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On estimation of a few demographic indicators

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Abstract
In this paper a seven parameters polynomial regression model showing relation between life expectancy at birth (e_0) and survival probabilities at ages zero, one, two, three, four and five is developed. The credibility of the model is shown by fitting in five UN and four Coal and Demeny model life tables. By using the proposed model, e_0 for five major states of India Kerala, Karnataka, Punjab, West Bengal and Himachal Pradesh - are estimated. Infant mortality rates, under five mortality rates of the five states of India, and North-Eastern (NE) Indian states and their districts are estimated by using with indirect techniques of estimation on census data of 2001 and 2011 of India in which Trussell's variant of Brass methods, Logit smoothing, Weibull survival function and Hill's method are employed and hence using proposed model, e_0 has been estimated for each of NE states and their districts.

Keywords: Infant Mortality Rate, Life Expectancy, Logit Smoothing, Model Life Table, Weibull Survival Function

1. Introduction

Life expectancy at birth (e_0), i.e., average number of years a newborn is expected to live, reflects overall level of mortality of a population. It is mortality history of a population that provides clue in understanding the socio-economic condition and health status of that particular population (Najafi, et al., 2018, Motlagh, et al., 2012) [7, 6]. Phukon and Ahamed (2019) [8] and Ahamed et al., (2019)[1] estimated e_0 by developing three second degree polynomial regression models in which e_0 is predicted by child survivorship probabilities at ages one and two in their first model, one, two, three and four in their second model, and one, two and three in their third model. Prior to this, Romo and Becker (2011) [9] and Sarma and Choudhury (2012) [10] had estimated the e_0 by developing the linear and quadratic regression models between e_0 and survivorship function at age one respectively. On the other hand, from the study of various observed data, it is also shown that e_0 is influenced by childhood survivorship probabilities (Phukon and Ahamed, 2019) [8].

In this paper, a seven parameters second degree polynomial regression model, in which e_0 is predicted by survivorship probabilities at ages zero, one, two, three, four and five, is proposed. The polynomial is fitted to the SRS data of India and its five states. The fitted polynomials are again used in estimating e_0 by using survivorship probabilities data taken from unabridged SRS life tables with MORTPAK software in which for each SRS life table the most suitable standard model life table (MLT) is used. For estimating the demographic parameters e_0, infant mortality rate (IMR) and under-five mortality rate (U5MR) using indirect techniques of estimation in NE states and districts of the NE states, children ever born (CEB), child surviving (CS) and total number of women in child bearing ages are taken from Indian Census data of 2001 and 2011. Selection of the most suitable standard MLTs from all the United Nations MLTs of developing countries (1983) [11] and four Princeton models-Coale & Demeny MLTs (1966) [4] for India and its five major states, for male and female, separately is also done in this paper.

Survivorship probabilities at childhood ages, 0 to 5, are found to affect e_0, since in developing countries like India those surviving hazards of early childhood ages have a higher life expectancy than the newborn and highest life expectancy does not occur at birth but at later age (Romo and Becker, 2011)[9]. It is also shown in the nature of fitting the polynomial to observed data that e_0 is highly influenced by the early childhood survivorship probabilities ages 0-5 in the considered states Kerala, Karnataka, Punjab, West Bengal and Himachal Pradesh.

2. Data and Methods

2.1. Data

We use 405 set of SRS-based abridged life tables of India, Kerala, Karnataka, Punjab, West Bengal and Himachal Pradesh for the years 1970-75 to 2012-16, which was published by the office of the Registrar General of India in which 69 each for Himachal Pradesh, Kerala, Punjab and India, 66 for Karnataka and 63 for West Bengal for male, female and total of male and female are taken. In using indirect techniques of estimation for estimating demographic indicators IMR and U5MR for the five states and e_0, IMR and U5MR for NE states and its districts, data on CEB, CS and total numbers of women in child-bearing ages are taken from censuses 2001 and 2011 of India.

2.2 Methods

2.2.1 Selection of Suitable Model Life Table Family for Indian states and NE States

The procedure used by Ahamed et al. (2019)[1] in the selection of suitable MLT family for Assam state will be used here in this paper too for India and five major Indian states: Kerala, Karnataka, Punjab, West Bengal and

Himachal Pradesh. NE states are a particular case of the study due to unavailability of SRS-based abridged life table data. A procedure is adopted here to select the standard MLT family for NE states.

For the seven NE states Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, neither SRS life tables nor SRS data on age-specific mortality rates are available. But, these small seven states are grouped into a category on the basis of geographical contiguity, cultural affinity and similarity in demographic characteristics, economic, health facilities and mainly vital statistics (NIMS, ICMR and UNICEF, 2012). With the exception of Nagaland that was carved out as a state in 1963, most of states were reorganized between 1971 and 1987 from the erstwhile united Assam (Bhaumik, 1996) [3]. North-east India is one of south Asia's last land frontiers. In terms of geographical, anthropological, cultural, health and economic condition, North-East Indian states have highly similar features (Baruah, 2005)[2]. Therefore, we assume that the seven small NE states follow the standard MLT which is suitable for Assam. Therefore, United Nations South Asian MLT is used as standard MLT for each of the seven states as Assam state follows United Nations South Asian MLT.

On the other hand, it is also stated that if no appropriate age-specific mortality pattern is available for a region, the selection of model can be a neighbouring population (Hill, 2013)[5]. Hence our assumption that seven small states of North-east follow United Nation South Asian model which is the selected model for Assam is somehow reasonable. Moreover, by using Hill's (2013)[5] method of estimating child mortality estimates in reference period of NE states, similarity between Assam and each of the other NE states are examined with the help of graph ($_1q_0$ vs $_4q_1$).

2.2.2 Seven Parameters Polynomial Regression Model

A second degree polynomial regression model has been derived by establishing the relationship between the e_0 and the survivorship probabilities l_1, l_2, l_3, l_4 and l_5. Considering the equation used by Romo Becker (2011) [9], Sarma and Choudhury (2012) [10] and Ahamed et al. (2019) [1] respectively as follows

$$e_0(t) = {}_tL_0(t) + e_1(t)l_1(t) \quad (1)$$

$$e_0 = a + (b+c)l_1 + d\,l_1^2 \quad (2)$$

$$e_0(t) = \lambda + \gamma * l_1 + \delta * l_2 + \phi * l_3 + \psi * l_3^2 \quad (3)$$

Where $_1L_0(t)$ is the person-years lived between birth and age one, $e_1(t)$ is the life expectancy at age one and $l_1(t)$ is the probability of survivorship function at age one.

The equations (1) and (3) can be extended as

$$e_0(t) = \int_0^1 l(\alpha, t)\,d\alpha + \int_1^2 l(\alpha, t)\,d\alpha + \int_2^3 l(\alpha, t)\,d\alpha + \int_3^4 l(\alpha, t)\,d\alpha + \int_4^5 l(\alpha, t)\,d\alpha + \int_5^{\mu} l(\alpha, t)\,d\alpha$$

where μ is the highest age attained by a member of population.

Considering the effect of childhood mortality changes in age interval (0-5) on e_0, the following equation can be obtained:

$$e_0(t) = {}_1L_0(t) + {}_1L_1(t) + {}_1L_2(t) + {}_1L_3(t) + {}_1L_4(t) + e_5 * l_5(t) \quad (4)$$

$_1L_0(t)$ is a weighted linear function of $l_1(t)$ and so also each of $_1L_1(t)$, $_1L_2(t)$, $_1L_3(t)$, and $_1L_4(t)$ is a weighted linear function of $l_1(t)$, $l_2(t)$; $l_2(t)$, $l_3(t)$; $l_3(t)$, $l_4(t)$ and $l_4(t)$, $l_5(t)$ respectively.

Earlier, we have, $_1L_0 = 0.3l_0 + 0.7l_1$, $_1L_1 = 0.4l_0 + 0.6l_1$ or $_1L_1 = \frac{1}{2}(l_1 + l_2)$, $_1L_2 = \frac{1}{2}(l_2 + l_3)$, $_1L_3 = \frac{1}{2}(l_3 + l_4)$, $_1L_4 = \frac{1}{2}(l_4 + l_5)$ and $T_x = \int_0^{w-x} l(x+t)\,dt$, $T_x = \sum_{i=x}^{w-n} \frac{n}{2}(l_i + l_{i+n}),\ i = x, x+n, \ldots .w-n$

Moreover, by assuming l_1, l_2, l_3, l_4 as a linear function of $l_5(t)$, the equation (4) may be expressed as:

$$e_0(t) = f + g * l_1 + h * l_1 + i * l_2 + j * l_2 + k * l_3 + m * l_4 + (n + p\,l_5) * l_5$$

$$e_0(t) = \alpha + \beta * l_1 + \delta * l_2 + \eta * l_3 + \psi * l_4 + \upsilon l_5 + \gamma * l_5^2 \quad (5)$$

Where, $\alpha, \beta, \delta, \eta, \psi, \upsilon$ and γ are the seven para meters (regression coefficients) of the second degree polynomial regression equation.

The polynomial regression model is fitted to nine standard MLTs and SRS data of India and five major Indian states, male, female and male and female combined separately and fitted equations are shown in Table 2 and Table 3 respectively. The assumption $e_5(t)$ as a linear function of $l_5(t)$ used in obtaining the proposed model (5) is supported by high correlation coefficient between the two variables. Pearson's Correlation coefficients between e_5 and l_5 on nine standard families of MLTs are also shown in Table 1. By using each of the fitted polynomials, e_0 is estimated for each state and India for all the years taken into consideration.

In using the indirect techniques of estimation such as Trussell's variant of Brass methods, Logit smoothing, Weibull survival function, the procedure used by the Ahamed et al. (2019) [1] is followed in this paper. For NE states, IMR and U5MR are estimated from the data CEB, CS and total number of women in their child-bearing ages 15 to 49 from censuses of 2001 and 2011of India by using Hill's method (2013) [5] of estimating IMR and U5MR in the reference years.

3. Result and Discussion

In Table 1, Pearson correlation coefficients between e_5 and l_5 on the nine standard families of MLTs are given. In demography, if any assumption for building relation between two or more demographic determinants is made, it must be substantiated analytically as well as empirically. The empirical illustration in this case is done in the families of standard MLTs, i.e., United Nations MLTs and Coale and Demeny MLTs in which the presence of high Pearson correlation coefficients between the variables in all cases have supported our assumption of linear relationship between $e_5(t)$ and $l_5(t)$. Moreover, the fitted seven parameters polynomial regression equations on nine standard families of MLTs, male and female separately, along with their coefficient of determination (R^2) and standard error (SE)

values are shown in Table 2. The goodness of fit of the proposed model can be seen from the table. In Table 3, as stated above, the fitted polynomial regression equations of the model (5) for India and five major Indian states, male, female and male and female separately are shown along with their R^2 and standard error (SE).

Table 1: Pearson correlation coefficients between e_5 and l_5 for standard MLTs

United Nations Model Life Table Families							Coale and Demeny Model Life Table Families			
Model	Relation between	Chilean	Far Eastern	General	Latin America	South Asian	East	North	South	West
Female	e_5 and l_5	0.9968	0.9639	0.9953	0.9964	0.997	0.9855	0.9847	0.9922	0.9846
Male		0.9029	0.9787	0.9888	0.992	0.9923	0.9868	0.9854	0.9901	0.9854

Table 2: Fitting of Polynomial regression model (5) to standard MLTs

MLTs	Sex	$\alpha+\beta*l_1+\delta*l_2+\eta*l_3+\psi*l_4+\upsilon*l_5+\gamma*l_5^2$	R^2	SE
Chilean	Male	$-372.7+6373.2\,l_1-19179.2\,l_2+9922.8\,l_3+18308.3\,l_4-14962\,l_5-7.0\,l_5^2$	0.9999	0.0830
	Female	$-273.8+2913.1\,l_1-4154.48\,l_2-222.4\,l_3-1344.8\,l_4+3159.9\,l_5+9.6\,l_5^2$	0.9999	0.0437
Far Eastern	Male	$-682.16+2258.4\,l_1-5339.1\,l_2+8256.5\,l_3-3502.6\,l_4-759.8\,l_5-151.7\,l_5^2$	0.9998	0.1665
	Female	$-537.3+3796.6\,l_1-5846.2\,l_2-5971.2\,l_3+17520.2\,l_4-8908.6\,l_5+33.1\,l_5^2$	0.9998	0.1571
General	Male	$-287.1+3671.3\,l_1-6566.7\,l_2-473.5\,l_3+4441.6\,l_4-736.40\,l_5+32.6\,l_5^2$	0.9999	0.0625
	Female	$-40.1+6815\,l_1-24513.4\,l_2-15313.6\,l_3+22627.3\,l_4-20520.2\,l_5+404.4\,l_5^2$	0.9999	0.1447
Latin America	Male	$-270.6+1979.9\,l_1-6604.3\,l_2+6811.1\,l_3+2754.0\,l_4-4656.7\,l_5+70.1\,l_5^2$	0.9999	0.0585
	Female	$-260.90+2023.64\,l_1-2178.6\,l_2-1430.6\,l_3+825.4\,l_4+981.7\,l_5+127.18\,l_5^2$	0.0999	0.0152
South Asian	Male	$-234.7+2101.5\,l_1-4788.5\,l_2+1859.1\,l_3+3882.6\,l_4-2790.9\,l_5+53.8\,l_5^2$	0.9999	0.0434
	Female	$-189.9+1821.7\,l_1-5529.5\,l_2+4373.2\,l_3+3279.8\,l_4-3757.15\,l_5+88.0\,l_5^2$	0.9999	0.0255
East	Male	$-50.4+3427.7\,l_1-14130.8\,l_2+9900.7\,l_3+16401.3\,l_4-15665.4\,l_5+194.3\,l_5^2$	0.9998	0.2656
	Female	$-73.4+527.4\,l_1-21025.9\,l_2+13320.3\,l_3+24112.9\,l_4-21761.8\,l_5+232.8\,l_5^2$	0.9999	0.1964
North	Male	$-188.66+2763.2\,l_1-6903.5\,l_2+3608.7\,l_3+4926.3\,l_4-4321.0\,l_5+197.0\,l_5^2$	0.9999	0.1988
	Female	$-84.3+870.8\,l_1-2814.4\,l_2+1722.2\,l_3+5230.5\,l_4-5119.7\,l_5+278.2\,l_5^2$	0.9998	0.2689
South	Male	$-54.3+802.7\,l_1-3231.1\,l_2+4342.9\,l_3-408.7\,l_4-1499.3\,l_5+131.2\,l_5^2$	0.9999	0.0779
	Female	$-4.5-489.3\,l_1+4056.8\,l_2-11121.2\,l_3+13145.9\,l_4-5627.9\,l_5+125.2\,l_5^2$	0.9995	0.1498
West	Male	$-110.3+3653.9\,l_1-16497\,l_2+22064.9\,l_3-1457.1\,l_4-7861.3\,l_5+285.8\,l_5^2$	0.9999	0.1508
	Female	$-116.3+2310.9\,l_1-8614.9\,l_2+8152.8\,l_3+6682.0\,l_4-8620.1\,l_5+287.2\,l_5^2$	0.9999	0.1956

Table 3: Fitted polynomial regression equations for the model (5) for Himachal Pradesh, Karnataka, Kerala, Punjab, West Bengal and India

States & India	Sex	$\alpha+\beta*l_1+\delta*l_2+\eta*l_3+\psi*l_4+\upsilon*l_5+\gamma*l_5^2$	R^2	SE
Himachal Pradesh	Male	$1144.7-2581.6\,l_1+14688.7\,l_2-26446.8\,l_3+15340\,l_4-3346.2\,l_5+1279\,l_5^2$	0.9885	0.4953
	Female	$336.4+1415.9\,l_1-11790.3\,l_2+31874.2\,l_3-35582.2\,l_4+13327.9\,l_5+503.3\,l_5^2$	0.9860	0.8744
	Persons	$320.1+1486.2\,l_1-6575.9\,l_2+8304.8\,l_3-3565.9\,l_4-341.4\,l_5+452.3\,l_5^2$	0.9981	0.2999
Karnataka	Male	$-464.2-92.5\,l_1-2428.6\,l_2+9364.7\,l_3-8840.3\,l_4+2998.9\,l_5-470\,l_5^2$	0.9601	0.8041
	Female	$-427.3-1489.7\,l_1+5859.2\,l_2-5863\,l_3-586.9\,l_4+3051.3\,l_5-469.8\,l_5^2$	0.9905	0.4436
	Persons	$307.7-963.9\,l_1+3551.7\,l_2-150.6\,l_3-9155.9\,l_4+6140.3\,l_5+344.8\,l_5^2$	0.9953	0.2727
Kerala	Male	$632.4+529.9\,l_1-2153.6\,l_2+8037.7\,l_3-15211.7\,l_4+7508.6\,l_5+730.8\,l_5^2$	0.9926	0.2047

	Female	$1083.8+110.8\,l_1+2358.6\,l_2-10653.8\,l_3+9866\,l_4-3766.6\,l_5+1080.4\,l_5^2$	0.9882	0.4672
	Persons	$354.5-1766.2\,l_1+8610.2\,l_2-9693.1\,l_3 5296.7\,l_4+7596.7\,l_5+273.4\,l_5^2$	0.9900	0.3898
Punjab	Male	$-492.7+25.3\,l_1-9238.2\,l_2+47941.6\,l_3-71197.8\,l_4+33501.1\,l_5-465.9\,l_5^2$	0.8252	1.3520
	Female	$39.5+1579.4\,l_1-13209.9\,l_2+38360.2\,l_3-45417.1\,l_4+18635.4\,l_5+90.35\,l_5^2$	0.9476	1.2073
	Persons	$200.5+3116.7\,l_1-24549.8\,l_2+62094.5\,l_3-63311.2\,l_4+22232.2\,l_5+293.3\,l_5^2$	0.9712	0.6906
West Bengal	Male	$665.9-2280.6\,l_1+11152.1\,l_2-18270.1\,l_3+10511.6\,l_4-2449.4\,l_5+745.3\,l_5^2$	0.9963	0.2500
	Female	$-413.2-4504.3\,l_1+13799.9\,l_2+4138.4\,l_3-35360.8\,l_4+22858.1\,l_5-442.7\,l_5^2$	0.9969	0.2570
	Persons	$329.1-2146.9\,l_1+4480.6\,l_2+8346.5\,l_3-23425.8\,l_4+12105.2\,l_5+386.8\,l_5^2$	0.9977	0.2098
Assam	Male	$53.2+1384.1\,l_1-9478.6\,l_2+20472.5\,l_3-18139.2\,l_4+5664.9\,l_5+114.81\,l_5^2$	0.9886	0.5533
	Female	$-96.3-431.2\,l_1+3362.8\,l_2-5926.1\,l_3+2974.2\,l_4+189.6\,l_5+4.8\,l_5^2$	0.9973	0.3403
	Persons	$18.6-2168.9\,l_1+11959.1\,l_2-19725.9\,l_3+11181\,l_4-1283.5\,l_5+95.2\,l_5^2$	0.9957	0.3829
India	Male	$19.5-1980.2\,l_1+5821.9\,l_2+2707.2\,l_3-16666.6\,l_4+10128\,l_5+42.14\,l_5^2$	0.9984	0.2130
	Female	$40.6-1424\,l_1+5737.8\,l_2-5658.3\,l_3-1119.4\,l_4+2444.9\,l_5+50.6\,l_5^2$	0.9990	0.1695
	Persons	$-95.7-3095.3\,l_1+9552.3\,l_2+4374.2\,l_3-29174.8\,l_4+18645.6\,l_5-132.5\,l_5^2$	0.9995	0.1314

As it was done by Ahamed et al. (2019), in order to find the most suitable standard model life table that the SRS data of any of the states or the country follows, we use $\sum_{i=1}^{n}\left(1-\frac{m_x}{M_x}\right)^2$ where ${}_nm_x$ is age-specific central mortality rate of observed data and ${}_nM_x$ is age specific central mortality rate for every standard model life tables, UN- Chilean, Far-Eastern, General, Latin America, South Asian; and Coale and Demeny- South, North, East and West and L is the number of levels of a family of model life tables (UN,1983, Manual X) [11]. The least value of the sums $\sum_{i=1}^{n}\left(1-\frac{m_x}{M_x}\right)^2$ indicates the model life table to be selected for the particular observed life table. In Table 4.1 we have indicated values of the sums for male and female; the least ones are underlined for selecting corresponding model life table. Thus the selected standard models for all observed life tables are shown in Table 4.2.

Table 4: Calculated values of $\sum_{i=1}^{n}\left(1-\frac{m_x}{M_x}\right)^2$ for selection MLT (five major states, Assam state and India for male and females)

Sex	States	United Nations MLTs					Coale and Demeny MLTs			
		Chilean	Far Eastern	General	Latin American	South Asian	West	North	South	East
	Himachal Pradesh	7.48	7.81	10.4	13.6	14.54	14.49	15.63	16.29	14.28
Male	Karnataka	3.27	4.24	7.57	10.78	12.73	12.39	14.07	14.93	12.03
	Kerala	15.94	9.43	13.37	15.94	17.12	18	18.79	19.14	17.79
	Punjab	4.45	5.33	8.69	11.79	13.59	15.72	17.37	18.16	15.31
	West Bengal	9.28	8.81	12.52	13.43	11.82	13.35	15.25	16.23	12.93
	Assam	326.85	226.18	93.63	35.09	15.02	393.23	139.91	71.52	484.13
	India	5.11	4.35	7.77	10.22	10.34	16.68	18.16	18.86	16.29
Female	Himachal Pradesh	6.18	5.12	8.61	11.71	12.21	41.48	17.02	13.86	31.87
	Karnataka	3.2	2.48	5.96	7.47	10.15	23.12	12.78	12.75	18.25
	Kerala	13.04	11.99	14.9	16.23	16.48	16.99	18.38	19.4	16.94
	Punjab	2.72	6.2	2.85	5.47	5.93	12.77	13.56	12.85	13.56
	West Bengal	4.25	2.72	7.55	10.29	10.76	12.77	14.49	15.35	12.37
	Assam	9.80	6.25	5.27	5.02	3.35	44.158	19.58	13.54	53.47
	India	2.46	5.59	1.54	3.82	4.41	12.08	11.02	11.61	12.96

Table 5: Selection of MLT families for five major states, Assam state and India for male and females

India and States	Standard Model Family Patterns	
	Female	Male
Himachal Pradesh	Chilean	Chilean
Karnataka	Far Eastern	Chilean
Kerala	Far Eastern	Chilean
West Bengal	Far Eastern	Far Eastern
Assam	South Asian	South Asian
India	General	Far Eastern

Table 6: Estimated e_0 for Himachal Pradesh, Karnataka, Kerala, Punjab, West Bengal and India, Male

Year	Himachal Pradesh	Karnataka	Kerala	Punjab	West Bengal	India
1970-75	55.23	-	60.67	60.01	-	50.39
1976-80	58.04	55.89	62.84	60.46	-	51.95
1981-85	58.7	61.35	65.11	62.85	57.03	54.75
1986-90	62.09	61.49	67.02	64.56	60.2	57.42
1991-95	63.66	64.19	69.23	65.37	62.58	59.55
1995-99	65.31	66.45	69.33	64.92	63.85	60.83
1996-00	66.31	66.81	69.21	65.5	64.06	61.32
1997-01	66.59	67	69.03	64.97	64.98	61.66
1998-02	66.54	67.18	69.06	66.77	65.43	62.02
1999-03	66.8	67.53	70.04	66.87	66.07	62.31
2000-04	67.08	67.9	70.12	67.29	66.46	62.6
2001-05	67.4	67.87	70.32	67.63	66.94	62.81
2002-06	67.6	68.65	70.63	67.53	67.36	63.14
2003-07	68.49	69.24	70.94	67.7	67.64	63.46
2004-08	68.53	69.52	71.21	67.8	68.18	63.86
2005-09	68.52	69.56	71.62	67.92	68.45	64.29
2006-10	68.48	70.01	71.62	67.82	68.55	64.73
2007-11	68.23	70.11	71.66	67.79	68.93	65.11
2008-12	68.57	70.29	71.81	67.94	69.39	65.59
2009-13	69.11	70.66	71.78	69.17	69.69	65.94
2010-14	68.82	71.12	71.68	67.67	70.25	66.43
2011-15	68.46	71.35	71.95	68	70.57	66.78
2012-16	69.93	71.47	72.18	69.85	70.83	67.12

Table 7: Estimated e_0 for Himachal Pradesh, Karnataka, Kerala, Punjab, West Bengal and India, Female

Year	Himachal Pradesh	Karnataka	Kerala	Punjab	West Bengal	India
1970-75	50.91	-	62.96	59.87	-	50.51
1976-80	54.41	55.89	66.57	61.88	-	51.72
1981-85	61.87	61.34	71.21	60.69	58.04	54.92
1986-90	63.18	61.49	73.22	65.44	60.81	57.5
1991-95	67.05	64.16	76	68.63	62.31	59.49
1995-99	68.09	66.47	74.78	68.31	65.11	60.52
1996-00	68.29	66.81	74.87	68.29	66	61.05
1997-01	70.51	67.03	75.42	68.13	66.94	61.5
1998-02	71.09	67.21	75.83	68.17	67.39	61.98
1999-03	72.7	67.52	76.46	68.6	67.58	62.44
2000-04	72.96	67.91	76.67	68.97	68.12	62.78
2001-05	71.86	67.86	76.62	69.73	68.41	63
2002-06	70.83	68.66	76.55	70.41	69.13	63.41
2003-07	72.23	69.23	76.88	70.78	69.46	63.61
2004-08	71.69	69.5	77.03	71.01	70.2	64.02
2005-09	71.11	69.56	77.09	71.25	70.3	64.34
2006-10	72.7	70.02	77.29	71.47	70.83	64.66
2007-11	73	70.12	77.28	72.22	71.17	65.02
2008-12	72.27	70.31	77.21	72.86	71.27	65.48
2009-13	72.78	70.63	77.43	73.39	71.34	65.81
2010-14	74.31	71.15	77.42	73.87	71.5	66.3
2011-15	75.34	71.31	77.24	74.27	71.99	66.78
2012-16	75.56	71.46	76.87	74.4	72.38	67.24

Table 8: Estimated e_0 for Himachal Pradesh, Karnataka, Kerala, Punjab, West Bengal and India, Total of Male and Female

Year	Himachal Pradesh	Karnataka	Kerala	Punjab	West Bengal	India
1970-75	47.14	-	62	58.77	-	49.49
1976-80	56.19	55.53	64.79	60.43	-	51.56
1981-85	59.81	60.26	68.22	63.98	57.02	54.82
1986-90	63.04	60.6	70.74	64.95	59.98	57.55
1991-95	64.75	62.67	72.74	66.85	62.02	59.95
1995-99	66.22	64.25	71.78	67.26	63.86	61.29
1996-00	67.08	64.6	71.65	67.32	64.5	61.83
1997-01	68.14	64.55	71.96	67.38	65.06	62.47
1998-02	68.08	64.92	72.15	67.43	65.61	62.86
1999-03	69.09	65.15	73.27	67.51	66.07	63.39
2000-04	69.52	65.53	73.47	67.69	66.52	63.97
2001-05	69.35	65.73	73.37	68.08	66.92	64.17

2002-06	69.41	66.22	73.59	68.33	67.35	64.61
2003-07	70.2	66.88	74.05	68.55	67.72	64.87
2004-08	70.15	66.45	74.15	69.04	68.47	65.22
2005-09	69.86	66.91	74.34	69.3	68.78	65.62
2006-10	70.45	67.38	74.63	69.57	69.15	66.17
2007-11	70.59	67.56	74.6	70.22	69.29	66.5
2008-12	70.61	67.92	74.76	70.64	69.48	66.93
2009-13	70.94	68.46	74.88	71.11	69.72	67.41
2010-14	71.5	69.02	74.84	71.64	70.3	68.01
2011-15	71.22	69.38	74.94	72.08	70.46	68.35
2012-16	72.13	69.58	74.89	73.35	70.98	68.68

Comparison of mortality patterns of other North-eastern states with that of Assam

By using Hill's (2013)[5] method, ${}_1q_0$ and ${}_4q_1$ for Assam and every other NE states are estimated for reference years (1985 to 2009) from CEB and CS data of 2001 and 2011, which are shown in Tables 6.1 and 6.2. Graph is drawn by taking ${}_1q_0$ along *x*-axis and ${}_4q_1$ along y-axis for each state- Arunachal Pradesh Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura in such a way mortality pattern of Assam is compared with mortality pattern of each and every other state. Such graphs are shown below in figure 1. Thus in each case, we have seen similarity in childhood mortality pattern of Assam with that of other states of North-east.

Table 9: ${}_4q_1$ and ${}_1q_0$ values of North-eastern states for 1985-2009, male and female combined

Arunachal Pradesh		**Assam**		**Manipur**		**Meghalaya**	
${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$
0.0380	0.0082	0.0141	0.0514	0.0071	0.0053	0.0168	0.0143
0.0405	0.0114	0.0186	0.0099	0.0094	0.0374	0.0217	0.0184
0.0442	0.0175	0.0259	0.0352	0.0142	0.0222	0.0300	0.0253
0.0607	0.0315	0.0421	0.0219	0.0259	0.0123	0.0479	0.0398
0.0243	0.0535	0.0115	0.0726	0.0443	0.0082	0.0157	0.0134
0.0843	0.0080	0.0626	0.0158	0.0061	0.0053	0.0706	0.0576
0.1227	0.0823	0.0997	0.0121	0.0732	0.0062	0.1077	0.0853
0.0258	0.0106	0.0152	0.0429	0.0082	0.0071	0.0201	0.0171
0.0294	0.0157	0.0211	0.0289	0.0121	0.0105	0.0284	0.0240
0.0439	0.0268	0.0344	0.0179	0.0213	0.0184	0.0453	0.0377
0.0599	0.0440	0.0519	0.0130	0.0359	0.0306	0.0681	0.0556
0.0910	0.0769	0.0905	0.0794	0.0656	0.0545	0.1094	0.0865

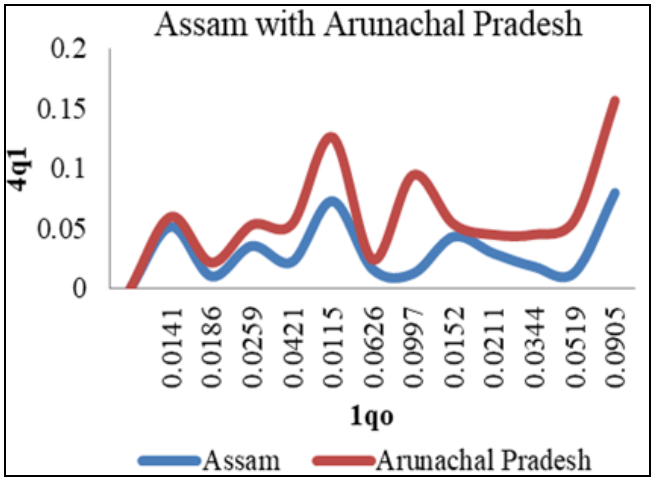
Table 10: ${}_4q_1$ and ${}_1q_0$ values of North-eastern states for 1985-2009, male and female combined

Mizoram		**Nagaland**		**Sikkim**		**Tripura**	
${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$	${}_1q_0$	${}_4q_1$
0.0121	0.0104	0.0094	0.0082	0.0114	0.0102	0.0106	0.0095
0.0145	0.0125	0.0131	0.0114	0.0156	0.0139	0.0153	0.0136
0.0200	0.0172	0.0202	0.0175	0.0209	0.0186	0.0223	0.0198
0.0317	0.0269	0.0370	0.0315	0.0357	0.0313	0.0095	0.0085
0.0086	0.0074	0.0645	0.0535	0.0 080	0.0072	0.0381	0.0333
0.0475	0.0397	0.0092	0.0080	0.0515	0.0445	0.0542	0.0468
0.0769	0.0628	0.1022	0.0823	0.0872	0.0732	0.0133	0.0119
0.0113	0.0097	0.0123	0.0106	0.0103	0.0092	0.0846	0.0711
0.0158	0.0136	0.0182	0.0157	0.0146	0.0130	0.0195	0.0174
0.0277	0.0236	0.0313	0.0268	0.0251	0.0222	0.0330	0.0290
0.0440	0.0369	0.0524	0.0440	0.0386	0.0338	0.0462	0.0401
0.0775	0.0632	0.0949	0.0769	0.0699	0.0595	0.0757	0.0641

In the introduction section, inherent resemblance among the geographically contiguous NE states in terms of socio-economic profile and vital statistics has been discussed. Moreover, in the analysis through graphical representations shown in figure 1, consideration of MLT suitable for Assam and fitted polynomial for Assam as the suitable MLT and polynomial for other NE states is substantiated to a certain extent. This similarity is seen in the graphical representation which compares mortality pattern in the reference periods of other NE states with Assam's mortality pattern in the reference Period, where mortality rates of NE states for reference period are computed by using Hill's (2013)[5] method. Therefore, United Nations South Asian family of MLTs taken as the standard model family of life tables for all the eight NE states is justifiable as Assam state follows United Nations.

South Asian family of MLTs. To estimate the demographic indicators in district level of North-east India, the same standard MLTs family is used.

Graphs for comparing the mortality patterns of Assam with that of other North-eastern states: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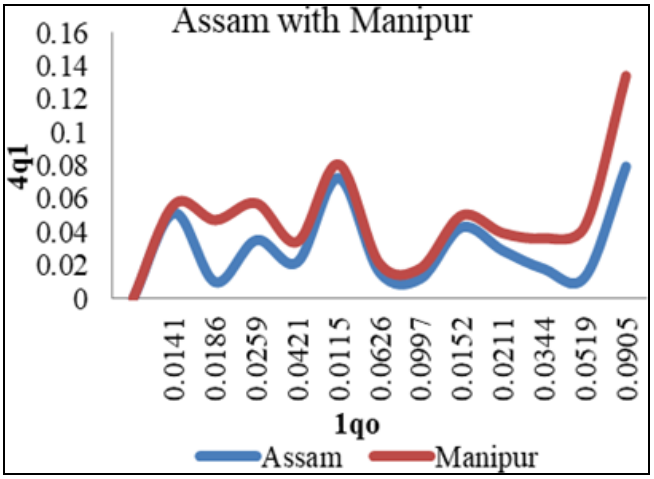
1qo
Assam
Arunachal Pradesh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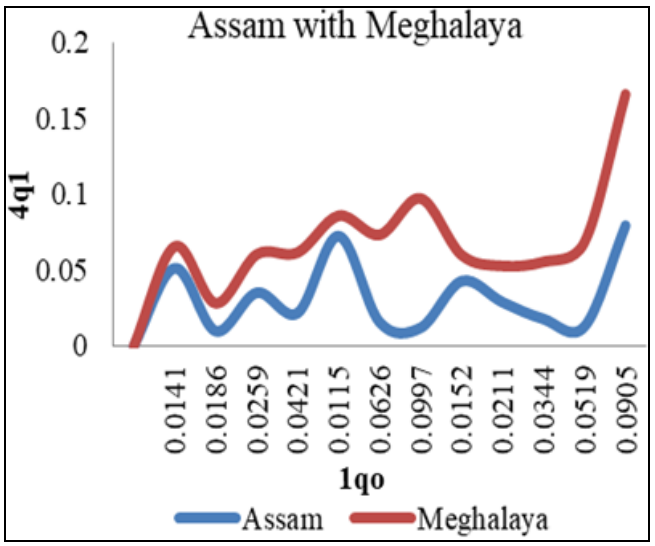
Assam
Manipur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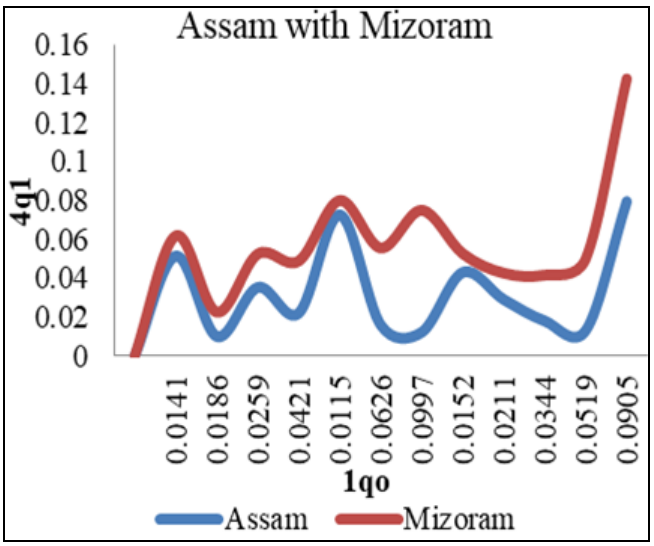
Assam
Meghalaya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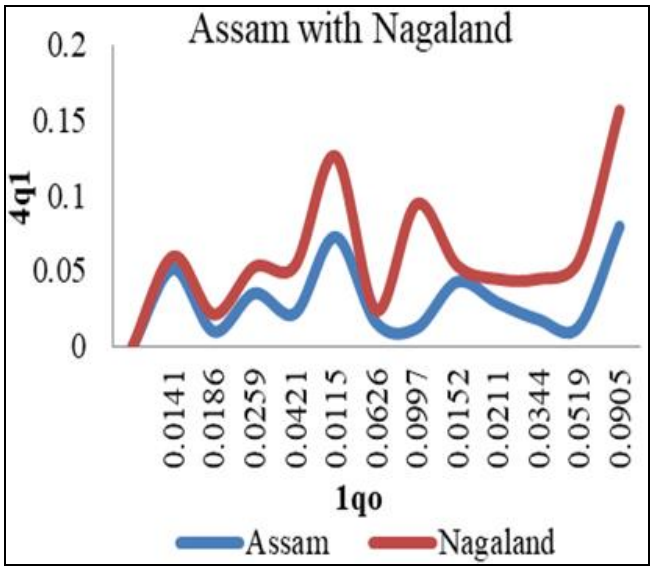
1qo
Assam
Mizoram


Assam with Nagaland
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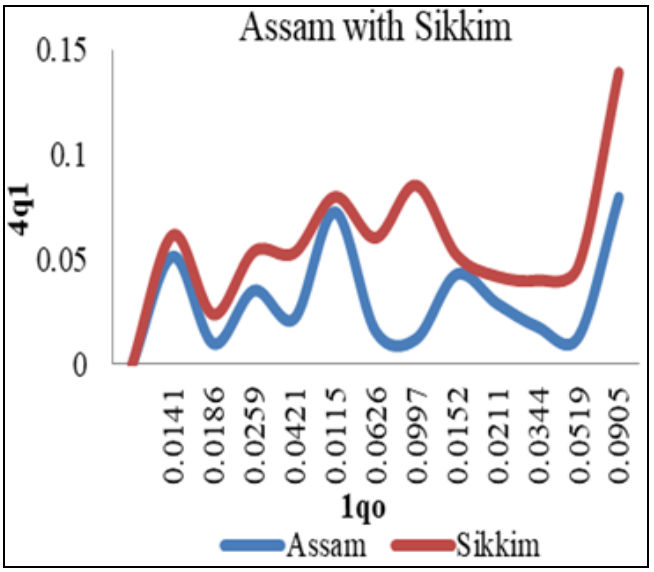
1qo
Assam
Nagaland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Assam
Sikkim

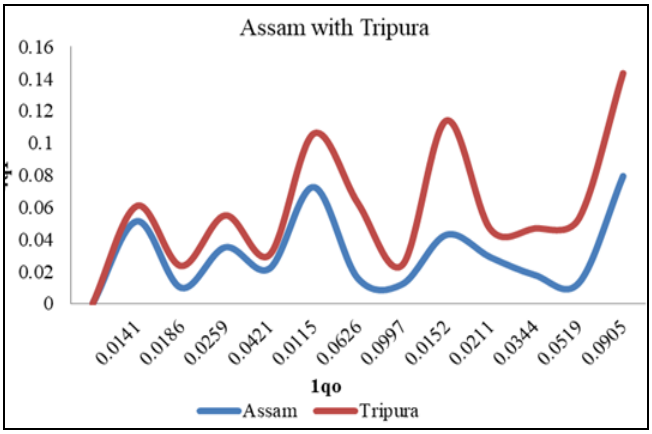

Fig 1: comparing the mortality patterns of Assam with that of other North-eastern states

Tables 7.1 gives estimated IMR, U5MR and Decadal Changes for 2001 and 2011 for Five considered states of India, and Table 7.2 to 7.8 presents the estimated life expectancies at birth (e_o), IMRs and U5MRs of each of districts of NE states (male and female separately), except Assam which was shown by Ahamed et al.,(2019)[1].

Table: 11: IMR, U5MR and Decadal Changes for 2001 and 2011, Combined

States	IMR		Decadal Change (%)	U5MR		Decadal Change (%)
	2001	2011		2001	2011	
Himachal Pradesh	57	48	-0.16	89	75	-0.16
Karnataka	50	54	0.08	78	85	0.09
Kerala	34	25	-0.26	54	39	-0.28
Punjab	60	49	-0.18	93	77	-0.17
West Bengal	61	39	-0.36	96	62	-0.35

In the above tables, IMR and U5MR of five major Indian states are presented along with their decadal changes during 2001 census year to 2011 census year. In this analysis it has been found that the states Karnataka shows 8% increase in IMR and 9% increase in U5MR, whereas the other four states show decreasing trend.

Table 12: e_o , IMR & U5MR, for Arunachal Pradesh and its districts along with percentage increase/decrease in the decade (2001-11), male and female combined

Districts	2001	2011	Increase/ Decrease (%)	2001	2011	Increase/ Decrease (%)	2001	2011	Increase/ Decrease (%)
	e_o	e_o		IMR	IMR		U5MR	U5MR	
Changlang	58.01	62.49	0.08	73	51	-0.30	113	79	-0.30
Dibang Valley	55.70	55.81	0.00	81	81	-0.04	125	124	-0.01
East Kameng	40.50	49.91	0.23	169	111	-0.34	246	168	-0.32
East Siang	61.49	65.56	0.07	55	38	-0.31	86	59	-0.31
Lohit	58.79	61.06	0.04	67	57	-0.15	104	89	-0.14
Lower Subansiri	44.32	61.51	0.39	144	55	-0.62	213	86	-0.60
Papum Pare	58.48	62.71	0.07	68	56	-0.18	106	78	-0.26
Tawang	48.99	60.44	0.23	116	60	-0.48	175	93	-0.47
Tirap	52.41	59.67	0.14	98	63	-0.36	149	98	-0.34
Upper Siang	56.16	63.98	0.14	79	44	-0.44	122	70	-0.43
Upper Subansiri	47.46	54.23	0.14	125	89	-0.29	187	136	-0.27
West Kameng	55.15	59.62	0.08	84	63	-0.24	129	98	-0.23
West Siang	57.87	62.08	0.07	71	52	-0.27	110	82	-0.25
Arunachal Pradesh	54.20	59	0.09	89	64	-0.28	136	100	-0.26
Anjaw	-	49.80	-	-	112	-	-	169	-
KurungKumey	-	51.43	-	-	103	-	-	156	-
Lower Dibang	-	60.75	-	-	58	-	-	91	-

In Table 7.2, the district-level analysis of three demographic indicators of Arunachal Pradesh, male and female combined, is presented, it has been observed that the life expectancy at birth has shown increasing. IMR and U5MR are decreasing. Lower Subansiri shows highest increase (39%) in life expectancy at birth, while both East Kameng and Tawang districts show 23% increases in life expectancy at birth. In case of IMR lower Subansiri shows highest decadal change, as it decreases by 62%. Tawang decreases by 48%, and Upper Siang decreases by 44% from 2001 to 2011. In case of U5MR, highest decrease is shown in lower Subansiri district of Arunachal Pradesh with 60%, second highest is in Tawang by 47% and Upper Siang shows 43% decrease. Dibang Valley is the only district where expectancy at birth does not increase, IMR and U5MR decrease are the lowest of all the districts of Arunachal

Pradesh.

Table 13: e_o , IMR & U5MR, for Manipur and its districts along with percentage increase/decrease in the decade (2001 to 2011), male and female combined

Districts	2001 e_0	2011 e_0	Increase/ Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Manipur	63.25	65.02	0.03	47	40	-0.15	74	63	-0.15
Bishnupur	63.43	65.36	0.03	47	38	-0.19	73	61	-0.16
Chandel	61.18	62.97	0.03	56	48	-0.14	88	76	-0.14
Imphal East	64.05	65.37	0.02	44	38	-0.14	69	61	-0.12
Imphal West	66.26	64.95	-0.02	35	40	0.14	55	63	0.15
Senapati	59.55	65.39	0.10	64	38	-0.41	99	61	-0.38
Tamenglong	57.04	66.39	0.16	75	34	-0.55	116	54	-0.53
Thoubal	65.02	64.92	0.00	40	40	00	63	64	0.02
Ukhrul	59.16	63.46	0.07	65	46	-0.29	101	73	-0.28
Churchandpur	-	65.52	-	-	38	-	-	60	-

From the above table, it is seen that, in Manipur highest increase in life expectancy at birth shows Tamenglong district with 16% increase, in case of IMR and U5MR Tamenglong district shows highest decreases, i.e., 55% and 53% respectively. Imphal West is the only district where life expectancy at birth is decreasing up to 2%, and IMR, U5MR are increasing 14% and 15% respectively.

Table 14: e_o , IMR & U5MR, for Meghalaya and its districts along with percentage increase/decrease in the decade (2001 to 2011), male and female combined

Districts	2001 e_o	2011 e_o	Increase/ Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Meghalaya	56.45	57.04	0.01	78	75	-0.04	120	116	-0.03
East Garo Hills	55.63	57.49	0.03	82	73	-0.11	126	113	-0.10
East Khasi Hills	60.11	58.94	-0.02	61	66	0.08	95	103	0.08
Jaintia Hills	55.41	56.49	0.02	83	78	-0.06	127	120	-0.06
Ri-Bhoi	58.25	57.64	-0.01	69	72	0.04	107	112	0.05
South Garo Hills	51.01	55.95	0.10	105	80	-0.24	159	123	-0.23
West Garo Hills	53.59	53.67	0.00	92	92	0.00	140	140	0.00
West Khasi Hills	56.90	59.03	0.04	76	66	-0.13	117	102	-0.13

In Meghalaya, district-level analysis has shown that East Khasi Hills and Ri-Bhoi are the only two districts where life expectancy at birth is decreasing from 2001 to 2011 by 2% and 1% respectively. While inspecting IMR and U5MR, both the districts show increasing in nature. East Khasi Hills shows as 8% increase in both the demographic indicators, IMR and U5MR, while Ri-Bhoi district shows increase 4% in IMR and 5% in U5MR.

Table 15: e_o , IMR & U5MR, for Mizoram and its districts along with percentage increase/decrease in the decade (2001 to 2011), male and female combined

Districts	2001 e_o	2011 e_o	Increase/ Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Mizoram	62.02	62.81	0.01	53	49	-0.08	82	77	-0.06
Aizowl	65.30	67.55	0.03	39	30	-0.23	61	47	-0.23
Champhari	63.54	65.51	0.03	46	38	-0.17	72	60	-0.17
Kolasib	60.98	64.77	0.06	57	42	-0.26	89	65	-0.27
Lawngtlai	55.11	54.47	-0.01	84	88	0.05	129	134	0.04
Lunglei	60.04	62.26	0.04	61	52	-0.15	95	81	-0.15
Mamit	58.59	59.22	0.01	68	65	-0.04	105	101	-0.04
Saiha	64.39	61.26	-0.05	42	56	0.33	67	87	0.30
Serchhip	62.14	65.74	0.06	52	37	-0.29	81	58	-0.28

In Mizoram, district-level analysis has shown that Lawngtlai and Saiha are the only two districts where life expectancy at birth is decreasing from 2001 to 2011 by 1% and 5% respectively. While inspecting IMR and U5MR, both the districts show increasing trend. Lawngtlai shows 5% increase in IMR and 4% increase in U5MR, whereas Saiha district shows 33% increases in IMR and 30% in U5MR.

Table 16: e_o , IMR & U5MR, for Nagaland and its districts along with percentage increase/decrease in the decade (2001 to 2011), male and female combined

Districts	2001 e_o	2011 e_o	Increase/ Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Nagaland	58.62	60.70	0.04	68	58	-0.15	105	91	-0.13
Kohima	61.52	64.25	0.04	55	43	-0.22	86	68	-0.21
Mokokchung	54.04	60.78	0.12	90	58	-0.36	137	90	-0.34
Mon	57.74	56.68	-0.02	72	77	0.07	111	118	0.06
Phek	61.27	61.03	-0.004	56	57	0.02	87	89	0.02
Tuensang	55.00	59.21	0.08	85	65	-0.24	130	101	-0.22
Wokha	61.34	61.83	0.01	56	53	-0.05	87	84	-0.03
Zunheboto	55.05	62.94	0.14	85	49	-0.42	130	76	-0.42
Dimapur	61.61	61.83	0.004	54	53	-0.02	85	84	-0.01
Kiphire	-	56.44	-	-	78	-	-	120	-
Longleng	-	61.47	-	-	55	-	-	86	-
Peren	-	60.06	-	-	61	-	-	95	-

In Nagaland, district-level analysis has shown that Mon and Phek are the only two districts where life expectancies at birth are decreasing from 2001 to 2011 by 2% and 0.4% respectively. While inspecting IMR and U5MR, both the districts show increasing trend. Mon district of Nagaland shows as 7% increase in IMR and 6% increase in U5MR, whereas Phek district shows increase 2% in both IMR and U5MR.

Table 17: e_o , IMR & U5MR, for Sikkim and its districts along with percentage increase/decrease in the decade (2001 to 2011), male and female combined

Districts	2001 e_o	2011 e_o	Increase/Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Sikkim	60.47	63.91	0.06	59	44	-0.25	92	70	-0.24
East Sikkim	61.16	64.32	0.05	56	43	-0.23	88	67	-0.24
North Sikkim	60.52	63.62	0.05	59	46	-0.22	92	72	-0.22
South Sikkim	61.71	63.98	0.04	54	44	-0.19	84	70	-0.17
West Sikkim	57.90	63.25	0.09	71	47	-0.34	110	74	-0.33

In the district-level analysis of Sikkim, it has been found that West Sikkim shows highest increase in life expectancy at birth, i.e., 9%, lowest in South Sikkim district 4%. In case of IMR and U5MR, highest decreases are seen in West Sikkim district as, 34% and 33% respectively.

Table 18: e_o , IMR & U5MR, for Tripura and its districts along with percentage increase/decrease in the decade (2001 to 2011) male and female combined

Districts	2001 e_o	2011 e_o	Increase/ Decrease (%)	2001 IMR	2011 IMR	Increase/ Decrease (%)	2001 U5MR	2011 U5MR	Increase/ Decrease (%)
Tripura	60.07	61.87	0.03	61	53	-0.13	95	83	-0.13
Dhalai	59.39	58.86	-0.01	64	67	0.05	100	103	0.03
North Tripura	57.19	59.62	0.04	74	63	-0.15	115	98	-0.15
South Tripura	59.33	61.34	0.03	65	56	-0.14	100	87	-0.13
West Tripura	61.83	64.06	0.04	53	44	-0.17	84	69	-0.18

In the district level analysis of Tripura, it has been found that Dhalai is the only district where life expectancy at birth decreases by 1%, IMR and U5MR increase by 5% and 3% respectively.

4. Conclusion

In this paper, the proposed second-degree polynomial regression model is found to be very effective in estimating life expectancy at birth. Life expectancy at birth for small states of North-East India and their districts are also estimated from census data of 2001 and 2011 by using the both proposed model and indirect techniques of estimation although no SRS data are available for these states. The estimated life expectancy at birth, IMR and U5MR of the major states, and small states and their districts give an insight into the demographic indicators of the states and districts.

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