THE STUDY Of BIRTH INTERVALS THROUGH LIFE TABLE APPROACH

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Abstract

The study of birth intervals as an important factor to understand and analyze human fertility is relatively new. However, a variety of mathematical models based on birth intervals have been used to study the human reproduction process and its components. Life tables are one of the most important tools used in demographic analysis and one of the most efficient means of scientific analysis in the study and analysis of the phenomenon of births. Therefore, this paper uses the life table approach to illustrate the analysis of birth intervals using real data extracted from Egypt's Demographic and Health Survey conducted in 2014; based on assumptions of human reproductive process, and some mathematical functions and relationships associated with fertility tables. The survey is carried out based on 59,266 married females. In this paper, fertility tables for parity $m = 1, 2, 3$ and for some selected variables are produced. The variables studied are the place of residence and educational status. The results obtained through the application are logical and compatible with the real-life.

Keywords **—** Birth Intervals; Fertility Tables; Parity; Life Tables; Survival Data.

I. INTRODUCTION

Life table analysis is one of the oldest statistical techniques extensively used by medical statisticians and by actuaries to analyze survival data. While most treatments of the life table are given in the context of death, the idea is quite general and applies to any situation where a well-defined population is subject to decrementation due to the operation of a certain force [or forces] of decrement as time elapses. This feature makes the life table a basic tool of demographic analysis.

Statistical methods are of great importance in many different fields. The analysis of survival is one of the most important of these methods where it is concerned with analyzing data in which the variable of interest is the time needed for a particular event. There are many ways

to estimate the survival function such as the parametric, non-parametric and semi-parametric methods. Life tables are one of the most important non-parametric methods used to study reproduction, migration, fertility and population growth. [Shayan, et al. (2014)]

In recent years, many authors have shown keen interest in the study of probability models in fertility in general and in birth intervals in particular [See, for example; Srinivasan (1967), Singh, et al. (1982), Fagbamigbe, et al. (2012), Luguterah (2013), Gurmu and Etana (2014), Singh (2016), Singh, et al. (2018), Afolabi, et al. (2021), Mustefa and Belay (2021)].

This paper is organized as follows: The next section is devoted to illustrate the building of the suggested fertility tables. Section 3 presents an application based on real data extracted from Egypt's Demographic and Health survey in 2014, and the results obtained from the sample data. Section 4 closes with the final conclusions.

II. FERTILITY TABLES

Fertility is one of the responsible factors for the growth of human population. The demographers have given priority to understanding the determinants of fertility through statistical techniques. Natural fertility depends on the duration of effective reproductive span and length of birth interval. Analysis of those factors influencing the span and those affecting the length of birth interval has proven useful since in many cases they appear to differ greatly between populations. [Singh et al. (2010) and Singh (2016)]

Modeling fertility data is one of the greatest interests in population studies. Several indicators are used to measure fertility patterns, such as the open birth interval after marriage, the closed birth interval, forward birth interval and straddling birth interval. In this paper, our interest is the closed birth interval. The closed birth interval is the interval between the occurrences of two successive live births. Fertility is used in the sense that women proceed to at least one more live birth, in their reproductive life; it is the actual birth performance. [Shayan, et al. (2014) and Srinivasan (1968)]

In this paper, the population considered in fertility tables is the number of females in the reproductive age interval (15-49) who have parity m and the size of this population is decremented by having new birth [i.e. moving to parity $m + 1$].

A. Assumptions

- The population is homogeneous with regard to the characteristics under study.

- There is no relation between censorship and the occurrence of the event.

B. Basic Functions and Relations

- x_i $(i = 1, 2, \dots \dots n)$: The i^{th} interval.
- N_x : The number of females who have not a birth on or before the reference date in the interval x_i.
- b_x : The number of females who have a birth on or before the reference date in the interval x_i.
- c_x **:** The number of withdrawing during the interval x_i.
- q_x : Estimated conditional probability of the females who have a birth in the interval x_i.
- L_x : The total number of females- surviving without any birth in the interval x_i.
- T_x: The total time survived by the females without any birth in the interval x_i.
- e_x^0: An estimate of average waiting time to have a birth of a female after attainment of x_i. [Singh, et al. (2016)]

The mathematical relationships between these functions are presented as follows:

$$d_x = l_x\,(q_x) = l_x - l_{x+1} \qquad (1)$$

$$q_x = \frac{d_x}{l_x} \qquad (2)$$

$$p_x = 1 - q_x \qquad (3)$$

$$L_x = \left(\frac{l_x + l_{x+1}}{2}\right) \qquad (4)$$

$$T_x = L_x + T_{x+1} \qquad (5)$$

$$e_x^0 = \frac{T_x}{l_x} \qquad (6)$$

$S(x_i) = (p_{x-1})\ S(x_{i-1})$, where $S(x_1) = 1$ (7)

The probability density function $f(x_i)$ is estimated as follows:

$$\hat{f}(x_i) = \frac{S(x_i) - S(x_{i-1})}{w_i} = \frac{S(x_i)\,q_x}{w_i} \quad , \text{i} = 0,1,2, \dots \qquad (8)$$

The hazard function $h(x_i)$ is estimated as follows:

$$\hat{h}(x_i) = \frac{d_x}{w_i\,(n_x - \frac{1}{2}d_i)} = \frac{2q_x}{w_i(1+p_x)} \quad , \text{i} = 0,1,2, \dots. \qquad (9)$$

Where:

w_i: The width of the interval x_i that is needed to calculate the hazard and density functions [Wang and Lee (2003)].

C. Required Data

The required data to construct the suggested fertility tables are:

- The distribution of all ever married women in the reproductive ages (15-49) in a certain parity m by duration of exposure. For example the duration of exposure for parity one is the interval from marriage to either first birth or interview, whichever comes first.
- The distribution of births in parity m to all ever married women in the reproductive ages (15-49) by duration of exposure.
- The distribution of censored individuals by duration of exposure.

III. APPLICATION AND RESULTS

An application based on real data extracted from Demographic and Health Survey conducted in Egypt in 2014 is introduced. The survey is carried out based on 59,266 married females. In this paper, fertility tables for parity $m = 1,2,3$ and for some selected variables are produced. The variables studied are: place of residence and educational status.

Non-contraceptive married females in the reproductive ages (15-49) classified by place of residence and educational status are illustrated in Tables (1) to (3).

Table (1): Married females with parity one in the reproductive ages (15-49) classified by place of residence and educational status

Educational status / Place of residence	Illiterate	Intermediate	High	Total
Urban	493	2184	682	3359
Rural	1583	2800	361	4744
Total	2076	4984	1043	8103

Source: Demographic and Health Survey in Egypt (2014).

Table (2): Married females with parity two in the reproductive ages (15-49) classified by place of residence and educational status

Educational status / Place of residence	Illiterate	Intermediate	High	Total
Urban	430	1625	451	2506
Rural	1377	1988	212	3577
Total	1807	3613	663	6083

Source: Demographic and Health Survey in Egypt (2014).

Table (3): Married females with parity three in the reproductive ages (15-49) classified by place of residence and educational status

Educational status / Place of residence	Illiterate	Intermediate	High	Total
Urban	324	984	201	1509
Rural	1088	1171`	96	2355
Total	1412	2155	297	3864

Source: Demographic and Health Survey in Egypt (2014).

Samples of size 200 are selected from each sub-group for parity 1, 2 and 3. The samples include ever married females in the reproductive ages (15-49) who are not using contraceptive methods. Data with births in intervals less than 6 months are excluded and twins are treated as one birth, so the resulting sample sizes ranges from 96 to 201.

The statistical package SPSS version 16 is used in the calculation of the fertility tables. Fertility tables for all married females in the reproductive period (15-49) of Arab Republic of Egypt for different subgroups are illustrated in Tables (1-A) to (6-A) in Appendix A.

Summary measures of the main results of the fertility tables are illustrated in Tables (4) to (6).

The estimated average (e_x^0)* and the trimean (T) of the waiting time to have a birth are calculated, where:

- $(e_x^0)^*$ = (e_x^0) × 9 (The width of the interval x_i **),** the values of (e_x^0) in months.

- Trimean **(**T**)** is a measure of central tendency, which is calculated as follows:
  T = $(Q_1 + 2Q_2 + Q_3)/4$, where: Q_1, Q_2, Q_3 are the quartiles of the cumulative proportion. [Rodriguez and Hobcraft (1980)]

Table (4): Summary Measures for Birth Intervals of Illiterate Females

Parity / Measures	1		2		3	
	Urban	Rural	Urban	Rural	Urban	Rural
(e_x^0)*	29.16	30.15	33.39	31.86	40.23	34.92
Trimean (T)	22.64	20	26.19	21.07	34.40	25.51

Table (5): Summary Measures for Birth Intervals of Intermediate Educational Females

Parity / Measures	1		2		3	
	Urban	Rural	Urban	Rural	Urban	Rural
(e_x^0)*	24.57	20.43	33.03	31.86	47.88	40.41
Trimean (T)	10.85	8.79	23.67	21.83	38.47	30.25

Table (6): Summary Measures for Birth Intervals of High Educational Females

Parity / Measures	1		2		3	
	Urban	Rural	Urban	Rural	Urban	Rural
(e_x^0)*	20.97	20.25	34.83	31.68	49.23	40.59
Trimean (T)	8.26	8	23.9	21.33	38.20	30.71

The survival functions of married females in the reproductive ages (15-49) in urban and rural areas are shown in Figures (1) to (9).

Figure (1): Survival functions of illiterate married females with parity one in urban and rural areas

Figure (2): Survival functions of illiterate married females with parity two in urban and rural areas

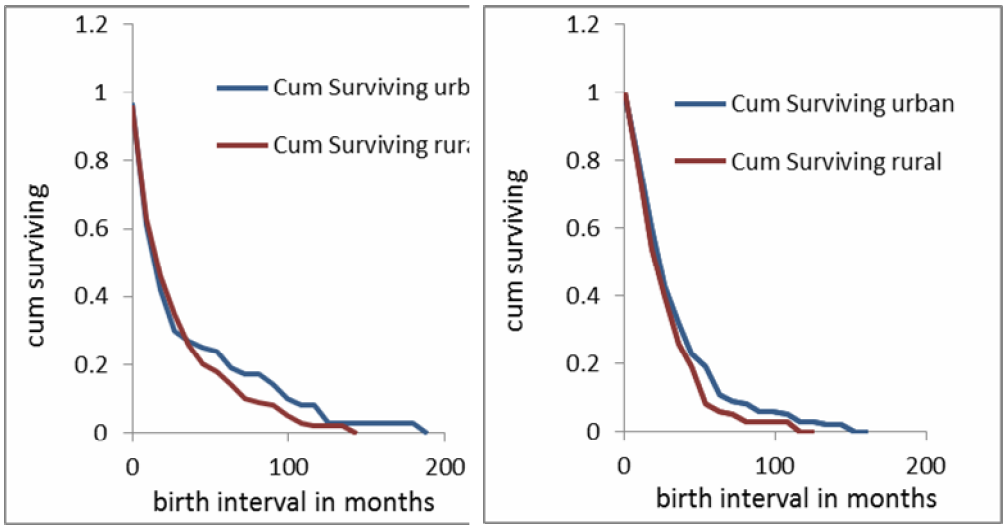


Figure (3): Survival functions of illiterate married females with parity three in urban and rural areas

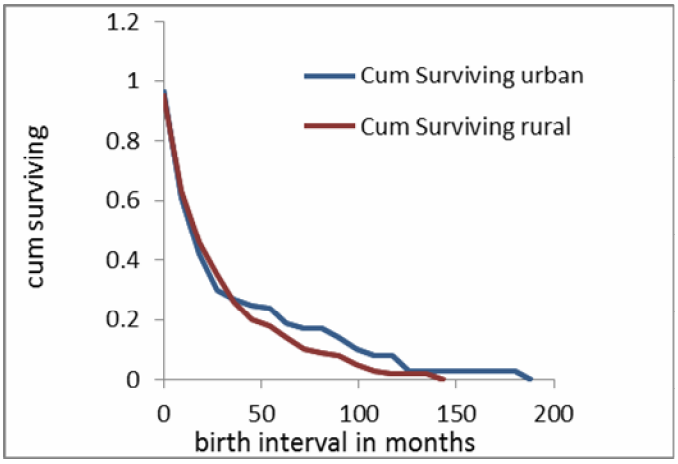


Figure (4): Survival functions of married females in the intermediate educational status with parity one in urban and rural areas

Figure (5): Survival functions of married females in the intermediate educational status with parity two in urban and rural areas

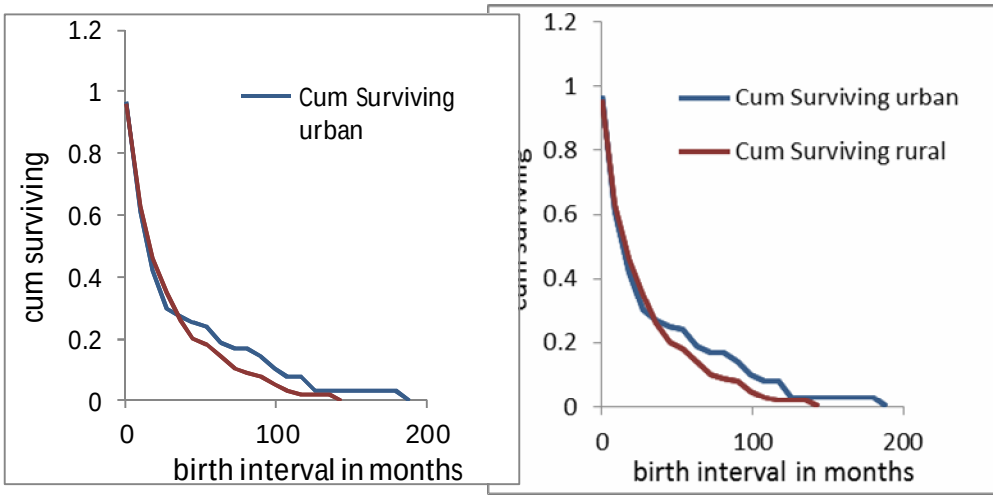


Figure (6): Survival functions of married females in the intermediate educational status with parity three in urban and rural areas

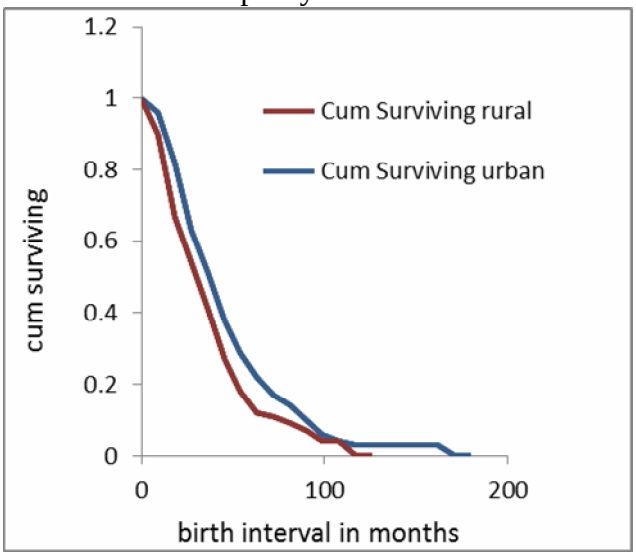


Figure (7): Survival functions of married females in high educational status with parity one in urban and rural areas

Figure (8):Survival functions of married females in high educational status with parity two in urban and rural areas

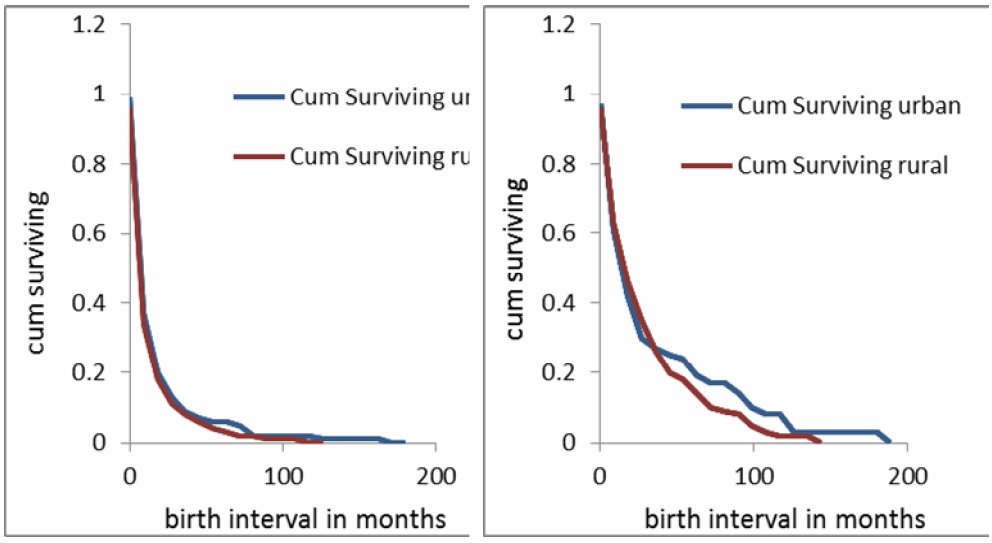
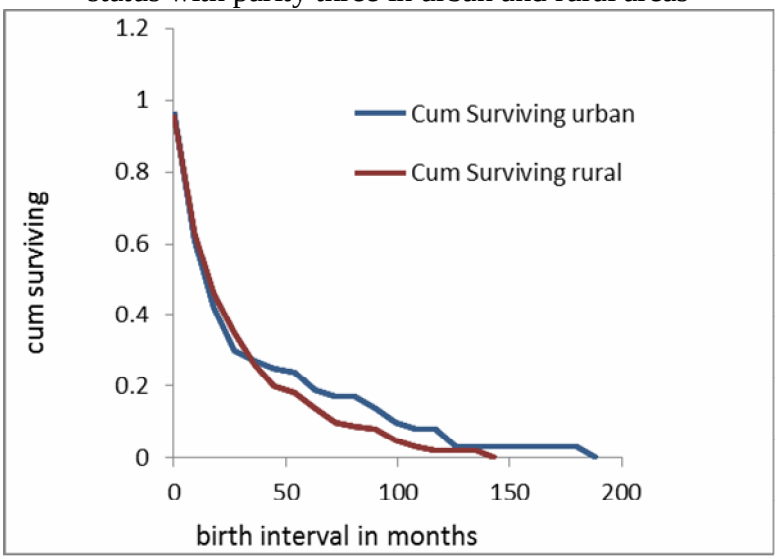


Figure (9): Survival functions of married females in high educational status with parity three in urban and rural areas



The hazard rate and density functions of married females in the reproductive ages (15-49) in urban and rural areas are shown in Figures (10) to (27).

Figure (10): Hazard rate and density functions of illiterate married females with parity one in urban areas

Figure (11): Hazard rate and density functions of illiterate married females with parity two in urban areas

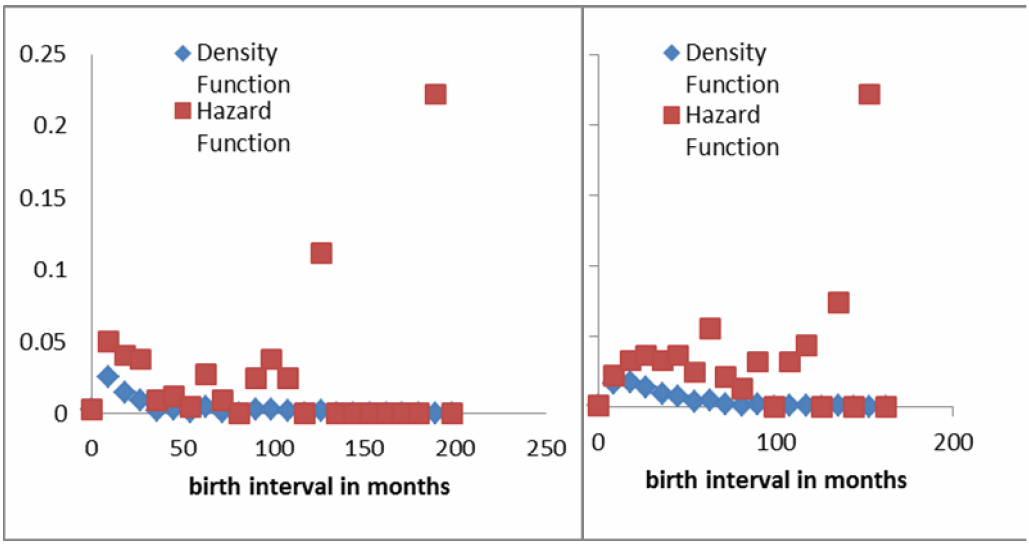


Figure (12): Hazard rate and density functions of illiterate married females with parity three in urban areas

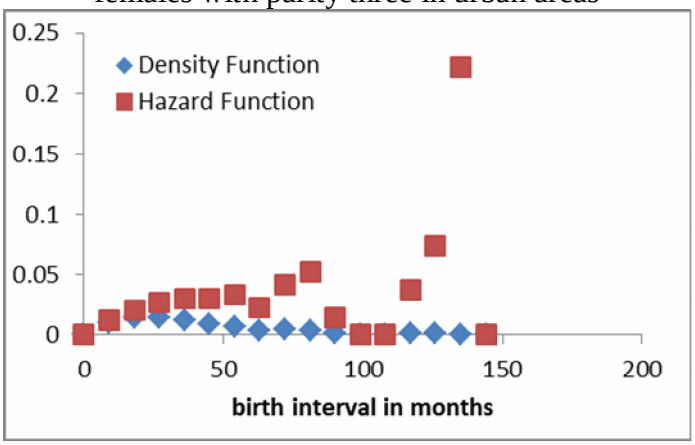
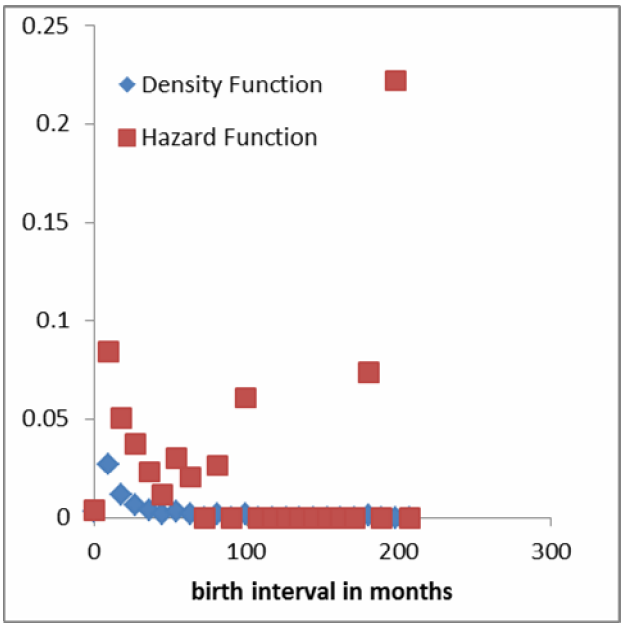


Figure (13): Hazard rate and density functions of married females in the intermediate educational status with parity one in urban

Figure (14): Hazard rate and density functions of married females in the intermediate educational status with parity two in urban areas

areas



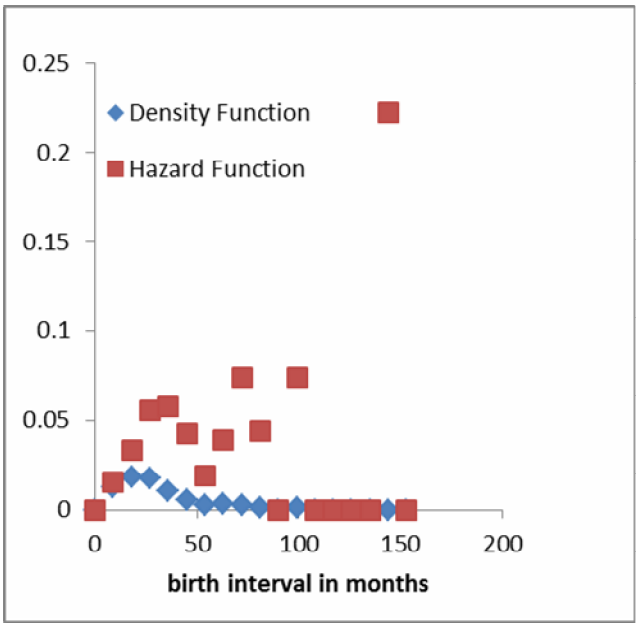


Figure (15): Hazard rate and density functions of married females in the intermediate educational status with parity three in urban areas

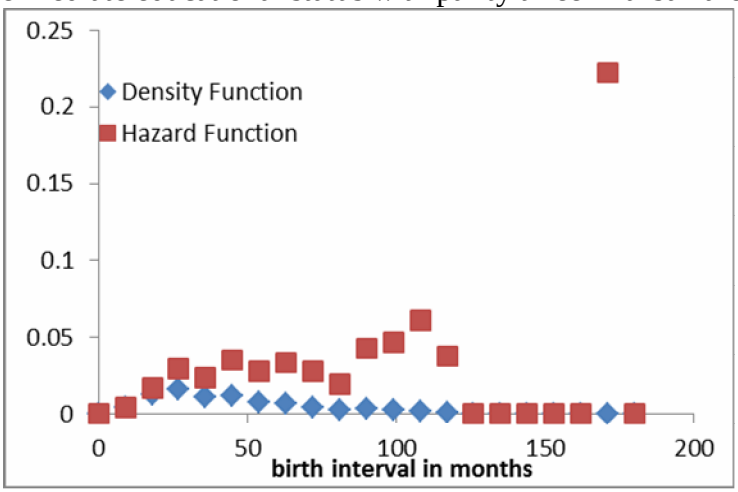
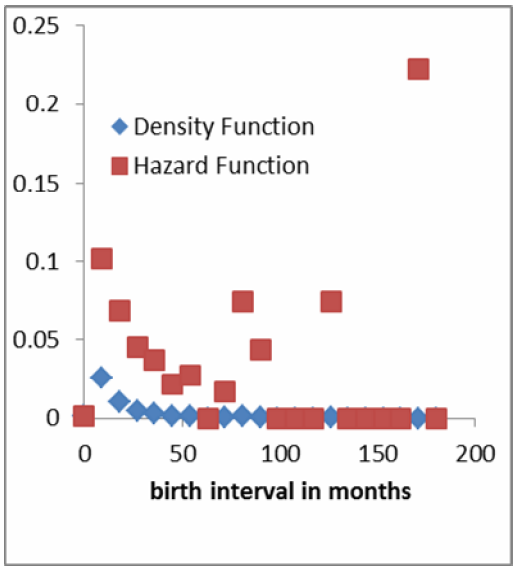


Figure (16): Hazard rate and density functions of married females in high educational status with parity one in

Figure (17): Hazard rate and density functions of married females in high educational status with parity two in urban

urban areas



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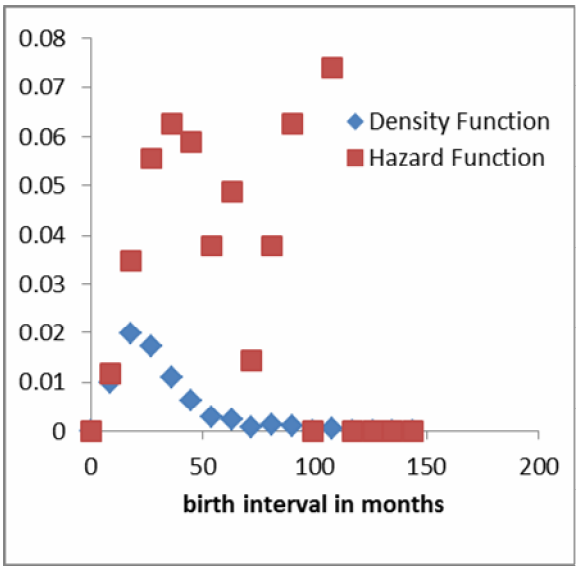


Figure (18): Hazard rate and density functions of married females in high educational status with parity three in urban areas

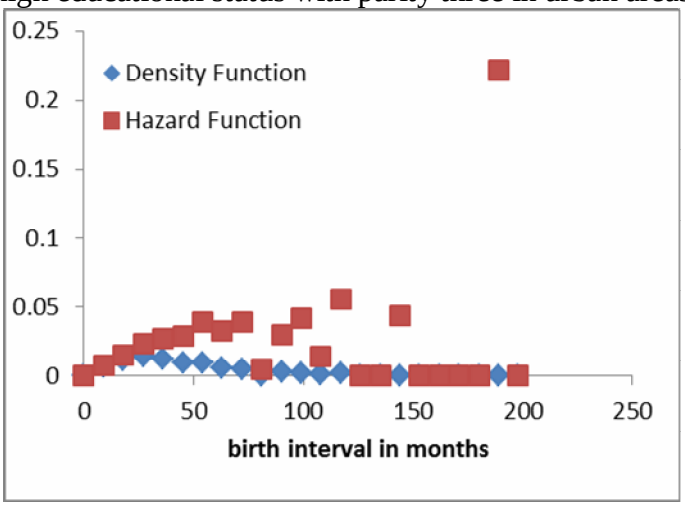


Figure (19): Hazard rate and density functions of illiterate married females with parity one in rural areas

Figure (20): Hazard rate and density functions of illiterate married females with parity two in rural areas

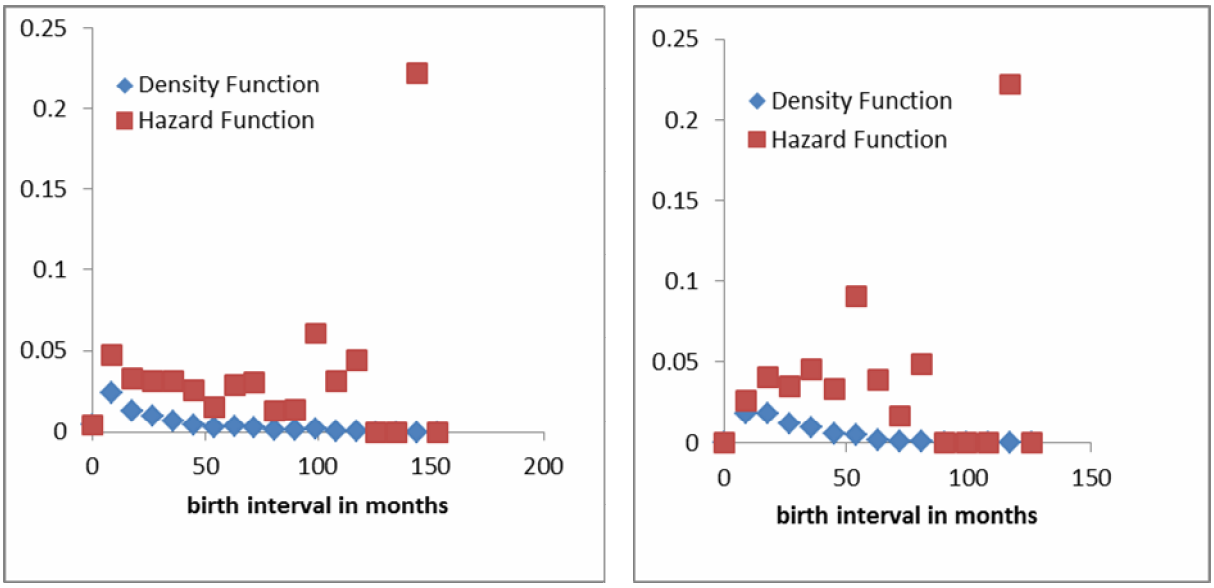


Figure (21): Hazard rate and density functions of illiterate married females with parity three in rural areas

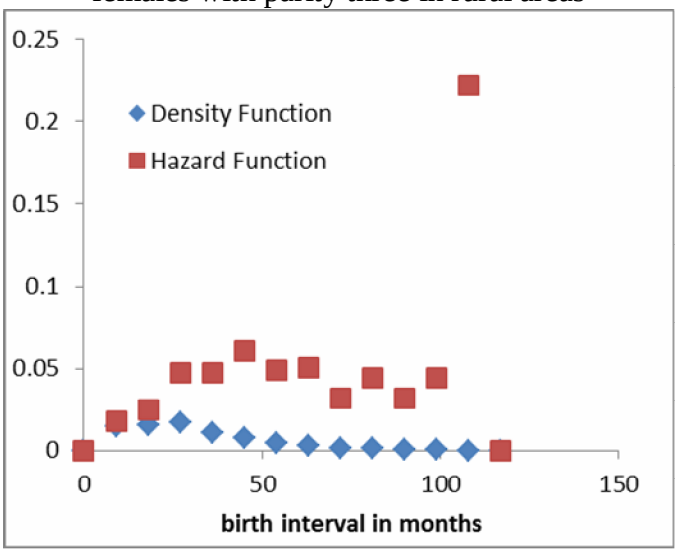
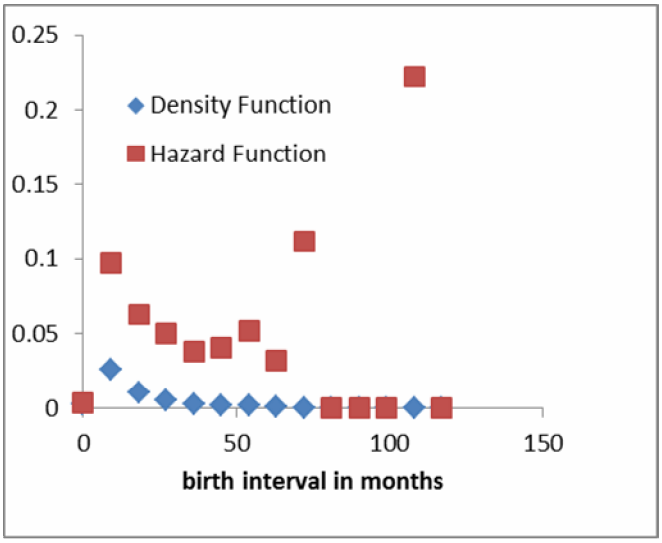


Figure (22): Hazard rate and density functions of married females in the intermediate educational status with parity one in rural areas

Figure (23): Hazard rate and density functions of married females in the intermediate educational status with parity two in rural areas



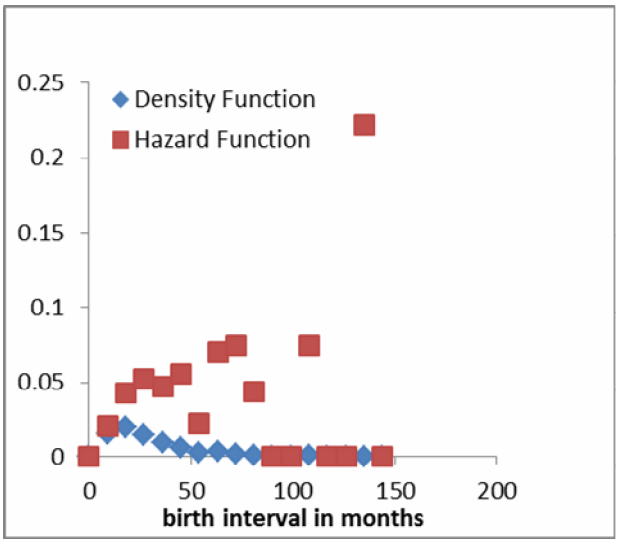


Figure (24): Hazard rate and density functions of married females in the intermediate educational status with parity three in rural areas

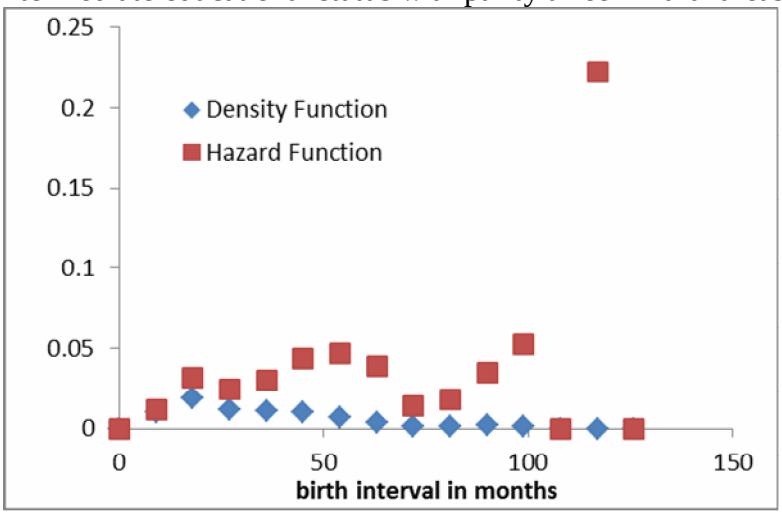


Figure (25): Hazard rate and density functions of married females in high educational status with parity one in rural areas

Figure (26): Hazard rate and density functions of married females in high educational status with parity two in rural areas

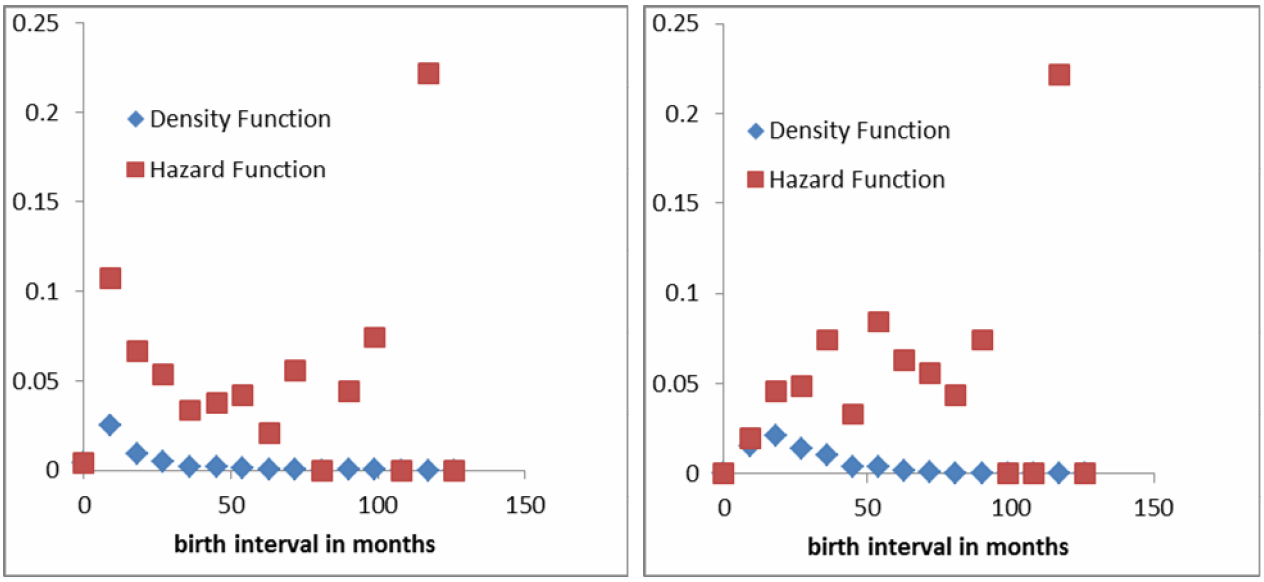
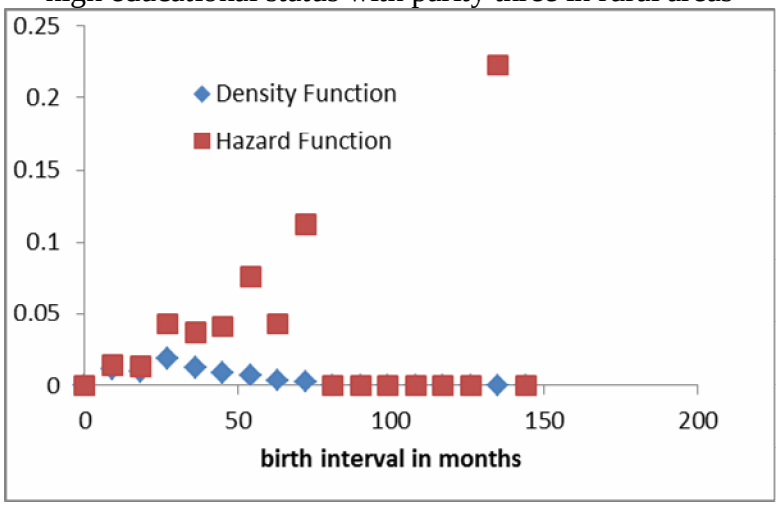


Figure (27): Hazard rate and density functions of married females in high educational status with parity three in rural areas



IV. FINAL CONCLUSIONS

According to the results obtained in Tables (4) to (6), and Figures (1) to (27), it is noticed that:

- The average waiting time to have a birth is greater in urban areas than in rural areas for all educational status groups and in all parities except illiterate females with parity one.
- As expected the average waiting time to have a birth is increasing as parity increases in urban and rural areas.
- The average waiting time to have a birth increases as the educational status increases in rural and urban areas except for parity one.
- The probability of having the first birth is greater than that of second and third birth in urban and rural areas.

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Appendix (A)

Table (1-A): Fertility table for the waiting time to first birth for illiterate females in rural society

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	197	8	1	.04	192.5	660.5	3.35	.96	0.0043	0.0045
9	188	64	7	.35	152.5	468.0	2.48	.63	0.0245	0.0471
18	117	29	11	.26	97	315.5	2.69	.46	0.0133	0.0332
27	77	19	4	.25	65.5	218.5	2.83	.35	0.0097	0.0317
36	54	13	5	.25	45	153.0	2.83	.26	0.0072	0.0317
45	36	7	5	.21	30	108.0	3	.20	0.0047	0.0261
54	24	3	3	.13	21	78.0	3.25	.18	0.0026	0.0154
63	18	4	1	.23	15.5	57.0	3.16	.14	0.0036	0.0289
72	13	3	1	.24	11	41.5	3.19	.10	0.0027	0.0303
81	9	1	0	.11	8.5	30.5	3.38	.09	0.0011	0.0129
90	8	1	0	.12	7.5	22.0	2.75	.08	0.0011	0.0142
99	7	3	0	.43	5.5	14.5	2.07	.05	0.0024	0.0609
108	4	1	0	.25	3.5	9.0	2.25	.03	0.0008	0.0317
117	3	1	0	.33	2.5	5.5	1.83	.02	0.0007	0.0439
126	2	0	1	.00	1.5	3.0	1.5	.02	0.0000	0.0000
135	1	0	0	.00	1	1.5	1.5	.02	0.0000	0.0000
144	1	1	0	1.00	0.5	0.5	0.5	.00	0.0000	0.2222
153	0	0	0	.0	0	0		0	0	0.0000

Table (2-A): Fertility table for the waiting time to first birth for intermediate females in rural society

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	198	6	0	.03	195	451.0	2.27	.97	0.0032	0.0034
9	192	115	8	.61	130.5	256.0	1.33	.38	0.0258	0.0975
18	69	30	3	.44	52.5	125.5	1.81	.21	0.0103	0.0627
27	36	13	1	.37	29	73.0	2.02	.13	0.0053	0.0504
36	22	6	3	.29	17.5	44.0	2	.09	0.0029	0.0377
45	13	4	0	.31	11	26.5	2.03	.06	0.0021	0.0408
54	9	3	2	.38	6.5	15.5	1.7	.04	0.0017	0.0521
63	4	1	0	.25	3.5	9.0	2.25	.03	0.0008	0.0317
72	3	2	0	.67	2	5.5	1.83	.01	0.0007	0.1119
81	1	0	0	.00	1	3.5	3.5	.01	0.0000	0.0000
90	1	0	0	.00	1	2.5	2.5	.01	0.0000	0.0000
99	1	0	0	.00	1	1.5	1.5	.01	0.0000	0.0000
108	1	1	0	1.00	0.5	0.5	0.5	.00	0.0000	0.2222
117	0	0	0	0	0	0		0	0.0000	0.0000

Table (3-A): Fertility table for the waiting time to first birth for higher females in rural society

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	199	8	0	.04	195.0	448.5	2.25	.96	0.0043	0.0045
9	191	122	6	.65	127.0	253.5	1.32	.34	0.0246	0.1070
18	63	28	4	.46	47.0	126.5	2.00	.18	0.0092	0.0664
27	31	12	0	.39	25.0	79.5	2.56	.11	0.0048	0.0538
36	19	5	0	.26	16.5	54.5	2.86	.08	0.0023	0.0332
45	14	4	0	.29	12.0	38.0	2.71	.06	0.0019	0.0377
54	10	3	1	.32	8.0	26.0	2.6	.04	0.0014	0.0423
63	6	1	0	.17	5.5	18.0	3	.03	0.0006	0.0206
72	5	2	0	.40	4.0	12.5	2.5	.02	0.0009	0.0556
81	3	0	0	.00	3.0	8.5	2.83	.02	0.0000	0.0000
90	3	1	0	.33	2.5	5.5	1.83	.01	0.0004	0.0439
99	2	1	0	.50	1.5	3.0	1.5	.01	0.0006	0.0741
108	1	0	0	.00	1.0	1.5	1.5	.01	0.0000	0.0000
117	1	1	0	1.00	0.5	0.5	0.5	.00	0.0000	0.2222
126	0	0	0	0	0	0		0	0.0000	0.0000

Table (4-A): Fertility table for the waiting time to first birth for illiterate females in urban society

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	196	6	2	.03	192.0	635.0	3.24	.97	0.0032	0.0034
9	188	67	17	.37	146.0	443.0	2.36	.61	0.0251	0.0504
18	104	31	8	.31	84.5	297.0	2.86	.42	0.0145	0.0408
27	65	18	7	.29	52.5	212.5	3.27	.30	0.0097	0.0377
36	40	3	3	.08	37.0	160.0	4.00	.27	0.0024	0.0093
45	34	3	6	.10	29.5	123.0	3.62	.25	0.0028	0.0117
54	25	1	4	.04	22.5	93.5	3.74	.24	0.0011	0.0045
63	20	4	3	.22	16.5	71.0	3.55	.19	0.0046	0.0275
72	13	1	1	.08	12.0	54.5	4.19	.17	0.0015	0.0093
81	11	0	0	.00	11.0	42.5	3.86	.17	0.0000	0.0000
90	11	2	2	.20	9.0	31.5	2.86	.14	0.0031	0.0247
99	7	2	0	.29	6.0	22.5	3.21	.10	0.0032	0.0377
108	5	1	0	.20	4.5	16.5	3.30	.08	0.0018	0.0247
117	4	0	1	.00	3.5	12.0	3.00	.08	0.0000	0.0000
126	3	2	0	.67	2.0	8.5	2.83	.03	0.0022	0.1119
135	1	0	0	.00	1.0	6.5	6.50	.03	0.0000	0.0000
144	1	0	0	.00	1.0	5.5	5.50	.03	0.0000	0.0000
153	1	0	0	.00	1.0	4.5	4.50	.03	0.0000	0.0000
162	1	0	0	.00	1.0	3.5	3.50	.03	0.0000	0.0000
171	1	0	0	.00	1.0	2.5	2.50	.03	0.0000	0.0000
180	1	0	0	.00	1.0	1.5	1.50	.03	0.0000	0.0000
189	1	1	0	1.00	0.5	0.5	0.50	.00	0.0000	0.2222
198	0	0	0	0	0	0		0	0.0000	0.0000

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	196	5	2	.03	192.5	535.0	2.73	.97	0.0032	0.0034
9	189	100	16	.55	131.0	342.5	1.81	.44	0.0269	0.0843
18	73	26	4	.37	58.0	211.5	2.90	.28	0.0115	0.0504
27	43	12	4	.29	35.0	153.5	3.57	.20	0.0064	0.0377
36	27	5	2	.19	23.5	118.5	4.39	.16	0.0034	0.0233
45	20	2	1	.10	18.5	95.0	4.75	.14	0.0016	0.0117
54	17	4	1	.24	14.5	76.5	4.50	.11	0.0029	0.0303
63	12	2	0	.17	11.0	62.0	5.17	.09	0.0017	0.0206
72	10	0	0	.00	10.0	51.0	5.10	.09	0.0000	0.0000
81	10	2	1	.21	8.5	41.0	4.10	.07	0.0016	0.0261
90	7	0	0	.00	7.0	32.5	4.64	.07	0.0000	0.0000
99	7	3	0	.43	5.5	25.5	3.64	.04	0.0019	0.0609
108	4	0	2	.00	3.0	20.0	5.00	.04	0.0000	0.0000
117	2	0	0	.00	2.0	17.0	8.50	.04	0.0000	0.0000
126	2	0	0	.00	2.0	15.0	7.50	.04	0.0000	0.0000
135	2	0	0	.00	2.0	13.0	6.50	.04	0.0000	0.0000
144	2	0	0	.00	2.0	11.0	5.50	.04	0.0000	0.0000
153	2	0	0	.00	2.0	9.0	4.50	.04	0.0000	0.0000
162	2	0	0	.00	2.0	7.0	3.50	.04	0.0000	0.0000
171	2	0	0	.00	2.0	5.0	2.50	.04	0.0000	0.0000
180	2	1	0	.50	1.5	3.0	1.50	.02	0.0011	0.0741
189	1	0	0	.00	1.0	1.5	1.50	.02	0.0000	0.0000
198	1	1	0	1.00	0.5	0.5	0.50	.00	0.0000	0.2222
207	0	0	0	0	0.0	0.0		0	0.0000	0.0000

Table (5-A): Fertility table for the waiting time to first birth for intermediate females in urban society

Table (6-A): Fertility table for the waiting time to first birth for higher females in urban society

x_i	N_x	b_x	c_x	q_x	L_x	T_x	e_x^0	$S_{(x_i)}$	$\hat{f}_{(x_i)}$	$\hat{h}_{(x_i)}$
0	200	2	2	.01	198.0	465.0	2.33	.99	0.0011	0.0011
9	196	119	13	.63	130.0	267.0	1.36	.37	0.0259	0.1022
18	64	29	4	.47	47.5	137.0	2.14	.20	0.0104	0.0683
27	31	10	3	.34	24.5	89.5	2.89	.13	0.0049	0.0455
36	18	5	2	.29	14.5	65.0	3.61	.09	0.0029	0.0377
45	11	2	0	.18	10.0	50.5	4.59	.07	0.0014	0.0220
54	9	2	0	.22	8.0	40.5	4.50	.06	0.0015	0.0275
63	7	0	0	.00	7.0	32.5	4.64	.06	0.0000	0.0000
72	7	1	0	.14	6.5	25.5	3.64	.05	0.0008	0.0167
81	6	3	0	.50	4.5	19.0	3.17	.02	0.0011	0.0741
90	3	1	0	.33	2.5	14.5	4.83	.02	0.0007	0.0439
99	2	0	0	.00	2.0	12.0	6.00	.02	0.0000	0.0000
108	2	0	0	.00	2.0	10.0	5.00	.02	0.0000	0.0000
117	2	0	0	.00	2.0	8.0	4.00	.02	0.0000	0.0000
126	2	1	0	.50	1.5	6.0	3.00	.01	0.0006	0.0741
135	1	0	0	.00	1.0	4.5	4.50	.01	0.0000	0.0000
144	1	0	0	.00	1.0	3.5	3.50	.01	0.0000	0.0000
153	1	0	0	.00	1.0	2.5	2.5	.01	0.0000	0.0000
162	1	0	0	.00	1.0	1.5	1.5	.01	0.0000	0.0000
171	1	1	0	1.00	0.5	0.5	0.5	.00	0.0000	0.2222
180	0	0	0	0	0	0		0	0.0000	0.0000