International Journal of Applied Research 2019; 5(4): 474-481

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2019; 5(4): 474-481
www.allresearchjournal.com
Received: 11-02-2019
Accepted: 14-03-2019

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Mortality deceleration at older ages in Kerala

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Abstract
The rate of mortality increases almost exponentially with age through most of the adult age range in human populations. However, the rate of mortality increase with age tends to slow down at older ages and evidences of this deceleration encouraged the researchers to switch from the exponential to the logistic power function in which the rate of mortality increase slows down with advancing age. The present study is an attempt to examine whether there exist any evidence of deceleration in the age pattern of mortality at older ages in general and for males and females separately in the state of Kerala in India. An attempt has also been made to compare the phenomenon of mortality deceleration at older ages in Kerala with that in India. Death rates for the elderly by age and sex during 1997-2016, taken at five year intervals, from the SRS of India were analysed using Life Table Ageing Rate (LAR) technique.
The study shows clear evidence of mortality deceleration taking place at older ages in Kerala and is around the age of 75 years. Even though females in Kerala live longer compared to males, the pace of mortality increase with age at older ages is faster for females. That is, females are frailer than males at their older ages in Kerala. The study also found evidences of mortality deceleration taking place at older ages in India. The implications of mortality deceleration are many. The Government need to provide more support programmes for the elderly, especially for the elderly women. Focus should be placed on frailty, which underlies mortality, morbidity and disability at older ages.

Keywords: Mortality, deceleration, older age, Kerala, life table ageing rate

1. Introduction
Old-age mortality decline is significantly faster in low mortality countries. The decline is proceeding without any strong indication of deceleration in some countries, whereas, it appears to have slowed down in other countries. Within each country, some segments of the population benefited more from the trend than others (Horiuchi and Robine, 2005) [13].
The rate of mortality increases almost exponentially with age through most of the adult age range in human populations. Researchers had noticed that the rate of mortality increase with age tends to slow down at older ages (Horiuchi and Coale, 1990; Manton, 1992; Horiuchi and Wilmoth, 1998) [11, 17, 12] and evidences of this deceleration encouraged them to switch from the exponential to the logistic power function in which the rate of mortality increase slows down with advancing age (Horiuchi and Wilmoth, 1998) [12]. Other models that took this deceleration into consideration include quadratic curve fitted to the logarithm of age specific death rates at very advanced ages and the exponential survival function for tails of survival curves (Witten, 1988; Coale and Kisker, 1990) [45, 4]. In modern human populations, the deceleration can be visually detected in the data for mortality above age 90 years, but life table ageing rates indicate that the slowing down actually starts earlier, typically between 75 and 80 years. In populations with lower levels of old age mortality the deceleration tends to be delayed at higher ages (Horiuchi and Wilmoth, 1998) [12].
The reason for the mortality deceleration is not fully known. There are at least two possible explanations for this phenomenon: the heterogeneity hypothesis and the individual-risk hypothesis (Khazaeli, Xiu and Curtsinger, 1995) [14]. According to the heterogeneity hypothesis, the deceleration is a statistical effect of selection through the attrition of mortality. Because the frailer tend to die at younger ages, survivors to older ages tend to have favourable health endowments and healthy life styles. This argument has been supported by several studies based on mathematical models and simulations (Vaupel, Manton and Stallard, 1979; Vaupel and Carey, 1993) [44, 43]. Some parametric models on the relationship between physiological changes and mortality patterns suggest that selective survival should cause

deceleration of age related increases in both mortality and disability at very old ages (Manton *et al.*, 1994; Manton *et al*., 1997) [18, 19].

According to the individual-risk hypothesis, the age related increase of mortality risk for individuals slows down at older ages for one or more reasons, including physiological, evolutionary and reliability-theoretical. Physiological reasons include a slower rate of living at older ages (Masoro, 1985; Remmen *et al*., 1995; Peer *et al*., 1993) [21, 36, 27]. Mueller and Rose (1996) [23], while conducting computer simulations of the evolution of senescence, could construct life tables with a steep mortality at very old ages. Those simulations were based on the theory that the age-related decline in the force of natural selection may lead, over the course of evolution, to an accumulation of genes that have deleterious effects at older ages.

The process of population ageing and the associated problems have now become one of the serious population issues in India, especially in Kerala. Life expectancy for both males and females has improved in India over the years. The expectation of life at birth for India during 2003-13 was 67.5 years (65.8 years for males and 69.3 years for females). Among the states, life expectancy is the highest for Kerala (74.8 years for total and 71.8 years and 77.8 years for males and females respectively) (RGI, 2016). Moreover, Kerala has the lowest average life loss in the country (Singh and Ladusingh, 2013) [42].

The Census of India (2011) reported that 8.6 percent of the population of India is elderly (60+) and Kerala has the highest percent (12.6) among the states. The percent of elderly among males and females are 8.2 and 9 for India and 11.8 and 13.3 for Kerala, respectively. The two states following Kerala in this respect are Tamil Nadu (10.4 percent) and Punjab (10.3 percent). In Kerala, the mortality rates started their downward trend at a much earlier period than in the rest of India (Panikar and Soman, 1981) [26]. According to the reports of Sample Registration System (2014) the Crude Death rate (CDR) of Kerala is 6.6 for total population and 7.6 and 5.8 for males and females respectively.

The state of Kerala has achieved high standards in socio-demographic areas and the health status of Kerala, as indicated by levels of mortality rate and life expectancy of its population is more akin to those of countries with much higher levels of per capita income (Navaneetham *et.al*, 2009) [25]. However, morbidity rate is repeatedly reported to be high (Panikar and Soman, 1981; Dilip, T.R. 2007; Navaneetham *et al*., 2009) [26, 7, 25].

There are only a few studies on old age mortality in a developing country like India, including in the state of Kerala. Such studies are very important for formulating and implementing health policies and programs. Gender differentials in mortality deceleration reflect discrimination against females. It is well known that women in India were at greater risk of suffering with poorer health conditions than men (Sengupta and Agree, 2003; Rajan, 2006; Dhak, 2009) [41, 30, 6]. The present study is an attempt to examine whether there exist any evidence of deceleration in the age pattern of mortality at older ages in general and for males and females separately in the state of Kerala in India. An attempt has also been made to compare the phenomenon of mortality deceleration at older ages in Kerala with that in India.

2. Data and Measurement

2.1 Data

The only source that provides state-wise age specific death rates by sex for India annually is the Sample Registration System (SRS). It is based on dual reporting system in which each event of birth and death is enumerated by two independent procedures; one is the registration of births and deaths and the other is the sample survey. The quality of death statistics obtained through SRS is often criticized. Bhat (2002) [3] pointed out the incompleteness in death registration in the SRS death records and he used the generalized version of Brass Growth Balance method in order to check the completeness. However, SRS data is considered the most reliable of all as far as death statistics are concerned (Roy and Lahiri, 1988; National Commission on Population, 2001; Mathers *et al*., 2005; Saikia *et al.*, 2010) [37, 24, 22, 38]. Saikia *et al.* (2011) [39] compared the infant mortality rates of the SRS and National Family Health Survey (NFHS) for the period 1979-2006 by residence and found a high level of agreement suggesting improvement in SRS data over the years. The SRS provides information on age specific death rates up to age 70+ years from 1970 onwards and from the year 1995 onwards, the rates are presented up to 85+ years. As such, in the present study, death rates for the elderly by age and sex during 1997-2016, taken at five year intervals, from the SRS of India are used.

2.2 Measurement

Age variations in mortality are usually examined by plotting the logarithm of the death rate against age. Significant patterns of mortality deceleration or acceleration, however, can easily escape the visual inspection of such a graph. A simple measure, the Life Table Ageing Rate (LAR) has proven to be powerful for detecting these patterns (Horiuchi, 1997; Horiuchi and Coale, 1990 [11]; Horiuchi and Wilmoth, 1998) [12].

The LAR at exact age 'x' is defined as,

$$k(x) = \frac{1}{m(x)} * \frac{dm(x)}{dx} = \frac{d \ln m(x)}{dx}$$

where m(x) is the force of mortality (instantaneous death rate) at age 'x' for some population. Thus the LAR measures the relative mortality increase with age.

An age related increase in LAR corresponds to acceleration in the age pattern of mortality, whereas a decrease implies a mortality deceleration. Thus the LAR also helps to measure the age range and extent of the mortality deceleration accurately.

When data are tabulated by five-year age groups, the LAR can be estimated as

$$k(x) = [\ln M(x,5) - \ln M(x-5,5)]/5$$

where M(x,5) is the death rate for the interval between exact ages 'x' and 'x+5'. This approximation has been shown to be sufficiently accurate (Horiuchi and Coale, 1990) [11].

LAR can be calculated period-wise or cohort-wise and for all-cause mortality and each cause of death.

3. Findings

3.1 Age Specific Death Rate

Figure: 1a-1b gives the age specific death rates at older ages in Kerala from 1997 to 2016. It is clear from the figure that death rates at older ages declined considerably over the years in Kerala. Clear gender differentials in the decline of death rate are seen. However, it is very difficult to assess the age variations in the pace of mortality increase or decrease from these figures. Calculating Life Table Ageing Rates fill this gap.

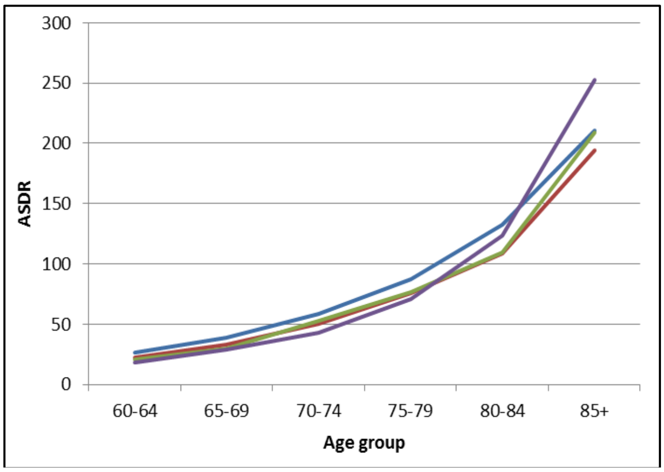


Fig 1a: ASDR Curve at older ages in Kerala, 1997-2016 (Male)

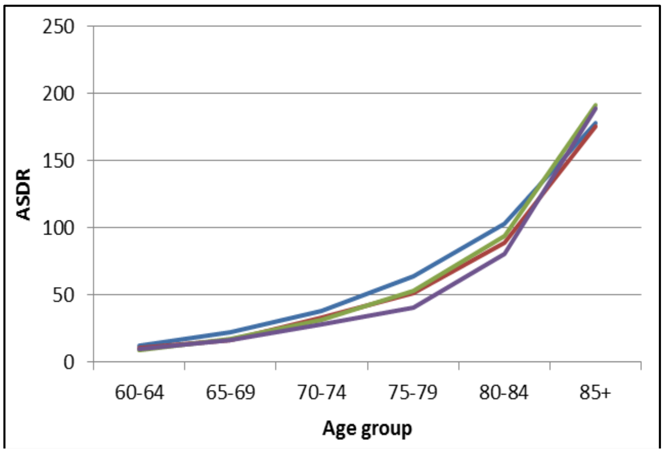


Fig 1b: ASDR Curve at older ages in Kerala, 1997-2016 (Female)

3.2 Life Table Ageing Rate (LAR)

LAR measures the relative mortality increase or decrease with age. An age related increase in LAR corresponds to acceleration in the age pattern of mortality, whereas a decrease implies a mortality deceleration.

The changes in life table ageing rates at older ages in Kerala from 1997-2001 to 2012-16 at five year intervals are given in Table:1 and Figure:2. The LAR curve shows peaks and troughs in most of the periods. Clear age variations in the pace of mortality change over the years are observed in Kerala. During the period 1997-2001, the LAR value decelerated at 80 years, whereas during the period 2002-06 the LAR decelerated at 65 and 75 years, the lowest being at 65 years. In the next two periods, 2007-2011 and 2012-2016, the curve had only one trough that was at 75 years, a clear evidence of mortality deceleration. Hence, over the last 15 years, the LAR curve for Kerala has changed and the pace of mortality increase shows a tendency to decelerate around 75 years during the recent period.

Table 1: LAR Values for Kerala, 1997-2016 (Total)

Age	1997-2001	2002-2006	2007-2011	2012-2016
60	0.11522	0.10922	0.09183	0.09199
65	0.09314	0.07935	0.09375	0.09724
70	0.09284	0.10676	0.11277	0.08703
75	0.09010	0.08213	0.08700	0.08576
80	0.08822	0.09071	0.09408	0.12174
85	0.10090	0.12588	0.13527	0.15461

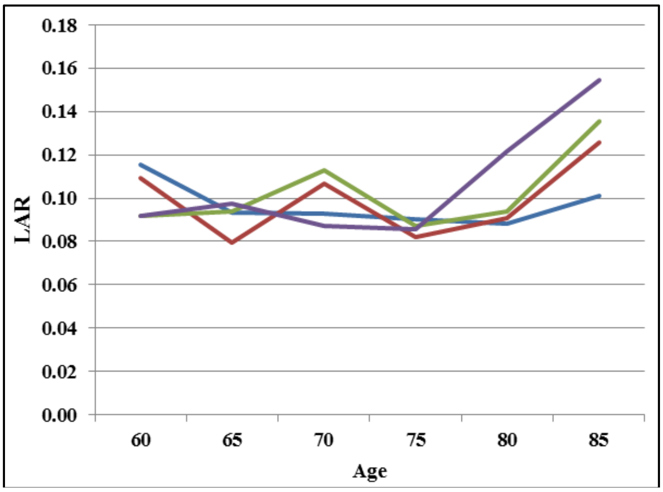


Fig 2: LAR Curves for Kerala, 1997-2016 (Total)

This table can also be interpreted in such a way by considering each age cohort. The SRS does not provide cohort-wise information on death rate. Hence the LAR values for each age cohort during 1997-2001 are followed through till the period 2012-16 by assuming that the survivors of the age group 60-64 years during 1997-2001 will reach 65-69 years during 2002-06 and so on.

The life table ageing rate at 60 years decelerated as they survived to the next age 65 years and after that it accelerated at 70 years and decelerated again at 75 years. For the age cohort 65 years LAR decelerated at the age of 75 years. The same trend could be seen for the age cohort 70 years also and for the cohort of 75 years the value of LAR accelerated as they survived to higher ages. These results also point to the fact that the mortality rate at older ages in Kerala shows a tendency to decelerate at the age of 75 years.

In order to understand the gender differentials, the LAR values are calculated separately for males and females. The LAR values corresponding to the period 1997-2001 for males (Table:2 and Figure:3a) shows deceleration at the ages 65 years and 75 years, the lowest value being at 65 years. Life table ageing rates decelerated at the age of 65 years and 80 years during the next two periods. But during the period 2012-16, deceleration in LAR occurred at 70 years.

Table 2: LAR Values for Kerala, 1997-2016 (Male)

Age	1997-2001	2002-2006	2007-2011	2012-2016
60	0.10848	0.10971	0.09187	0.08941
65	0.07817	0.07544	0.07769	0.09389
70	0.08328	0.08704	0.11320	0.07660
75	0.07986	0.08133	0.07399	0.10342
80	0.08266	0.07144	0.07210	0.10955
85	0.09316	0.11584	0.12853	0.14376

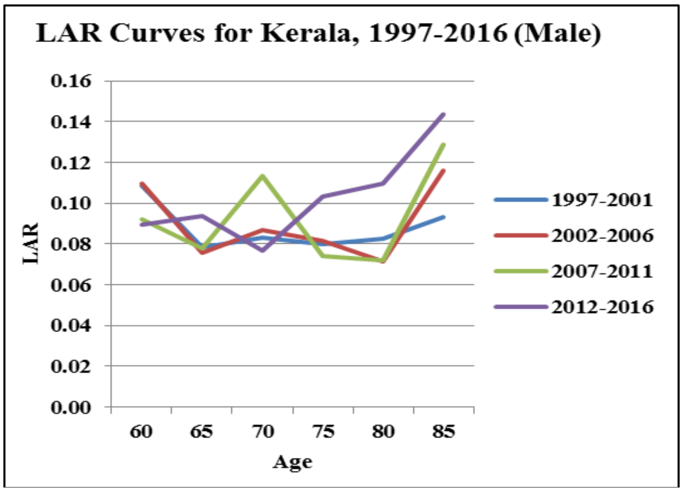


Fig 3a: LAR Curves for Kerala, 1997-2016 (Male)

The LAR curve for females depicted a different pattern as compared to that for males (Table: 3 and Figure: 3b). Life table ageing rate for females during all the periods except 1997-2001 show deceleration at the age of 75 years. Unlike that for males, deceleration is more prominent for females. That is, clear evidence of mortality deceleration could be observed for females and is at the age of 75 years.

Table 3: LAR Values for Kerala, 1997-2016 (Female)

Age	1997-2001	2002-2006	2007-2011	2012-2016
60	0.13432	0.11630	0.09229	0.09195
65	0.12440	0.09221	0.12911	0.11106
70	0.10850	0.13881	0.12061	0.10584
75	0.10196	0.08578	0.10526	0.07371
80	0.09638	0.11023	0.11517	0.13834
85	0.10912	0.13602	0.14143	0.16975

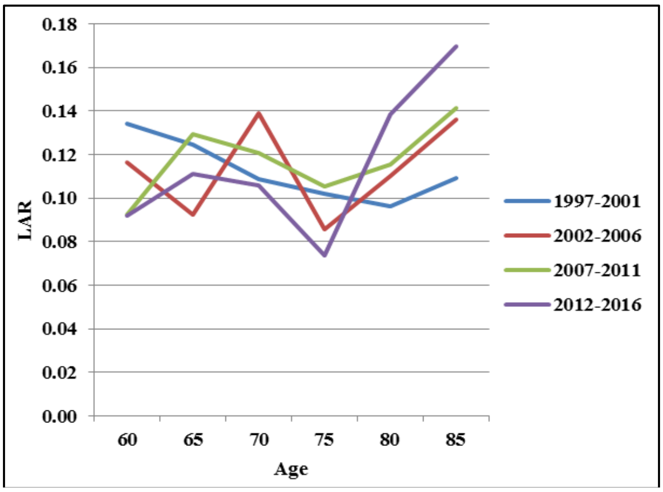
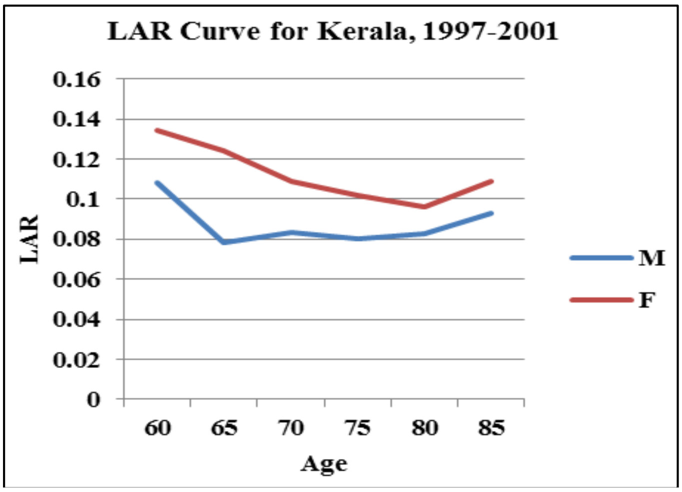
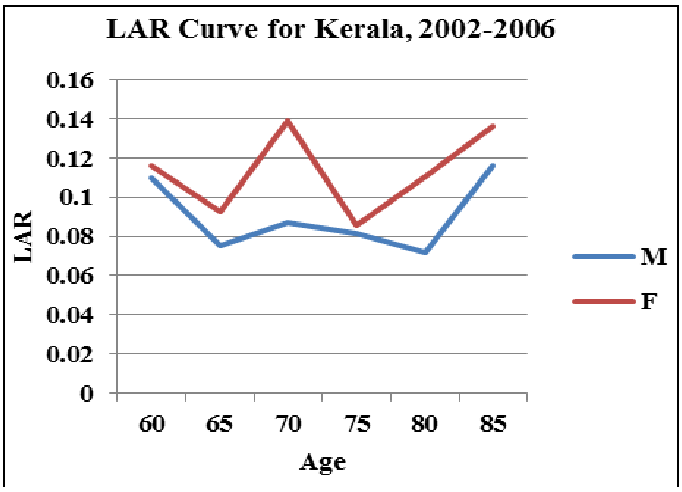


Fig 3b: LAR Curves for Kerala, 1997-2016 (Female)

The LAR curve at older ages for both males and females had changed over the years with clear evidence of mortality deceleration taking place at older ages. It is clear from Figure:4 that the LAR values for females are higher than that for males at most of the ages throughout the period. That is, in Kerala, the pace of age related increase in mortality is faster for females as compared to that for males.





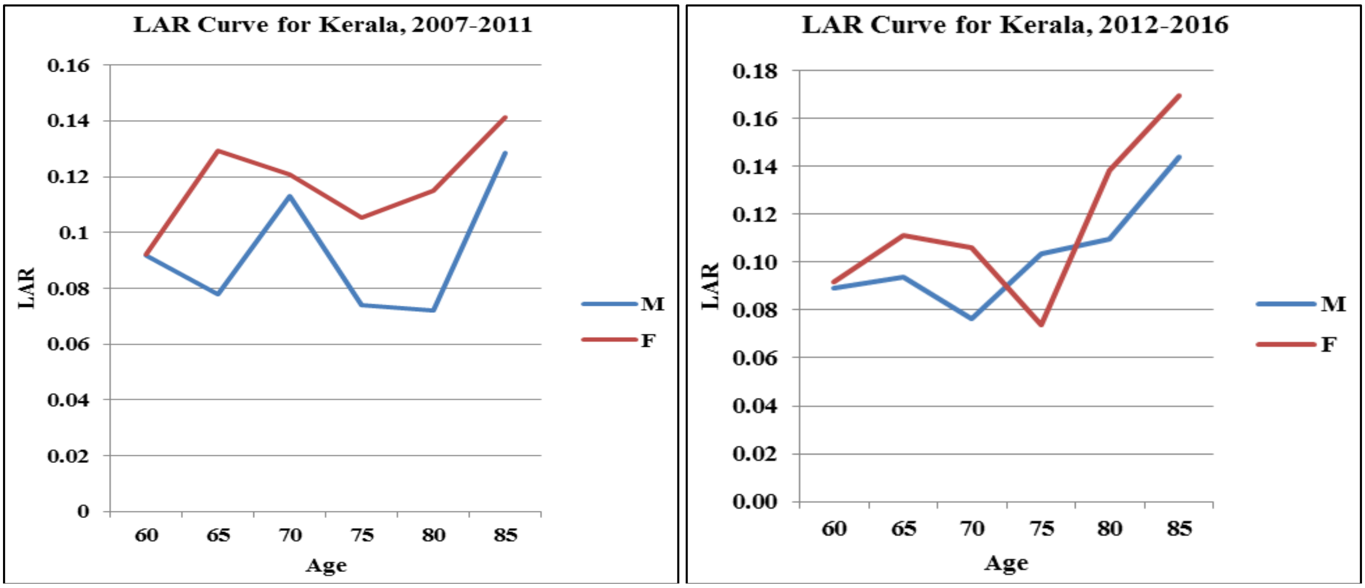


Fig 4

The phenomenon of mortality deceleration at older ages in Kerala is compared with that in India as a whole for the most recent period 2012-16.

Table 4: LAR Values for Kerala and India, 2012-2016

Age	Kerala			India		
	Total	Male	Female	Total	Male	Female
60	0.09199	0.08941	0.09195	0.08162	0.06401	0.10078
65	0.09724	0.09389	0.11106	0.08239	0.08021	0.08618
70	0.08703	0.07660	0.10584	0.08862	0.08760	0.09113
75	0.08576	0.10342	0.07371	0.08071	0.08136	0.08097
80	0.12174	0.10955	0.13834	0.10791	0.10117	0.11505
85	0.15461	0.14376	0.16975	0.11246	0.11876	0.10871

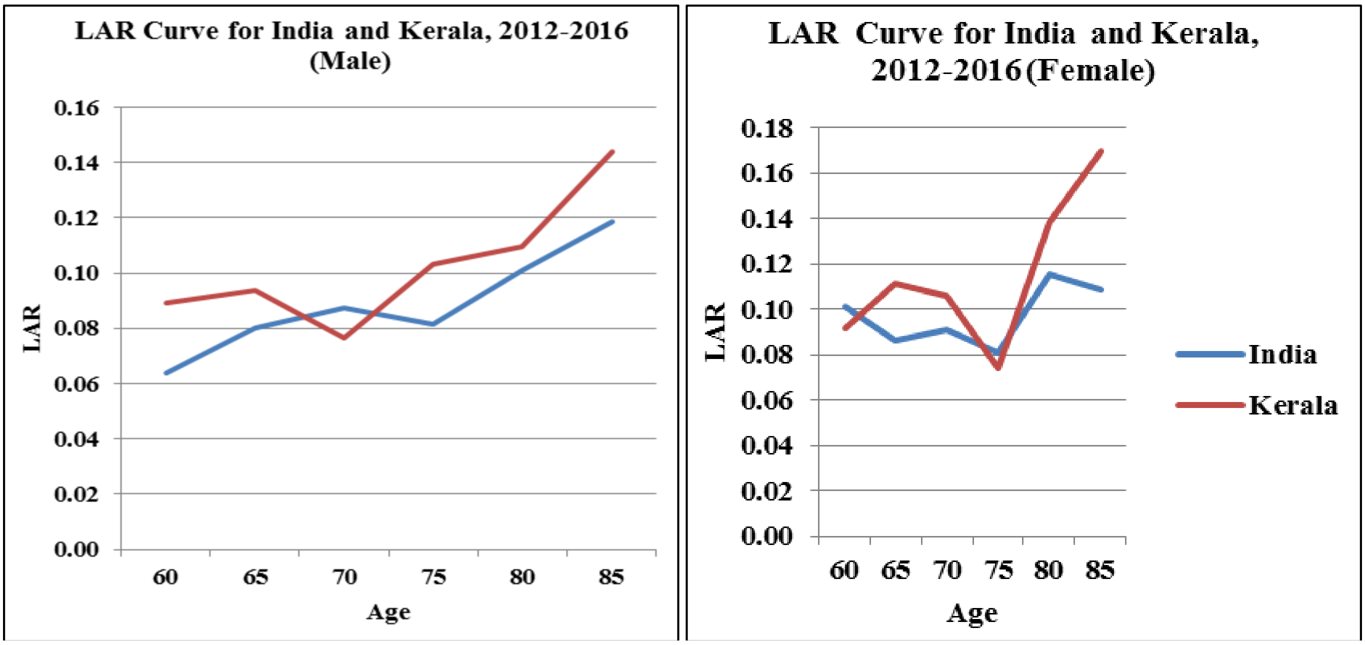


Fig 5

It is observed from the table (Table: 4) that, in most of the ages the LAR values are higher for Kerala than that for India. It is true when the LAR values are calculated separately for males and females also. Mortality rates at older ages have already declined significantly for both males and females in Kerala compared to any other state in India. Hence the age related increase in the pace of mortality at older ages would be higher in Kerala compared to that in India as a whole. The LAR curve for India shows deceleration at the age of 75 years for both males and females (Figure: 5). Clear evidence of gender differential is seen in India with females having higher LAR values at most of the ages, as observed in Kerala.

4. Discussion and Conclusion

Studies conducted in many low mortality populations showed mortality deceleration taking place at older ages. The results obtained in this study also reveal mortality deceleration taking place at older ages in Kerala and it being more pronounced among females. Mortality deceleration has occurred at both younger and older old age groups in Kerala. This can be explained by the heterogeneity hypothesis as deceleration is a statistical effect of the selection through the attrition of mortality. Because the frailer tend to die at younger ages, survivors to older ages tend to have favourable health endowments. At younger old ages, the proportion of mortality risk that is chance-related becomes negligibly small and at older old ages selective survival makes the population composition less frail, thereby slowing down the mortality increase with age (Horiuchi and Coale, 1990) [11].

According to the heterogeneity hypothesis, LAR at older ages should increase over time as the process of selective survival is weakened by a decline in total mortality. At older old ages total mortality is composed almost entirely of senescent mortality. Thus, assuming that the selective processes of senescent and background mortality are different, the rise in the LAR at older old ages must result from a general decline in senescent mortality. At these ages, trends in background mortality are irrelevant. At younger old ages the tendency for increasing LARs due to the decline in senescent mortality may be offset, or even reversed by the changing distribution of total mortality between background and senescent components. Because background mortality is a non-negligible fraction of total mortality at younger old ages, differential rates of decline in senescent and background mortality can have a substantial effect on the LAR curve (Horiuchi and Wilmoth, 1998) [12].

A faster reduction in senescent compared to background mortality decreases the proportion of total mortality due to senescent causes. This differential reduction tends to lower the LAR at younger old ages, as senescent mortality increases with much faster than does background mortality which is traditionally assumed constant over age (Makeham, 1860). On the other hand, a faster decline in background than senescent mortality would raise the LAR curve in this age range. These effects may be substantial at younger old ages, where the ratio of background to senescent mortality is relatively high, but they are negligible at older old ages where the proportion of total mortality due to senescent causes is close to unity and not highly variable over time (Horiuchi and Wilmoth, 1998) [12]. The impact of risk factors on mortality and morbidity tend to attenuate at old ages. Crimmins (2005) [5] while analyzing the longitudinal survey data in the U.S. indicated that educational differentials in mortality, disease incidence, disease prevalence and biological risk factors tend to lessen or disappear at old ages and explains the diminution as a result of selective survival. The prevalence of mortal diseases does not vary much with age, whereas the prevalence of non-mortal conditions markedly increases with age.

The present study shows clear evidence of mortality deceleration taking place at older ages in Kerala and is around the age of 75 years. Even though females in Kerala live longer compared to males, the pace of mortality increase with age at older ages is faster for females. That is, females are frailer than males at their older ages in Kerala. The study also found evidences of mortality deceleration taking place at older ages in India. The LAR curve for Kerala was found to be different from that for India. Clear gender differential was observed in India with females having higher LAR values. That is, in India the elderly women are at higher risk of mortality compared to the elderly men of the same age. Yadav *et al*. (2012) [46] had observed that LAR is decelerating up to age 70 and after that it is slightly increasing for the oldest age in India and is more pronounced for females as compared to males.

The expectation of life at birth for females in Kerala is higher by 6 years than that for males in the recent period 2009-13 (RGI, 2016). The results of the present study point to the fact that even though women live longer than men, they are frailer than men as male survivors to older ages may tend to have favourable health endowments. Hence the process of mortality deceleration at older ages as observed in Kerala explains the heterogeneity hypothesis (Khazaeli, Xiu and Curtsinger, 1995) [14].

The fact that women live longer than men does not, however, mean that they necessarily enjoy better health (Perls and Fretts, 1998) [28]. In the Indian context, sufficient evidence exists pertaining to the kind of deterioration in physical and mental health at old age (Gupta *et al.*, 2001; Rajan, 2004, 2008; Alam, 2006; Hiremath, 2012) [8, 29, 31, 1, 9]. The elderly in India experience a greater burden of multiple ailments and one out of two elderly suffers from at least one chronic disease which requires life-long medication (Rajan, 2006) [30]. Also, significant differences in health expenditure exist between the elderly men and women in India, with a higher amount spent on elderly men than on elderly women in all parts of India (Maharana and Ladusingh, 2014) [15].

Kerala is a state with a widespread system of health care facilities. The western medical system, which evolved during the British rule, has been strengthened in the post-colonial period. State intervention to provide health care facilities has also increased the spread of Ayurvedic and Homeopathic systems of medicine. Medical facilities in the private sector under the three medical systems have expanded to a great extent. The private sector has now become the largest provider of health care in the state. Higher literacy coupled with better availability and accessibility of health care infrastructure helped the state attain a better health care utilization compared to other states of India (Navaneetham *et al.*, 2009) [25].

Despite the overall progress in health and longevity in Kerala, socio-economic disparities in health are prominently observed at the population level (Sauvaget *et al.*, 2011) [40]. The health of females in Kerala deteriorated earlier in life than that of males. The economic background of the elderly is a significant predictor of the prevalence of chronic morbidity conditions among them (Dilip, 2007) [7]. Navaneetham *et al*. (2009) [25] observed significant gender inequality in morbidity existing in Kerala; females were found to be at greater risk of ill-health than males, and at older ages females were more vulnerable to morbidity. Non-communicable diseases were the main causes of morbidity, indicative of epidemiological transition in Kerala. Among the states of India, Kerala has the highest prevalence of multiple chronic diseases (Arokiasamy *et al.*, 2015) [2].

The implications of mortality deceleration taking place in Kerala are many. Since women live much longer, the proportion of the elderly widows in the population will be large in the future. According to the reports of Census of India (2011) the sex ratio of the elderly population in Kerala is 1222 females per 1000 males, whereas it is only 1035 females per 1000 males in India. A large proportion of the elderly widows, especially when they are frailer, in any population, may negatively affect its socio-economic development. Prolonging the lives of frailer individuals will result in rapidly increasing medical and other costs per person and thus increasing the social burden of caring for the aged.

The elderly women also face problems like loneliness, financial insecurity, lack of access to proper medical care facilities, etc., besides their health problems (Rajan 2006; Navaneetham *et al*. 2009; Ravisankar 2009) [30, 25, 32]. Since most of India's elderly are economically dependent on others in the family and the cost of treatment is often a burden on the household, many of the elderly ignore their ailments unless they become too acute (Rajan 2006) [30]. As mentioned earlier, non-communicable diseases dominate the morbidity profile of Kerala. Most of the diseases require sustained medical treatment, which is beyond the wherewithal of the average households. Hence, economic security of the elderly becomes one of the determining factors of utilization of medical care facilities.

Reducing the mortality rate alone will not improve the health status of any society. A considerable reduction in morbidity rates is also required. Since the elderly women are more vulnerable, special health programmes should be implemented for them. Definite health intervention measures are necessary to cater to specific diseases associated with old age (Rajan 2006) [30]. This study clearly showed discrimination against the elderly females in terms of health in Kerala. Though the life expectancy of women has overtaken that of men, gender role in the Indian society has not changed enough to prevent the discrimination against women (Maharana and Ladusingh, 2014) [15]. The Government need to provide more support programmes for the elderly and in order to assure proper utilization of these programmes gender discrimination among the elderly should be minimized. The policy experts and the government should address these issues seriously. Focus should be placed on frailty, which underlies mortality, morbidity and disability at older ages. A comprehensive health insurance scheme for the elderly is also recommended in order to support the rapidly increasing medical cost per aged person.

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