_0 = 0.3l_0 + 0.7l_1 \tag{25}$$

$${}_4L_1 = 1.3l_1 + 2.7l_5 \tag{26}$$

$${}_5L_0 = 0.3 + 2l_1 + 2.7l_5 \tag{27}$$

For the purpose of this study estimate of ${}_5L_0$ was derived from Kpedekpo (1982) expression mentioned above because the two approaches will yield fairly similar estimates.

3. Estimation of Adult Mortality

The measure of adult mortality adopted in this study is the expectation of life at age x (e_x) for $x=5,10,15\ldots$ From equation (17)

$$ {}_5L_x = {}_5L_0 \left(\frac{{}_5\overline{N}_x}{{}_5\overline{N}_0} \right) \exp[5\sum_{i=0}^{x-5} {}_5r_i], \quad x=5,10,15, \ldots\ \omega-5 \tag{28} $$

where,

$$ {}_5\overline{N}_x = \frac{[{}_5N_x^{(2)} - {}_5N_x^{(1)}]}{t\ {}_5r_x} \tag{29} $$

is the 5-year age distribution derived from the two censuses ${}_5N_x^{(1)}$ *and* ${}_5N_x^{(2)}$ and refer to the midpoint of the intercensal period.

$$ {}_5r_x = \frac{1}{t} Ln\left(\frac{{}_nN_x^{(2)}}{{}_nN_x^{(1)}} \right) \tag{30} $$

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

$$ l_x = \frac{1}{10}\left[{}_5L_{x-5} + {}_5L_x\right] \tag{31} $$

Hence,

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

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

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

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

$$ T_x = \sum_{i=x}^{\omega-5} {}_5L_i + L_{w+} \tag{32} $$

where L_{w+} is given in (21).

$$ e_x = \frac{T_x}{l_x}, \qquad x=5,10,15,\ldots \tag{33} $$

4. Result

Application of the Model to Nigeria: Female Population in the 1991 and 2006 Censuses

The proposed method was applied to age distributions of the Nigeria female populations, from the 1991 and 2006 Nigeria censuses as shown in Table 1 in appendix 1a. Estimates of $l_0, l_1, and\ l_5$ used in determining ${}_5L_0$ for Nigeria were derived from the 2013 NDHS whose reference period is approximately at the midpoint of the inter-censal period between 1991 and 2006. The age specific growth rates and populations at the midpoint of the interval are determined using equations (29) and (30) respectively. From the 2013 NDHS, $l_1 = 0.9048$, $l_5 =$ 0.8519, with $l_0 = 1$, ${}_5L_0$ is derived from (27) as ${}_5L_0 = 0.3 + 2l_1 + 2.7l_5 = 4.40973$. In column 11 in table 1, $e_{80} = \frac{L_{80+}}{l_{80}} =$ 4.5, where $L_{80+} = l_{80} \times \log_{10}(l_{80})$. For other life table functions, equations (17), (21) (31) and (32) were used to derive it for Nigeria Female population.

From equation (28), the factor $\left(\frac{{}_5\overline{N}_x}{{}_5\overline{N}_0}\right)\exp[5\sum_{i=0}^{x-5} {}_5r_i]$ must be 1 for the first age – group 0 – 4. When it is not 1, an adjustment is required to make it 1.

Application of the Model to Zambia: Female Population in the 2000 and 2010 Censuses

The model was applied to Zambia (female) population between 2000 and 2010 as shown in Table 2 (see appendix 1b). The age specific growth rates and populations at the midpoint of the interval are determined using equations (29) and (30) respectively. Equation (32) was used to derive the expectation of life (e_x) for Zambia females population. From the 2013-14 ZDHS, $l_1 = 0.9629$, $l_5 = 0.9050$ with $l_0 = 1$, ${}_5L_0$ is derived from (27) a ${}_5L_0 = 0.3 + 2l_1 + 2.7l_5 = 4.6693$. Estimates of $l_0, l_1, and\ l_5$ used in determining ${}_5L_0$ for Zambia were derived from the 2013-14 ZDHS, whose reference period is almost at the midpoint of the inter-censal period between 2000 and 2010.

Application of the Model to Cambodia: Male Population in the 1998 and 2008 Censuses

The model was applied to Cambodia – precisely, the male population between 1998 and 2008 as shown in Table 3 (in appendix 1c). The age specific growth rates and populations at the midpoint of the interval are determined using equations (29) and (30) respectively. Equation (32) was used to derive the expectation of life (e_x) for the male population. From the 2010 ZDHS, $l_1 = 0.8007$, $l_5 = 0.9271$ with $l_0 = 1$, ${}_5L_0$ is derived from (27), ${}_5L_0 = 0.3 + 2l_1 + 2.7l_5 = 4.40457$. Estimates of $l_0, l_1, and\ l_5$ used in determining ${}_5L_0$ for Cambodia were derived from the 2010 ZDHS whose reference period is almost at the midpoint of the inter-censal period between 1998 and 2008.

5. Discussion

The proposed model provides estimates of adult mortality in selected developing countries. Table 1 (in appendix 1a) shows that at age 5 (adult mortality), females in Nigeria from 1991 to 2006 – who experienced the observed age-specific growth rate – are expected to live below 60 years. The age-specific sequence of the estimates of the expectation of life obtained fell consistently from the aged 5-9 group to the aged 80-84 group. The model was also applied to the female population in Zambia between 2000 and 2010. Table 2 shows that life expectancy estimates appear smooth and linearly distributed from ages 5 to 65. At age 5, a female in Zambia from 2000 to 2010, on the average, is expected to live more than 60 years (61.3), while at age 10, it is about 56.7 years. Furthermore, at age 5, a male in Cambodia in 2008 is expected to live 61.2 years.

The results obtained from the application of the proposed method to selected developing countries was assessed using other sources. Table 4 (in appendix 3a) shows that the expectation of life estimates from the proposed method for Nigeria is consistently higher than the WHO estimates from ages 5 to 30 but below the Preston-Bennett method estimates from ages 5 to 20 respectively. The average of the first five life expectancy estimates is about 46.0 years for WHO, 50.3 years for the proposed method, and 54.2 years for Preston-Bennett.

For the female population in Zambia between 2000 and 2010, the results in Table 4 show that age-specific estimates of life expectancy from the proposed method dropped consistently from ages 5 to 60, while the mean of the first five estimates of the expectation of life from the three models is almost the same. The breakdown shows that the proposed method recorded 51.5 years, Preston-Bennett is about 49.9 years, while the WHO estimate is about 50.8 years. WHO did not publish the life table of Cambodia in 2008 so we assessed the estimates of the model with WHO 2010 life expectancy estimates for Cambodia. Estimates of life expectancy from the proposed model are for each age and are consistent with the estimates from WHO 2010, while remaining slightly lower than estimates from Preston-Bennett. This is perhaps due to the factor in equation (9) being ignored by Preston-Bennett. However, when the quality of data is good, the difference may not be much.

WHO estimates are not used as a direct comparison of results but a way of assessing estimates of the proposed method. This is because the data sources and methods of estimation are not the same. For most developing countries, estimation of all demographic parameters is very challenging, due to weak civil registration systems and poor census and survey data. In most cases, demographic parameters are inferred or interpolated from model life tables for such countries, very similar to WHO life table estimates. WHO life tables for most developing countries are derived from existing life tables, such as the United Nations model life tables (WHO 2016, 2018). But the data used in simulating the model life tables for developing countries are not from those countries and, therefore, demographic parameters derived from such life tables may not be a true representation of the situation on ground.

In summary, the proposed method is expected to perform very well when fertility and mortality are relatively stable for the reference period. The importance of this proposed model lies in its simplicity to apply and ability to incorporate the factor ignored by Preston-Bennett, which tends to overestimate expectation of life at age x. However, like other methods based on censuses, the estimates from the proposed model may be affected by differences in completeness of the two census age distributions and high net-migration (UN, 1983; ECA, 1988; UN, 2002). Furthermore, errors in the estimates of l_1 and l_5 used to compute ${}_5L_0$ may affect the age-specific estimates of the life expectancy.

6. Conclusion

This study proposes another approach to estimation of adult mortality in developing countries based on variable-r method. The method derives estimates of adult mortality from age-sex distributions of two population at two points in time with an arbitrary intercensal period. The results obtained by the application of the proposed method to selected countries in developing countries was assessed using other related sources. The proposed method is very simple and estimates from it compared favourably well with estimates from other related methods. More importantly, the estimates of the proposed method appear more consistent with WHO estimates than the Preston-Bennett method.

The method offers more insight for the race to find a 'perfect model' for the estimation of adult mortality in developing countries. The model helps narrow the research gap in adult mortality estimation in developing countries and provides alternative estimates apart from the interpolated estimates from WHO for most developing countries. Strengthening civil registration systems should not be abandoned because of the availability of indirect techniques in developing countries.

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Appendix 1a

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

Age	${}_5\bar{N}_x$	$({}_5r_x)$	$5({}_5r_x)$	$5\sum_{x=0}^{x-5} {}_5r_x$	$Exp[5\sum_{x=0}^{x-5} {}_5r_x]$	$\frac{{}_5N_X}{{}_5N_0}\exp[5\sum_{x=0}^{x-5} {}_5r_x]$	Adj (Col7)	${}_nL_x$ (Col8* ${}_5L_0$)	l_x	e_x
1	2	3	4	5	6	7	8	9	10	11
0-4	8,860,650	0.0317	0.1587	0.15875	1.1720	1.1720	1.0000	4.4097	-	63.5
5-9	8,309,338	0.0209	0.1047	0.26346	1.3014	1.2205	1.0413	4.5919	0.9002	59.1
10-14	6,415,589	0.0250	0.1250	0.38846	1.4747	1.0678	0.9110	4.0174	0.8609	54.5
15-19	5,994,389	0.0298	0.1490	0.53742	1.7116	1.1579	0.9880	4.3566	0.8374	50.5
20-24	5,659,102	0.0351	0.1753	0.71276	2.0396	1.3027	1.1114	4.9012	0.9258	46.1
25-29	5,228,822	0.0357	0.1784	0.89116	2.4380	1.4387	1.2275	5.4129	1.0314	41.2
30-34	3,961,545	0.0328	0.1638	1.05493	2.8718	1.2840	1.0955	4.8308	1.0244	35.8
35-39	2,756,163	0.0422	0.2108	1.26569	3.5455	1.1029	0.9410	4.1494	0.8980	31.0
40-44	2,419,578	0.0343	0.1713	1.43697	4.2079	1.1491	0.9804	4.3232	0.8473	26.8
45-49	1,493,585	0.0453	0.2265	1.66349	5.2777	0.8896	0.7590	3.3472	0.7670	22.5
50-54	1,506,466	0.0326	0.1631	1.82655	6.2124	1.0562	0.9012	3.9740	0.7321	19.2
55-59	659,324	0.0419	0.2093	2.03589	7.6591	0.5699	0.4863	2.1443	0.6118	15.2
60-64	931,522	0.0222	0.1108	2.14672	8.5567	0.8996	0.7675	3.3846	0.5529	13.0
65-69	434,787	0.0266	0.1328	2.27947	9.7715	0.4795	0.4091	1.8040	0.5189	9.7
70-74	474,266	0.0251	0.1256	2.40506	11.0791	0.5930	0.5060	2.2311	0.4035	7.8
75-79	200,576	0.0335	0.1673	2.57236	13.0967	0.2965	0.2529	1.1154	0.3347	5.6
80-84	282,121	0.0319	0.1594	2.73179	15.3604	0.4891	0.4173	1.8401	0.2956	4.5
85+	248,241	-	-	-	-	-	-	-	-	-

Note: **${}_5L_0$ = 4.40973, l_1 = 0.9048, l_5 = 0.8519 (derived from 2013 Nigeria DHS).**

Appendix 1b

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

Age Group	${}_5\bar{N}_x$	$({}_5r_x)$	$5({}_5r_x)$	$5\sum_{x=0}^{x-5} {}_5r_x$	$Exp[5\sum_{x=0}^{x-5} {}_5r_x]$	$\frac{{}_5N_X}{{}_5N_0}\exp[5\sum_{x=0}^{x-5} {}_5r_x]$	Adj (Col7)	${}_nL_x$	l_x	e_x
1	2	3	4	5	6	7	8	9	10	11
0-4	973,395	0.03086	0.1543	0.1543	1.1668	1.1668	1.0000	4.6693	-	66.0
5-9	841,695	0.02733	0.1367	0.2909	1.3377	1.1567	0.9913	4.6288	0.9298	61.3
10 -14	740,446	0.03933	0.1966	0.4876	1.6284	1.2387	1.0616	4.9568	0.9586	56.7
15-19	663,192	0.03405	0.1703	0.6578	1.9306	1.3154	1.1273	5.2637	1.0221	51.7
20-24	563,713	0.02639	0.1320	0.7898	2.2030	1.2758	1.0934	5.1053	1.0369	46.4
25-29	463,460	0.03885	0.1943	0.9841	2.6753	1.2738	1.0917	5.0973	1.0203	41.3
30-34	340,498	0.04101	0.2051	1.1891	3.2842	1.1488	0.9846	4.5973	0.9695	36.2
35-39	268,673	0.03990	0.1995	1.3886	4.0092	1.1066	0.9484	4.4284	0.9026	31.6
40-44	192,243	0.03029	0.1514	1.5400	4.6648	0.9213	0.7896	3.6867	0.8115	27.2
45-49	152,727	0.04209	0.2105	1.7505	5.7574	0.9033	0.7742	3.6150	0.7302	23.5
50-54	124,847	0.03231	0.1616	1.9120	6.7669	0.8679	0.7438	3.4732	0.7088	19.9
55-59	84,598	0.02897	0.1449	2.0569	7.8217	0.6798	0.5826	2.7203	0.6193	16.4
60-64	79,044	0.02716	0.1358	2.1927	8.9592	0.7275	0.6235	2.9114	0.5632	13.7
65-69	56,573	0.03203	0.1602	2.3529	10.5156	0.6112	0.5238	2.4457	0.5357	10.8
70-74	39,997	0.04384	0.2192	2.5720	13.0926	0.5380	0.4611	2.1529	0.4599	8.4
75-79	23,573	0.05848	0.2924	2.8645	17.5396	0.4248	0.3640	1.6998	0.3853	6.2
80-84	13,755	0.04433	0.2217	3.0861	21.8919	0.3094	0.2651	1.2380	0.2938	4.5
85+	13,669	-	-	-	-	-	-	-	-	-

Note: **${}_5L_0$ = 4.6693, l_1 = 0.9629, l_5 = 0.9050 (derived from 2013-14 Zambia DHS).**

Appendix 1c

Table 3: Proposed Fixed-base Model applied to Cambodia, Male: 1998-2008

Age	${}_5\overline{N}_x$	$({}_5r_x)$	$5({}_5r_x)$	$5\sum_{x=0}^{x-5} {}_5r_x$	$Exp[5\sum_{x=0}^{x-5} {}_5r_x]$	$\frac{{}_5N_X}{{}_5N_0}\exp[5\sum_{x=0}^{x-5} {}_5r_x]$	Adj (Col7)	${}_nL_x$ (Col8* ${}_5L_0$)	l_x	e_x
1	2	3	4	5	6	7	8	9	10	11
0-4	724,950	-0.0061	-0.0305	-0.03051	0.9700	0.9700	1.0000	4.4046	-	65.6
5-9	825,837	-0.0184	-0.0918	-0.12232	0.8849	1.0080	1.0392	4.5774	0.8982	61.2
10-14	855,269	0.0010	0.0048	-0.11748	0.8892	1.0490	1.0815	4.7635	0.9341	56.6
15-19	746,066	0.0228	0.1141	-0.00340	0.9966	1.0256	1.0574	4.6574	0.9421	51.8
20-24	495,107	0.0637	0.3184	0.31496	1.3702	0.9358	0.9648	4.2494	0.8907	47.2
25-29	511,139	0.0350	0.1748	0.48981	1.6320	1.1507	1.1863	5.2252	0.9475	42.9
30-34	352,278	-0.0099	-0.0497	0.44007	1.5528	0.7546	0.7779	3.4265	0.8652	37.7
35-39	365,244	0.0227	0.1136	0.55364	1.7396	0.8764	0.9036	3.9799	0.7406	34.3
40-44	265,471	0.0545	0.2723	0.82590	2.2839	0.8364	0.8623	3.7979	0.7778	30.3
45-49	231,525	0.0535	0.2677	1.09359	2.9850	0.9533	0.9828	4.3289	0.8127	26.5
50-54	162,094	0.0392	0.1959	1.28945	3.6308	0.8118	0.8370	3.6865	0.8015	22.2
55-59	134,579	0.0387	0.1937	1.48316	4.4069	0.8181	0.8434	3.7150	0.7401	18.5
60-64	100,918	0.0299	0.1493	1.63244	5.1163	0.7122	0.7343	3.2342	0.6949	14.8
65-69	80,181	0.0248	0.1239	1.75629	5.7909	0.6405	0.6603	2.9085	0.6143	11.5
70-74	54,907	0.0313	0.1563	1.91264	6.7709	0.5128	0.5287	2.3287	0.5237	8.6
75-79	34,745	0.0428	0.2140	2.12665	8.3867	0.4020	0.4144	1.8253	0.4154	6.3
80-84	16,149	0.0543	0.2716	2.39821	11.0035	0.2451	0.2527	1.1131	0.2938	4.5
85+	9,270	-	-	-	-	-	-	-	-	-

Note: **${}_5L_0$ = 4.40457, l_1 = 0.8007, l_5 = 0.9271 (derived from 2010 Cambodia DHS).**

Appendix 2a: Preston-Bennett Method applied to Nigeria, Females: 1991-2006

Age Group	Census population		${}_5\overline{N}_x$	$({}_5r_x)$	S_x	${}_5L_x$	T_x	l_x	e_x
	1991 ${}_5N_X^{(1)}$	2006 ${}_5N_X^{(2)}$							
0-4	6,999,435	11,025,749	8,860,650	0.03175	0.0794	9,592,627	136,345,921	-	-
5-9	7,126,144	9,616,769	8,309,338	0.02094	0.2111	10,262,403	126,753,294	1,985,503	63.8
10-14	5,336,143	7,631,631	6,415,589	0.02500	0.3260	8,887,942	116,490,891	1,915,035	60.8
15-19	4,806,977	7,362,887	5,994,389	0.02979	0.4629	9,523,557	107,602,949	1,841,150	58.4
20-24	4,357,267	7,197,530	5,659,102	0.03507	0.6251	10,573,594	98,079,392	2,009,715	48.8
25-29	4,006,932	6,676,968	5,228,822	0.03568	0.8020	11,659,812	87,505,798	2,223,341	39.4
30-34	3,105,298	4,962,352	3,961,545	0.03275	0.9730	10,482,192	75,845,986	2,214,200	34.3
35-39	2,007,882	3,670,622	2,756,163	0.04215	1.1603	8,794,685	65,363,794	1,927,688	33.9
40-44	1,874,721	3,060,981	2,419,578	0.03426	1.3513	9,345,753	56,569,109	1,814,044	31.2
45-49	1,061,332	2,029,767	1,493,585	0.04530	1.5502	7,038,604	47,223,356	1,638,436	28.8
50-54	1,182,149	1,885,282	1,506,466	0.03261	1.7450	8,626,060	40,184,753	1,566,466	25.7
55-59	481,394	876,477	659,324	0.04187	1.9312	4,547,979	31,558,693	1,317,404	24.0
60-64	791,573	1,087,067	931,522	0.02216	2.0913	7,541,116	27,010,713	1,208,910	22.3
65-69	357,400	522,612	434,787	0.02655	2.2131	3,975,669	19,469,597	1,151,678	16.9
70-74	394,116	564,609	474,266	0.02512	2.3423	4,934,615	15,493,929	891,028	17.4
75-79	156,368	252,422	200,576	0.03346	2.4887	2,416,084	10,559,314	735,070	14.4
80-84	222,627	351,373	282,121	0.03189	2.6521	4,001,443	8,143,230	641,753	12.7
85+	194,404	311,204	248,241	0.03288	2.8145	4,141,787	4,141,787	-	-

Appendix 2b: Preston-Bennett Method applied to Zambia, Females: 2000-2010

Age Group	Census population 2000 $_5N_X^{(1)}$	Census population 2010 $_5N_X^{(2)}$	$_5\overline{N}_x$	$_5r_x$	S_x	$_5L_x$	T_x	l_x	e_x
0-4	830931	1131280	973,395	0.03086	0.0771	1,051,454	14295593	-	-
5-9	731901	961955	841,695	0.02733	0.2226	1,051,557	13244139	210,301	63.0
10-14	604367	895562	740,446	0.03933	0.3893	1,092,813	12,192,582	214,437	56.9
15-19	556676	782499	663,192	0.03405	0.5727	1,175,874	11,099,769	226,869	48.9
20-24	492589	641375	563,713	0.02639	0.7238	1,162,537	9,923,895	233,841	42.4
25-29	379247	559303	463,460	0.03885	0.8869	1,125,121	8,761,357	228,766	38.3
30-34	275434	415081	340,498	0.04101	1.0866	1,009,280	7,636,236	213,440	35.8
35-39	218631	325824	268,673	0.03990	1.2889	974,917	6,626,957	198,420	33.4
40-44	164597	222823	192,243	0.03029	1.4643	831,372	5,652,040	180,629	31.3
45-49	122834	187117	152,727	0.04209	1.6453	791,491	4,820,667	162,286	29.7
50-54	105762	146100	124,847	0.03231	1.8313	779,265	4,029,176	157,076	25.7
55-59	72933	97444	84,598	0.02897	1.9845	615,465	3,249,911	139,473	23.3
60-64	68797	90262	79,044	0.02716	2.1248	661,696	2,634,446	127,716	20.6
65-69	47994	66117	56,573	0.03203	2.2728	549,109	1,972,751	121,080	16.3
70-74	31869	49403	39,997	0.04384	2.4625	469,314	1,423,642	101,842	14.0
75-79	17348	31134	23,573	0.05848	2.7183	357,221	954,328	82,653	11.5
80-84	10931	17029	13,755	0.04433	2.9753	269,542	597,107	62,676	9.5
85+	10294	17711	13,669	0.05426	3.1766	327,565	327,565	-	-

Appendix 2c: Preston-Bennett Method applied to Cambodia, Males: 1998-2008

Age Group	Census population		${}_5\overline{N}_x$	$({}_5r_x)$	S_x	${}_5L_x$	T_x	l_x	e_x
	1998 ${}_5N_X^{(1)}$	2008 ${}_5N_X^{(2)}$							
0-4	747,292	703,058	724,950	-0.00610	-0.0153	713,976	9,435,275	-	-
5-9	903,976	752,336	825,837	-0.01836	-0.0764	765,083	8,721,299	147,906	59.0
10-14	851,139	859,412	855,269	0.00097	-0.1199	758,631	7,956,217	152,371	52.2
15-19	664,184	834,416	746,066	0.02282	-0.0604	702,310	7,197,585	146,094	49.3
20-24	354,100	669,343	495,107	0.06367	0.1558	578,569	6,495,275	128,088	50.7
25-29	426,968	605,706	511,139	0.03497	0.4024	764,351	5,916,706	134,292	44.1
30-34	370,090	335,046	352,278	-0.00995	0.4649	560,795	5,152,356	132,515	38.9
35-39	325,331	408,295	365,244	0.02271	0.4969	600,294	4,591,560	116,109	39.5
40-44	199,722	344,275	265,471	0.05445	0.6898	529,152	3,991,266	112,945	35.3
45-49	175,052	299,005	231,525	0.05354	0.9597	604,516	3,462,114	113,367	30.5
50-54	132,413	195,911	162,094	0.03917	1.1915	533,628	2,857,598	113,814	25.1
55-59	110,189	162,328	134,579	0.03874	1.3863	538,325	2,323,970	107,195	21.7
60-64	86,602	116,731	100,918	0.02985	1.5578	479,196	1,785,645	101,752	17.5
65-69	70,660	90,521	80,181	0.02477	1.6944	436,440	1,306,449	91,564	14.3
70-74	46,769	63,938	54,907	0.03127	1.8345	343,814	870,009	78,025	11.2
75-79	27,838	42,710	34,745	0.04280	2.0196	261,827	526,195	60,564	8.7
80-84	12,159	20,930	16,149	0.05431	2.2624	155,138	264,367	41,697	6.3
85+	6,924	12,093	9,270	0.05576	2.4667	109,229	109,229	-	-

Appendix 3a

Table 4: Distribution of life expectancy estimates from the proposed method for selected Countries and other sources

	Nigeria (Females)			Zambia (Females)			Cambodia (Males)		
Age	**Proposed Model**	**Preston Bennett Method**	**WHO 2006**	**Proposed Model**	**Preston Bennett Method**	**WHO 2010**	**Proposed Model**	**Preston Bennett Method**	**WHO 2010**
5	59.1	63.8	54.1	61.3	63.0	59.3	61.2	59.0	62.3
10	54.5	60.8	50.3	56.7	56.9	55.2	56.6	52.2	57.6
15	50.5	58.4	45.9	51.7	48.9	50.7	51.8	49.3	52.8
20	46.1	48.8	41.8	46.4	42.4	46.4	47.2	50.7	48.2
25	41.2	39.4	38.1	41.3	38.3	42.3	42.9	44.1	43.7
30	35.8	34.3	34.6	36.2	35.8	38.5	37.7	38.9	39.2
35	31	33.9	31.3	31.6	33.4	34.9	34.3	39.5	34.8
40	26.8	31.2	28.0	27.2	31.3	31.5	30.3	35.3	30.5
45	22.5	28.8	24.5	23.5	29.7	28.1	26.5	30.5	26.4
50	19.2	25.7	20.7	19.9	25.7	24.6	22.2	25.1	22.5
55	15.2	24.0	17.1	16.4	23.3	21.0	18.5	21.7	18.9
60	13	22.3	13.4	13.7	20.6	17.4	14.8	17.5	15.5
65	9.7	16.9	10.4	10.8	16.3	14.0	11.5	14.3	12.6
70	7.8	17.4	7.7	8.4	14.0	10.9	8.6	11.2	9.9
75	5.6	14.4	5.6	6.2	11.5	8.3	6.3	8.7	7.7
80	4.5	12.7	4.0	4.5	9.5	6.1	4.5	6.3	5.7

Note: WHO life expectancy estimates were retrieved from WHO Global Health Observatory Data Repository. For details of Life expectancy estimates of Preston-Bennett Method see appendices 2a, 2b and 2c respectively.