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Estimation and Analysis of Adult Mortality and Construction of Life Table for Male Population of Bangladesh

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ABSTRACT

Life table is an important method of assessing the health of a population and it is used to measure mortality, survivorship, and the life expectancy of a population at varying ages. An abridged life table for the male population of Bangladesh in 2011 is constructed by the Widowhood Method and thereafter, age-specific death rates (ASDRs) are estimated from the constructed life table. Moreover, some mathematical models are fitted to survival function values, adult mortality, life expectancy, and ASDRs for the male population of Bangladesh in 2011. The distribution of the female population by current marital status due to age in the 2011 census is utilized as raw materials in this study. The model validation technique, cross-validity prediction power (CVPP) is applied here to verify the exactness of the model. The life expectancy at birth for the male population has been estimated using 2011 census data which is 63.46. It is observed that life expectancy at birth is increasing with time which indicates the health situation of Bangladesh is more developed than any earlier time. It is seen that the third-degree polynomial model has been fitted to survival function values, a second-degree polynomial model for adult mortality, and a third-degree polynomial model for life expectancy for the male population of Bangladesh. It is also noted that exponential models for ASDRs from age 0 to 10-14 and age 10-14 to 85+ have been fitted and the exactness of the fitted models are well according to shrinkage coefficients as well as F-test. The proportions of variation of these models are more than 97%.

Keywords: *Life Table, Mortality, Male Population, and Population Health*

1. INTRODUCTION

A life table is an important analytical technique in studying the expected remaining lifetime at a given age and a complete description of the mortality of the population of a nation. Life expectancy at birth is often taken as an overall measure of population health and mortality is a component of population dynamics in any region or country. The scenario of mortality of the total population also shows the health situation of any country. Adult mortality and age-specific death rates (ASDRs) are important measures of mortality in mortality analysis.

ASDRs are one of the best health indicators of specific ages of the population. Bangladesh has the highest population density with rapid population growth. The average annual growth rates of the population of Bangladesh were 2.17% and 1.59% in 1991 and 2001 respectively. The total male populations of Bangladesh were 57314 thousand, 64091 thousand, and 72109 thousand in 1991, 2001, and 2011 respectively (Bangladesh Bureau of Statistics, 2023). The important source of population data is the population census which is usually carried out at ten-year intervals. The data which are available in the developing countries is not adequate. However, the necessity of different types of demographic parameters is increasing for many reasons such as to justify the plans for health, education, and many functions of government and non-government organizations. To fulfill the above requirements, indirect techniques for the estimates of demographic parameters have been used especially for developing countries where a complete vital registration system has not started till now and the data are incomplete and not sufficient for estimating demographic parameters by using the direct method. Some of these methods are discussed in the United Nations Manual IV (United Nations, 1967). Levels and trends of adult male mortality in India and its major states during the post-independence period were shown by applying the widowhood method to census data (Saikia et al., 2013). By using 2010 census data from Lesotho and Nicaragua, this study investigated the use of censuses to calculate differential maternal mortality by using indirect demographic techniques, smoothing functions, and sensitivity analysis to analyze maternal mortality by age, residence, and education (Leone, 2013). Life tables have been constructed using the data of the 1981 census and ASDRs are calculated from these life tables. Moreover, the smoothed age structure of the 1981 census and the ASDRs are used to find CDR (Ali, 1990). The Widowhood method is applied to construct a life table for the male population of Bangladesh using the data of the female marital status of the 1991 census and then ASDRs, and CDR have been estimated. Furthermore, the crude birth rate (CBR) has also been estimated from a balancing equation (Islam et al., 2003). Islam (2019) studied mortality rates in Bangladesh and showed that the mortality rate in urban areas is lower than in rural areas at all ages except for children aged 53.5 months. Several studies for the construction of life tables were carried out by applying the widowhood method in Bangladesh (Islam, 2004, 2005, 2006; Islam et al., 2005, 2013). (Hossain & Islam, 2013; Islam & Hossain, 2014a; Islam & Hossain, 2014b; Islam & Hossain, 2015; Islam et al., 2014; Islam et al., 2016 & Hossain et al., 2023) utilized several models to analyze the trends and to forecast variables and got significant results. Life expectancy has increased for Matlab over the last few decades (Rabbi & Karmaker, 2013).

Moreover, it is found that the trend of population in Bangladesh is increasing over time. Therefore, the objectives of this study are as follows:

i) to estimate adult mortality and then, to construct a life table and to estimate ASDRs for the male population of Bangladesh in 2011, and

ii) to fit some mathematical models to adult mortality, survival functions, life expectancy at ages, and ASDRs for the male population of Bangladesh in 2011.

2. SOURCES OF DATA

To fulfill the above objectives of this study, the marital status composition for the female population of Bangladesh in the census year, 2011 is taken from Statistical Year Book Bangladesh 2022 (Bangladesh Bureau of Statistics, 2023).

3. METHODOLOGY

3.1 Estimation of Adult Mortality and Construction of Life Table by Widowhood Method

Adult mortality for the male population of Bangladesh is estimated by using the marital status composition for the female population of Bangladesh with the help of the Widowhood method which was proposed by Hill (1977). For this purpose corrected proportion not widowed for females, $\hat{\pi}^{f}(x)$ is calculated as

$$\hat{\pi}^{f}(x)=\frac{\pi^{f}(x)}{1+p} \qquad \text{(Brass, 1978)}$$

where, $\pi^{f}(x)$ and p are the proportion not widowed for females and the remarriage rate of females respectively, as p is assumed to be small for females, and no correction is made for proportions of females not widowed. The term $\frac{l_{(x+5)}}{l_{22.5}}$ is used to indicate the probability of survival from age 22.5 to (x+5) where x=20, 25,….., 60 and the term $\frac{d_{(x+5)}}{d_{22.5}}$ is for the probability of dying from age 22.5 to (x+5) where x=20, 25,….., 60. In this matter two events may occur like surviving or dying. Sum of the probability of these two events must be equal to one as $\frac{l_{(x+5)}}{l_{22.5}}+\frac{d_{(x+5)}}{d_{22.5}}=1$. These values are launched in Table 1. l_2 value is estimated using the Orphanhood Method (Sivamurthy and Seetharam, 1980) for linking infant mortality to adult mortality. For this, a linear function $Y_x=a+bY_x^s$ is fitted by iteration method according to Sivamurthy and Seetharam (1980), where $Y_x = \log it\ value\ of\ l_x = \frac{1}{2}\log\frac{l_x}{(1-l_x)}$ and Y_x^s is the logit survival function of standard life table l_x^s of standard life table (United Nations, 1982). Mortality for male population, Y_x are then converted to the survival function l_x values, the number of persons surviving at an exact age of x. Then, the l_x values have been applied to construct a life table using the relationships among life table functions and presented in Table 2.

Table 1. Adult Mortality Estimates for Male Population of Bangladesh in 2011 by Widowhood Method Using Data on Marital Status for Female

Age Group	Proportion Not Widowed (x)	Central Age (x)	Corrected Weights W(x)	$\frac{l_{(x+5)}}{l_{22.5}}$	$\frac{d_{(x+5)}}{d_{22.5}}$
15-19	0.9916				
		20	0.3405	0.9933	0.0067
20-24	0.9941				
		25	0.2241	0.9914	0.0086
25-29	0.9906				
		30	0.3432	0.9842	0.0158
30-34	0.9808				
		35	0.4777	0.9721	0.0279
35-39	0.9642				
		40	0.5431	0.9473	0.0527
40-44	0.9272				
		45	0.7268	0.9167	0.0833
45-49	0.8885				
		50	0.8071	0.8730	0.127
50-54	0.8065				
		55	0.8809	0.8005	0.1995
55-59	0.7559				
		60	0.9003	0.7406	0.2594
60-64	0.6033				
		65	0.9071		

Table 2. Abridged Life Table for Male Population of Bangladesh in 2011

Age (x)	l_x	${}_n d_x$	${}_n q_x$	${}_n L_x$	T_x	e_x
0	100000	5704	0.05704	96007	6345501	63.46
1	94296	1410	0.01495	93450	6249494	66.28
2	92886	702	0.00756	92535	6156044	66.28
3	92184	427	0.00463	91971	6063509	65.78
4	91757	289	0.00315	91613	5971539	65.08
5	91468	659	0.00721	455692	5879926	64.28
10	90809	305	0.00336	453280	5424234	59.73
15	90503	380	0.00420	451566	4970954	54.93
20	90123	453	0.00502	449485	4519388	50.15
25	89671	567	0.00632	446937	4069903	45.39
30	89104	704	0.00790	443761	3622966	40.66
35	88400	1016	0.01149	439462	3179204	35.96
40	87384	1573	0.01800	432990	2739742	31.35
45	85812	2508	0.02922	422789	2306752	26.88
50	83304	4167	0.05002	406101	1883963	22.62
55	79137	6391	0.08076	379705	1477861	18.67
60	72745	9718	0.13359	339432	1098156	15.10
65	63027	12787	0.20287	283171	758724	12.04
70	50241	14950	0.29756	213830	475554	9.47
75	35291	14150	0.40095	141081	261724	7.42
80	21141	10739	0.50798	78858	120643	5.71
85+	10402	10402	1.00000	41786	41786	4.02

3.2 Estimation of ASDRs

ASDRs have been estimated from the constructed life table using the formula $ASDR = \frac{{}_n d_x}{{}_n L_x}$, where ${}_n d_x$ is the number of deaths in the age interval x to x+n and ${}_n L_x$ is the stationary population in the life table.

3.3 Smoothing of ASDRs

It is observed that there is some sort of unexpected distortions in the data aggregate if the ASDRs for the male population by age group are to be placed on graph paper. For this reason, adjustment is needed to diminish the unpredicted distortions. As a result, a modification is made, that is, ASDRs are smoothened using the Package Minitab Release 12.1 by the most up-to-date smoothing technique “4253H, twice” (Velleman, 1980). After that, the smoothed data have been used to fit mathematical model and these smoothed data are launched in Table 3.

Table 3. Estimated and Smoothed ASDRs for Male Population of Bangladesh in 2011

Age Group	**2011**	
	Estimated ASDRs	**Smoothed ASDRs**
0	0.05941	0.053887
1	0.01509	0.02664
2	0.00758	0.01014
3	0.00464	0.004157
4	0.00315	0.002462
5-9	0.00145	0.001472
10-14	0.00067	0.000888
15-19	0.00084	0.000791
20-24	0.00101	0.000893
25-29	0.00127	0.001128
30-34	0.00159	0.001551
35-39	0.00231	0.002258
40-44	0.00363	0.003551
45-49	0.00593	0.005906
50-54	0.01026	0.010032
55-59	0.01683	0.017105
60-64	0.02863	0.028608
65-69	0.04516	0.045589
70-74	0.06991	0.068805
75-79	0.10030	0.103106
80-84	0.13619	0.160943
85+	0.24894	0.244527

3.4 Model Fitting for Adult Mortality and ASDRs

Polynomial models are selected for survival function, adult mortality, and life expectancy for the male population of Bangladesh in 2011, and using the scattered plots (Fig.3-Fig.5) by age, it seems that the data can be fitted by polynomial models concerning different ages in years. Therefore, an nth-degree polynomial model is considered and the form of the model is

$$y = a_0 + \sum_{i=1}^{n} a_i \; x^{i} + u \; ;$$

where x indicates age group; y is survival function or adult mortality or life expectancy; is the constant; is the coefficient of (i =1, 2, 3, ..., n) and u is the disturbance term of the model. Here, a suitable n is found for which the error sum of the square is minimum.

For fitting the mathematical model to ASDRs for the male population of Bangladesh, the smoothed ASDRs for the male population by age in years are divided into two divisions such as i) ASDRs from age 0 to 10-14 and ii) ASDRs from age 10-14 to 85+ to choose exponential model of the form $y = \exp(a + bx) + e$. Here, x represents the age group; y represents the ASDRs, e is the error term of the model; and a and b are unknown parameters. These models are fitted by handling the software STATISTICA.

3.5 Model Validation Technique

To test out the stability of the models, the cross validity prediction power (CVPP), ρ_{cv}^2 is applied.

$$\rho_{cv}^2 = 1 - \frac{(n-1)(n-2)(n+1)}{n(n-k-1)(n-k-2)}(1-R^2)$$ (Steven, 1996)

where n is the sample size or number of cases, k is the number of predictors in the model, and cross-validation R is the correlation between observed and predicted values of the dependent variable. The shrinkage of the model is the positive value of $\lambda = (\rho_{cv}^2 - R^2)$; where ρ_{cv}^2 is CVPP & R^2 is the coefficient of determination of the model. 1- λ is the stability of R^2 of the model. The estimated CVPP analogous and related information on model fittings are summarized in Table 4. This technique is used as a model validation technique (Islam, 2007; 2008; 2011; 2012a; 2012b; 2013; Islam & Hossain, 2013a; 2013b; Hossain & Islam, 2013).

Table 4. Estimated Cross Validity Prediction Power (ρ_{cv}^2) of the Predicted Equations.

Models	n	k	R^2	ρ_{cv}^2	Shrinkage	Cal. F	Tab.F (at 1% level)	Variance explained (%)
Equation 1	22	4	0.99258	0.988022	0.00455814	6942.493	5.09 with (3,18) d.f.	99.258
Equation 2	9	3	0.97808	0.931804	0.04627556	263.0858	10.92 with (2,6) d.f	97.808
Equation 3	22	4	0.99771	0.996303	0.00140676	7381.327	5.09 with (3,18) d.f	99.771
Equation 4	7	2	0.99616	0.989029	0.00713143	1027.123	16.26 with (1,5) d.f	99.616
Equation 5	16	2	0.99807	0.997240	0.00083046	4734.960	8.86 with (1,14) d.f	99.807

3.6 F-test

The F-test is used to verify the overall measure of the significance level of the fitted models as well as the significance of R^2. The formula for the F-test is given by

$$F = \frac{R^2 / (k-1)}{(1-R^2) / (n-k)}$$ with (k-1, n-k) degrees of freedom (d.f.);

where k is the number of parameters of the fitted model, n is the number of cases, and R^2 is the coefficient of determination in the model.

It is noted that Statistical Package for Social Sciences (SPSS), MINITAB Release 12.1, and STATISTICA are used in this study.

4. RESULTS AND DISCUSSION

Here, the adult mortality rates are estimated from the probability of survival from age 22.5 to (x+5) for x=20, 25,……., 60. Column 8 of Table 1 represents the adult mortality of the male population at different ages which shows the probability of dying from age 22.5 to (x+5) for x=20, 25,……., 60. The pattern of adult mortality rates from age 22.5 to (x+5) for x=20, 25,……., 60 for the male population of Bangladesh in the census 2011 is observed that it shows an upward trend with ages. The adult mortality has been estimated which is in Figure 3 and shows that the probability is becoming very high after age 55. That means different types of cause-specific deaths occur normally after age 55 years.

After estimating adult mortality, the life table for the male population of Bangladesh has been constructed by the Widowhood Method and presented in Table 2 in which the life expectancy at birth for the male population of Bangladesh for the census year 2011 is found to be 63.46 years. To observe the trend of life expectancy at birth, the life expectancy at birth for the male population of Bangladesh in 1961, 1974, 1981, and 1991 were 43.42, 45.15, 48.33, and 55.13 years respectively taken from Islam (2003). Again, another mortality measure ASDRs for the male population of Bangladesh in the census 2011 have been estimated from the constructed life table and shown in column 2 of Table 3. Thereafter, ASDRs have been smoothed and presented in column 3 of Table 3 and depicted in Figure 1 which shows the patterns of estimated and smoothed ASDRs. Furthermore, it is observed that ASDRs from age 0 to 1 were very high and gradually declined to age 3 and then stable till age 40. After age 40, it was again upward but in slow motion to till the age of 65. It is also observed that

ASDRs after the age of 65 were greater than any younger ages of the male population of Bangladesh.

The fitted equations are as follows:

$$Y = 94139.09 - 614.21x + 23.40x^2 - 0.33x^3 \text{ for survival functions } l_x \text{ values for male in } 2011 \quad (1)$$

t-stat	85.7226	-4.0669	5.1233	-9.0615
P-value	0.0000	0.0007	0.0000	0.0000

$$Y = 0.367719 - 0.020383x + 0.000313x^2 \text{ for adult mortality for male in } 2011 \quad (2)$$

t-stat	7.69437	-7.97258	9.89737
P-value	0.0002	0.0002	0.0000

$$Y = 66.8260 - 0.6902x - 0.0079x^2 + 0.00009x^3 \text{ for life expectancy for male in } 2011 \quad (3)$$

t-stat	113.115	-8.4957	-3.2540	4.4099
P-value	0.0000	0.0000	0.0044	0.0003

$$Y = \exp(-2.73983 - 0.80244x) \text{ for ASDRs from age } 0 \text{ to } 10-14 \text{ for male in } 2011 \quad (4)$$

t-stat	-113.197	-20.139
P-value	0.0000	0.0000

$$Y = \exp(-11.2635 + 0.1171x) \text{ for ASDRs from age } 10-14 \text{ to } 85+ \text{ for male in } 2011 \quad (5)$$

t-stat	-51.8338	45.9858
P-value	0.0000	0.0000

The estimated CVPP, ρ_{cv}^2 corresponding to their R^2 are shown in Table 4. The observed and fitted values are depicted in Figure 2 to Figure 6. In this table, all fitted models from equation (1) to equation (5) are highly cross-validated and their shrinkages are very small. Moreover, it is observed that all the parameters of the fitted models are statistically significant with a large proportion of variation explained. Hence, all these models are fitted well.

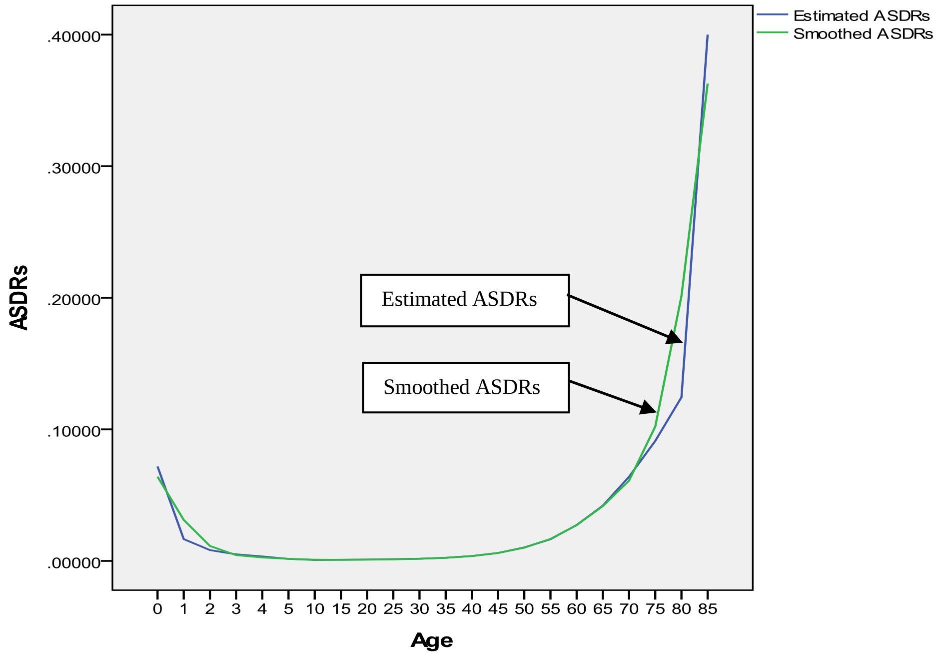

Figure 1. The Graph of Estimated ASDRs and Smoothed ASDRs for Male Population of Bangladesh in 2011

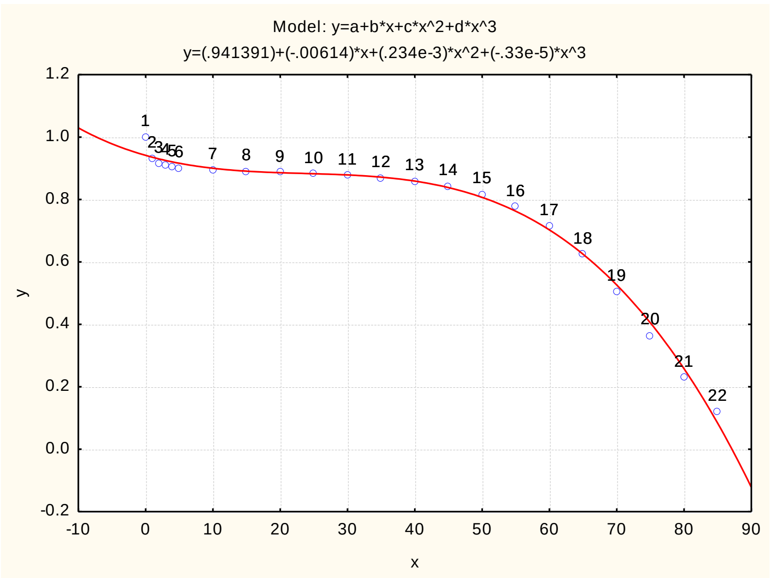

Figure 2. Observed and Fitted survival functions l_x values for Male Population of Bangladesh in 2011. X Axis Represents Age Group and Y Axis Represents survival functions l_x values

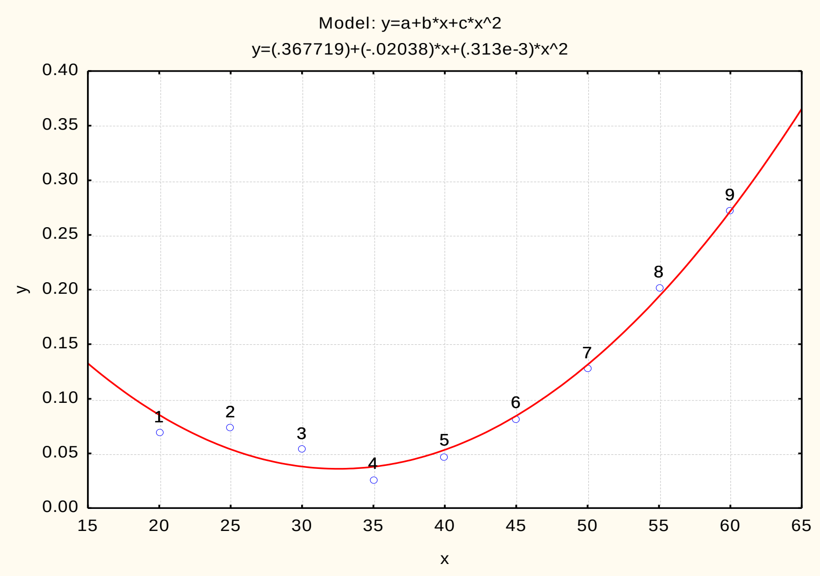

Figure 3. Observed and Fitted Adult Mortality for Male Population of Bangladesh in 2011 from Age 20 to 60. X Axis Represents Age Group and Y Axis Represents Adult Mortality

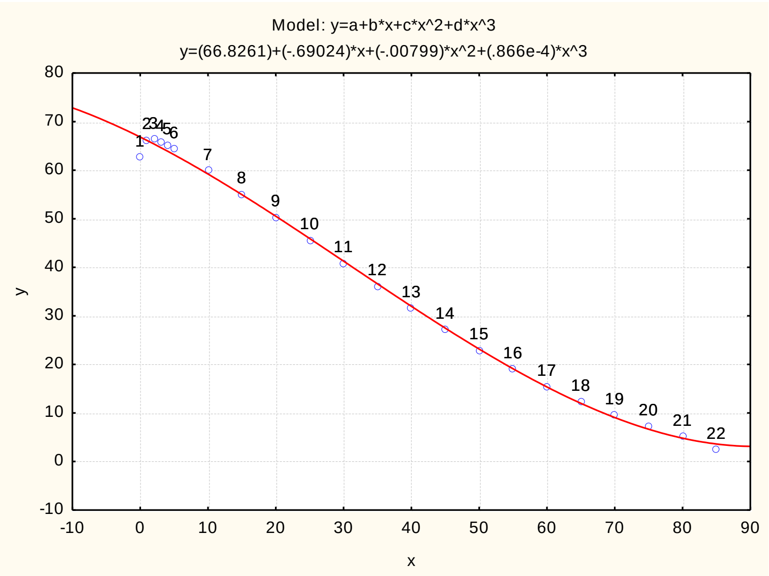

Figure 4. Observed and Fitted Life Expectancy for Male Population of Bangladesh in 2011. X Axis Represents Age Group and Y Axis Represents Life Expectancy for Male Population

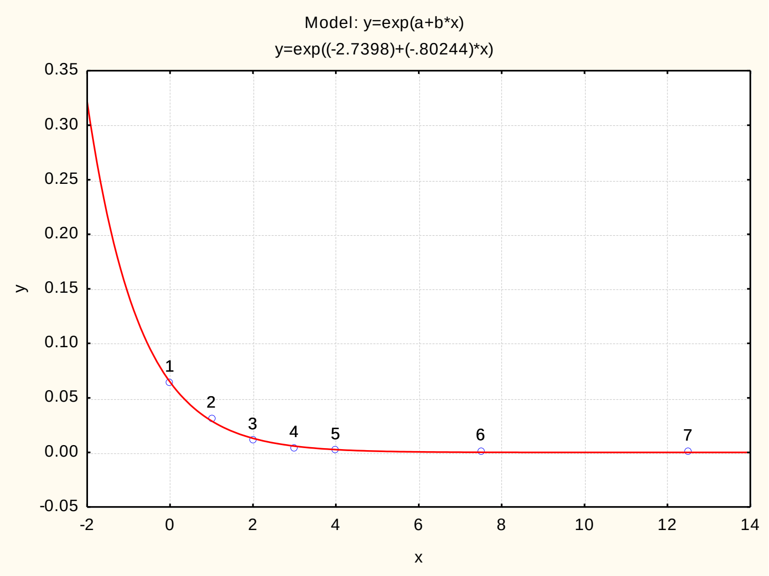

Figure 5. Observed and Fitted ASDRs from Age 0 to 10-14 for Male Population of Bangladesh in 2011. X Axis Represents Age Group and Y Axis Represents ASDRs

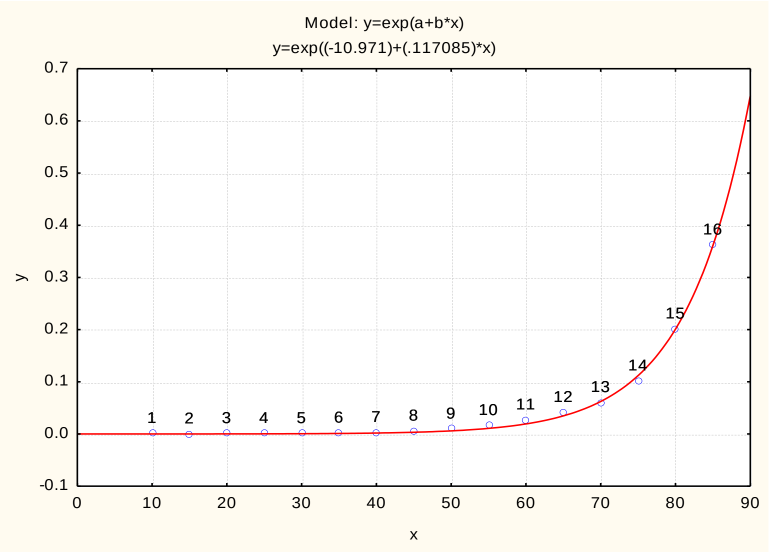

Figure 6. Observed and Fitted ASDRs from Age 10-14 to 85+ for Male Population of Bangladesh in 2011. X Axis Represents Age Group and Y Axis Represents ASDRs

5. Conclusions

Adult Mortality and life table for the male population of Bangladesh have been constructed by using census data of 2011 and then, ASDRs have been estimated. It is observed that life expectancy is increasing which indicates the health situation is improving day by day. The parameters that are estimated are perspective and reasonable. It is also found that third third-degree polynomial model is fitted for survival functions, the second-degree polynomial model for adult mortality, and again the third-degree polynomial model for life expectancy for the male population of Bangladesh in 2011. Moreover, it is found that exponential models with acceptable variation are fitted to ASDRs in two categories based on ages like 0 to 10-14 and 10-14 to 85+ respectively. It is also seen that these models are a better fit concerning their coefficient of determination as well as their shrinkage coefficients. A most important finding is the mortality rate for the male population after age 55 is high. Government, non-government, and policymakers should take several steps to develop health facilities for all population of Bangladesh especially more for the male population of Bangladesh after 55. Research organizations or individual researchers may do the next research for every district of Bangladesh.

Declaration of interest

The authors declare no conflict of interest.

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