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(Research Article)

Uneven contributions to life expectancy gains in Ethiopia: The dominant role of "Other Effect" and the limiting impact of old age groups

Hailay Mebrahtom Gebreegziabiher [1,*] and Kinfe Abraha Gebre-Egziabher [2]

[1] *Department of Demography, Institute of Population Studies, Mekelle University, Tigray, Ethiopia.*
[2] *Department of Development Studies, Institute of Population Studies, Mekelle University, Tigray, Ethiopia.*

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Abstract

This study investigates the contributions of different age groups to changes in life expectancy at birth in Ethiopia and its regional states over a period of thirty years. Using the Arriaga decomposition method, we separated the contributions of direct and other effects analyzing the role of old age groups. Our analysis revealed that while overall life expectancy has increased, old age groups contributed minimally, and in many cases even negatively to the overall increase in life expectancy and to the other effect component as well. Conversely, other effect, primarily reflecting changes in mortality patterns across all ages, emerge as the dominant driver of life expectancy gains. This suggests that improvements in life expectancy in Ethiopia in the period 1990 – 2019 were primarily driven by factors affecting younger age groups and not significant gains in longevity at older ages. Our findings highlight the need for targeted interventions addressing mortality across all age groups and aimed at improving health outcomes for older adults. Regionally, no significant contribution differences were observed but Addis Ababa exhibited a negative other effect contribution in the old ages.

Key words: Arriaga method; Ethiopia; Life Expectancy decomposition; 1990; 2019

1. Introduction

Life expectancy at birth summarizes in a single number the mortality conditions of a given population, and it does so in a way that is independent of the age structure of the underlying population (Gisbert, 2020; Auger et al., 2014). It has been utilized as a quantitative measure of mortality and longevity within and across societies (Jembere et al., 2018).

When analyzing changes in life expectancy at birth or studying differences in life expectancy between two populations, it is sometimes useful to estimate what mortality differences in a specific age group contribute to the total difference in life expectancy (Preston et.al, 2001) because an increase or decrease in life expectancy at birth might be due to the changes that take place in the mortality conditions of different age groups over a period of time (Ponnapalli, 2005). Marked differences in life expectancy are also observed between sub-populations within the same country (Na'amnih et al., 2010).

Methods of decomposition in demography can provide important insight into the causes of the differences in aggregate measures (such as LE) between well-defined population groups (Goldman and Andrasfay, 2022). Those methods aim at estimating contributions of differences between elementary rates of demographic events to the overall difference between two values of the aggregate measure (Andreev et al., 2002). In order to explain the dynamics behind changes in mortality, demographers have developed several techniques to decompose changes in life expectancy by different components of mortality, such as ages and causes of death (Bergeron-Boucher et al., 2015). This is due to the fact that

* Corresponding author: Hailay Mebrahtom Gebreegziabiher

mortality reductions are translated into gains in life expectancy at birth and can be attributed to specific age groups (Aburto et al., 2021).

Since a change in life expectancy (at any age) does not necessarily mean that mortality rates change in the same magnitude or even in the same direction at all ages, it would be useful to explain or decompose differences in two life expectancies pertaining to two populations (male-female, urban-rural, states, ethnic groups, etc.) in relation to the mortality differential at each age (Arriaga, 1984).

Andreev (1982), Arriaga (1984), and Pressat (1985) (cited in Beltran-Sanchez and Preston, 2007; Romo, 2003) independently developed discrete methods of decomposing life expectancies in the 1980s. The formulae for decomposition by Andreev and Pressat are exactly equivalent (Andreev et al., 2002; Ponnapalli, 2005; Pollard, 1988).

This paper is, therefore, devoted to decomposing differences between life expectancies in Ethiopia and among its regional states age-wise using Arriaga's method to assess the contribution of the old age groups to the differences in the overall life expectancies over the period 1990-2019 and make inferences with regard to the Ethiopian healthcare system accordingly.

Ethiopia with a total population of 112,134,000, with an annual growth rate of 2.6, with a total fertility rate of 4.15 in 2019 (Leong et al., 2018), and with a life expectancy of 66.6 years in 2019 had achieved in improving its life expectancy by over 18 years over the period 1990-2015 (Jembere et al., 2018). These significant gains in life expectancy of the nation enthused the researchers to decompose them into their respective age-specific components for further analyses.

Objectives

This paper aims at decomposing life expectancy gaps between Ethiopia and each of its regional states into age specific components; identifying the age groups that contribute most to the overall life expectancy gap between Ethiopia and its regional states; identifying which age groups in which regions and which sex have experienced the greatest improvements in mortality rates, and which ones still have the highest mortality rates; and proposing targeted interventions to reduce mortality rates at specific age groups.

2. Methods and Materials

2.1. Data

In order to have life expectancies for decomposition analysis, we extracted survival functions (l_x) from The United Nations World Population Prospects 2022 web source and we used them to derive standard survival functions (${l_x}^s$) by sex. Using Infant Mortality rates (IMRs) and Under Five Mortality Rates (U5MRs) collected form " Tessema GA, Berheto TM, Pereira G, Misganaw A, Kinfu Y, GBD 2019 Ethiopia Child Mortality Collaborators (2023) National and subnational burden of under-5, infant, and neonatal mortality in Ethiopia, 1990–2019: Findings from the Global Burden of Disease Study 2019. PLOS Glob Public Health 3(6): e0001471. https://doi.org/ 10.1371/journal.pgph.0001471" as our input data and using Brass' logit method, we produced model based abridged life tables for Ethiopia and for each of its regional states. Since those abridged life tables contained life expectancies, we went on decomposing them further into their relative age specific components.

2.2. Methods

2.2.1. Decomposition of Life Expectancy

Any effort for the evaluation of the differences in life expectancies at birth between two populations or two-time points within the same population must manifest the mortality differences in each age group of human life span (Zafeiris, 2020). Many methods such as Andreev (1982), Pollard (1982, 1988), Pressat (1985), and Arriaga (1984) were developed for the purpose of decomposing life expectancies and measuring relative age specific contributions to the overall change. Because all these methods lead to similar results (Pollard, 1988; Ponnapalli, 2005), we used the decomposition method developed by Arriaga (1984) to measure the contribution of each age group to the overall changes in life expectancy of Ethiopia and its regional states over the period 1990-2019. Our choice of Arriaga's decomposition method was based on the fact that it gives reliable and consistent results (Zafeiris, 2020).

Life expectancy at birth is a functional of the vector of age-specific death rates, which has to be computed by complex accumulation of these rates by means of the life table (Andreev et al., 2002). When comparing abridged life tables with different levels of mortality, it is observed in most cases that mortality differs in all age groups by different magnitudes

(Arriaga, 1984). The connection between expectation of life and the mortality rate at a particular age, however, is not a particularly simple one (Pollard, 1988). This is because although changes in mortality in a particular age group affect life expectancy in direct and indirect ways, contributions to life expectancy increase cannot be measured only in terms of changes in mortality in each age group (de Castro, 2001); the overall change has associated with it the notion of interaction effects (Arriaga, 1984; Ponnapalli, 2005; de Castro, 2001).

The following mathematical relations reveal this problem and enable us differentiate the direct, indirect, and interaction effects that are found embedded in the overall change in life expectancy:

The life expectancy at birth e_0 is given by

$$e_0 = \int_0^{\omega} p(a)da, \text{.....................} \quad (1)$$

Where, ω is the oldest age considered beyond which no one survives and $p(a)$ is the probability of surviving from birth to age a given by

$$p(a) = exp\left(-\int_0^{a} \mu(u)du\right), \text{..................}(2)$$

Where, $\mu(u)$ is the force of mortality at age u.

Combining the two equations given above, we see that

$$e_0 = \int_0^{\omega} exp\left(-\int_0^{a} \mu(u)du\right)da \text{....................}(3)$$

Now, when $\mu(u)$ changes in the age interval$(x, x+i)$, both the probability of surviving and the average time lived at those ages will change. The effect resulted from these changes is then said to be **direct effect**. This change in $\mu(u)$ will also affect the number of survivors that will move on to the next age group, and hence the time lived at ages$(x+i, \omega)$. The effect resulted here is called **indirect effect**. However, changes in $\mu(u)$ are observed at all ages, and not only at a particular age group. That means new survivors at age $x+i$ will spend more time on $(x+i, \omega)$ than on$(x, x+i)$. The effect here is named **interaction effect**.

Interaction effect according to Arriaga (1984) is that 'which cannot be allocated to any particular age group alone, but to the change in mortality at all ages'. Arriaga adds that the indirect and the interaction effects add up to an effect called **other effect**.

Using a discrete perspective of basic functions of the life table, Arriaga (1984) presents the following relations for each of the effects, given a change in mortality at ages x to $x+i$, observed between the periods t and $t+n$ (de Castro, 2001):

$$\text{Direct Effect,} {}_i{}^{DE}{}_x = \frac{l_x^t}{l_a^t}\left(\frac{T_x^{t+n} - T_{x+i}^{t+n}}{l_x^{t+n}} - \frac{T_x^t - T_{x+i}^t}{l_x^t}\right), \text{..................} (4)$$

Where l and T are the life table functions, x is the initial age of the age interval i being considered, a is the age at which the life expectancy is calculated (if life expectancy at birth,$a = 0$).

The effect that mortality change in the open-ended age group produces on the total change in life expectancy at age a will be only the direct effect. Since this is the last age group, the indirect and the interaction effects do not exist.

$$\text{Direct Effect for the open ended interval, } DE_{x+} = \frac{l_x^t}{l_a^t}\left(e_x^{t+n} - e_x^t\right) = \frac{l_x^t}{l_a^t}\left(\frac{T_x^{t+n}}{l_x^{t+n}} - \frac{T_x^t}{l_x^t}\right) \text{..........}(5)$$

$$\text{Indirect Effect, } {}_i{}^{IE}{}_x = \frac{T_{x+i}^t}{l_a^t}\left(\frac{l_x^t l_{x+i}^{t+n}}{l_{x+i}^t l_x^{t+n}} - 1\right) \quad \text{.....................}(6)$$

$$\text{Other Effect, } {}_i{}^{OE}{}_x = \frac{T_{x+i}^{t+n}}{l_a^t}\left(\frac{l_x^t}{l_x^{t+n}} - \frac{l_{x+i}^t}{l_{x+i}^{t+n}}\right) \text{.....................}(7)$$

$$\text{Interaction Effect, } {}_i{}^{I}{}_x = {}_i{}^{OE}{}_x - {}_i{}^{IE}{}_x \text{......................}(8)$$

When the open-ended interval does not have reliable data (as is the usual case), similar formulae to the above ones could be used to calculate life expectancies between any two specific ages. These life expectancies are said to be temporary life expectancies. The temporary life expectancy from age x to $x + i$ is the average number of years that a group of persons alive at exact age x will live from age x to $x + i$ years. In symbols, it would be

$$i^{e}x = \frac{T_{x} - T_{x+i}}{l_x} \quad \text{………………(9)}$$

Where x is the lower limit and i the upper limit of the age range considered$(x \geq 0, i < \omega)$.

We constructed model based Abridged Life Tables for the forthcoming life expectancy decomposition analysis using Brass' (1971) logit method. Then, we further used the life table functions to decompose the life expectancy of Ethiopia, of its regional states, and of the sexes over the period 1990-2019 using the above discussed Arriaga (1984) formulae.

3. Results and Discussion

We conducted an age-wise breakdown of life expectancies in Ethiopia and a few selected regional states from 1990 to 2019. We broke down life expectancies for Ethiopia and all of its states, but for the purpose of ease of analysis, we only included Ethiopia and four of its regional states: Addis Ababa, Tigray, Somali, and Benshangul Gumuz. The findings reveal that life expectancy has generally increased in Ethiopia and all of its regional states over the period 1990-2019. This is attributed to a combination of decreases in infant mortality rates, decreases in child mortality rates, and decreases in adult mortality rates. The age-wise life expectancy contributions showed that the highest contributions were resulted from declines in infant mortalities.

3.1. The total improvement in life expectancy of the nation over the past three decades was 16.977 years

All of the regional states made significant contributions to the overall transformation, but Addis Ababa, Tigray, Benshangul Gumuz, and Somali were among the lowest and the highest contributors with contributions of 7.536, 16.2, 9.0, and 19.3 years, respectively. The contributions from Somali and Addis Ababa were the lowest of all the other Ethiopian regional states. Their meanings were different, though, in that Addis Ababa started out in a better position than the other regions in terms of improved life expectancy and succeeded in doing so over the reference period, albeit not significantly better than the others, whereas Somali made less of an impact on overall life expectancy.

The age groups 0–1 and 5–10 made the largest contributions to the overall improvement in life expectancy in Ethiopia and all of its regional states. This suggests that the improvement in life expectancy at birth was primarily due to the dramatic declines in Infant Mortality Rates (IMRs) and Under Five Mortality Rates (U5MRs) over time.

Of the total 16.977 years of improvement in life expectancy for both sexes combined in Ethiopia over the period of thirty years, an amount of 8.9 years that stands for over 50% of the total improvement was contributed by the age groups of 0-5, an indication that the country worked hard to reduce child mortality.

The late adult age contributions to overall life expectancy were uniformly low across all regions, but Addis Ababa was notable for having negative total effect contributions from individuals 65 years of age and above. This suggests that mortality had increased in those adult age groups, possibly but not only as a result of rising rates of chronic illnesses and rising rates of risk factors for chronic illnesses, such as obesity, smoking, and experiences with sedentary lifestyles. The population's average life expectancy must have decreased, the number of premature deaths increased, the quality of life for older adults decreased, and fewer people were living a disability-free life as a consequence.

In all age groups across all regions and between the sexes, the indirect effect and the interaction effect together, regardless of their overall magnitudes, significantly influenced the change in life expectancy at birth more than the direct effect did. One implication of this is that it is not enough to focus on interventions that directly target the exposure of interest to increase life expectancy but is necessary to consider the interventions that target the indirect and the interaction effects.

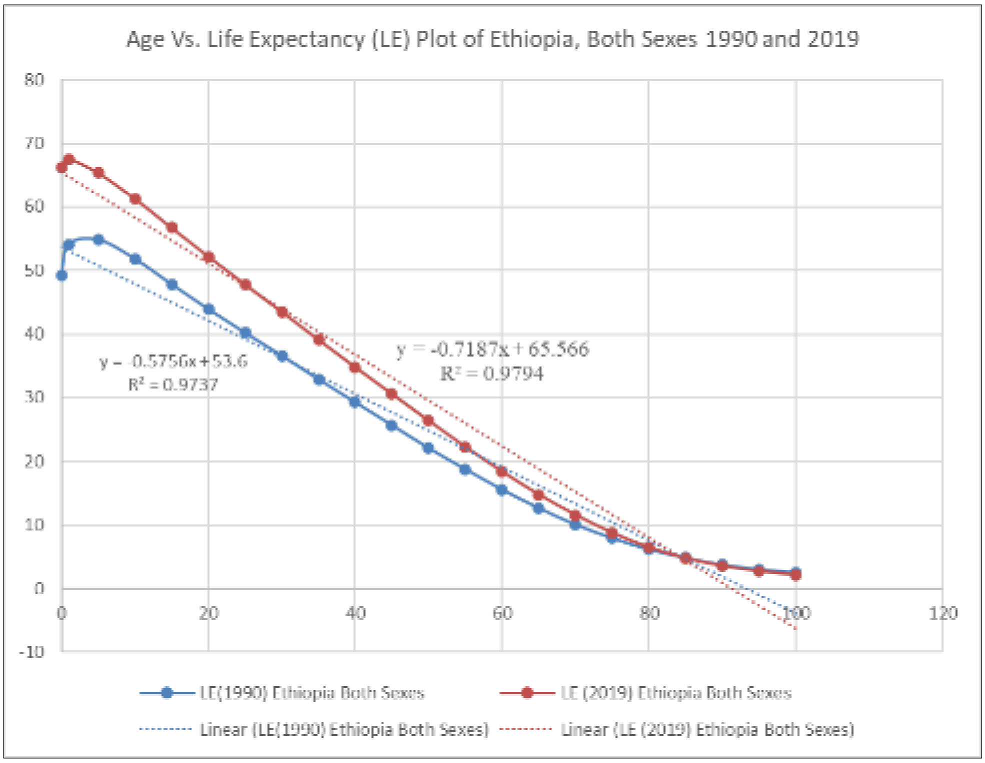

Figure 1 Life Expectancy Plot of Ethiopia, Both Sexes 1990-2019

The y-intercept of the linear trend line of the 2019 life expectancy curve here reads 65.566 which is very close to the calculated life expectancy at birth, 66.23 years. This is a good indication that a linear line fits well to the scatter points of changes in life expectancy than do the exponential or the logarithmic ones. Moreover, the R^2 value shows that almost 98% of the variations in the data (changes in life expectancy) were explained by age in this regression model and it means that this model is a good fit for the data. Comparing the slopes of the trend lines, we can observe that changes in life expectancy happened to decline more rapidly on a relative basis in 2019 than they did in 1990.

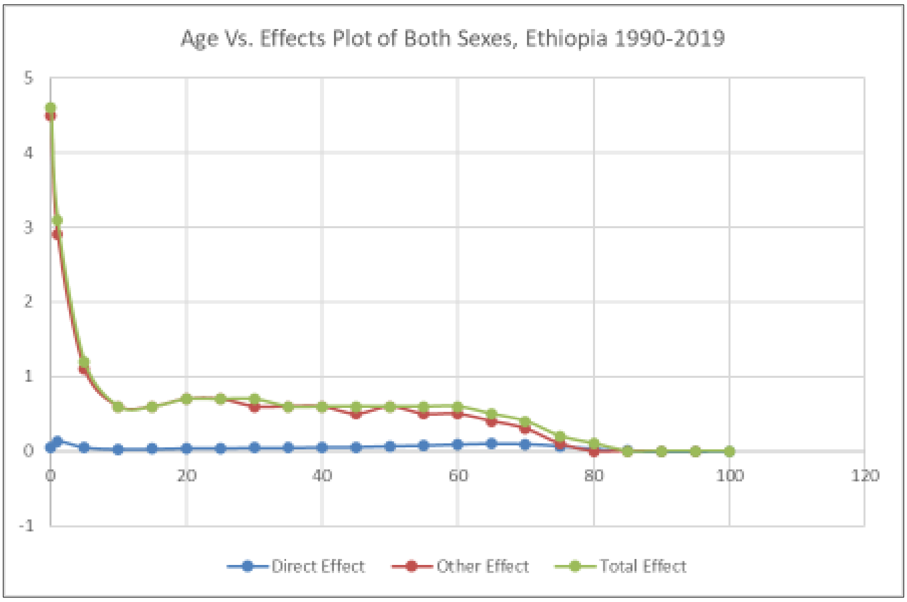

Figure 2 Direct Effect, Other Effect, and Total Effect Life Expectancy decomposition plot of Ethiopia, Both sexes, 1990-2019

The contribution of the direct effect to the total effect in life expectancy is relatively low as we can see from the sketch. However, the other effect almost equals the total effect except in a few points. This depicts that it was the indirect effect and the interaction effect of life expectancy that contributed the most to the overall change in life expectancy at birth of Ethiopia over the past three decades. At infancy, the direct effect contribution was relatively better than that of the other age groups. Within the age interval(5,55), the direct effect was almost close to zero and within(55, 80), little increments were observed. The other effect curve is almost coincident with the total effect curve throughout the plane except at the age intervals(25,35),(40,50), and (50,80). This means that the direct effect contribution was generally marginal.

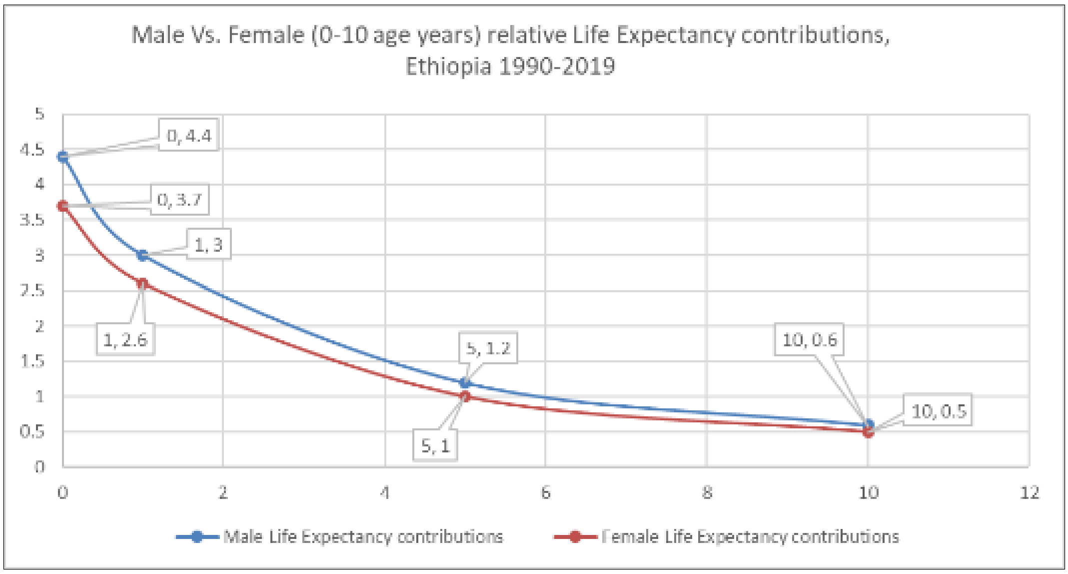

Figure 3 Sketch of young age Male and Female relative total effect Life Expectancy contributions

This sketch was confined only to the age group 0-10 because it was this age distribution that contributed many of the years to the overall change in life expectancy at birth of Ethiopia across all the regional states and between the sexes than any other age group or distribution over the period 1990-2019. On average, males on this age group contributed more to the overall life expectancy of the population than their female counterparts did on that age group. While females at age 0 contributed a total of 3.7 years to the whole transformation, their male counterparts at that age contributed 4.4 years. This means that on average, males can expect to live 0.7 years longer than females at age 0. The overall trend of life expectancy contribution within this age range shows that variations get narrower through time. Ideally, these numbers tell us that if all risk factors that reduce the expected life expectancy were eliminated, males and females as cohorts would respectively live 4.4 years and 3.7 years longer on average.

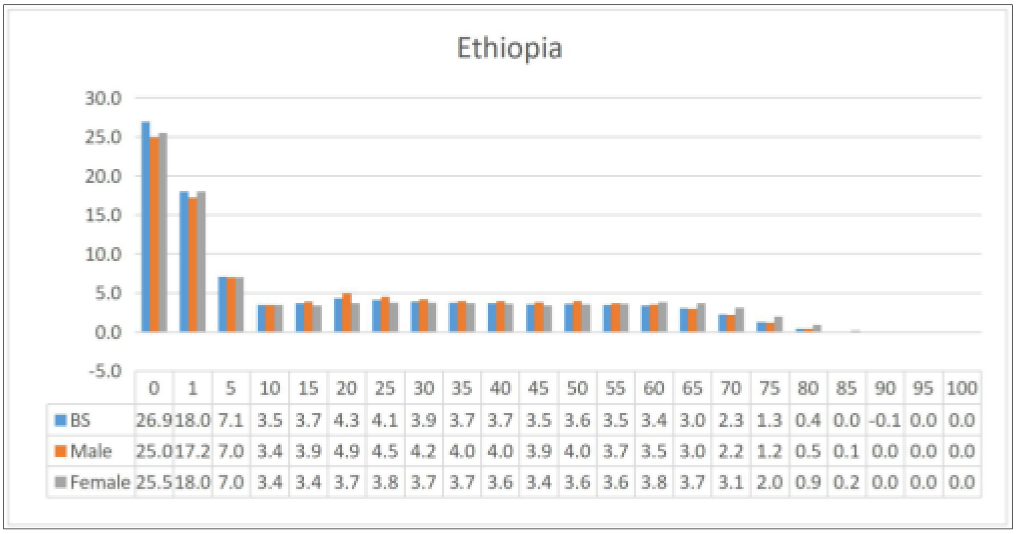

Figure 4 Percentage decomposed changes in Life Expectancy at birth (LEB) for both sexes, males, and females of Ethiopia, 1990-2019

Comparing the percentage contributions to the overall change in LEB of the country over the three decades, 52% in both sexes was gained from the under 5 years of age. Similarly, 49.2% and 50.5% of the actual gains in the Ethiopian LEB were contributed by the male and female populations of 0-5 age groups respectively.

When we look at the percentage contributions to the country's overall change in LEB over the course of three decades, children under the age of five accounted for 52% of the gain in both sexes. Similarly, the male and female populations in the 0–5 age groups contributed 49.2% and 50.5% of the actual gains in the Ethiopian LEB, respectively.

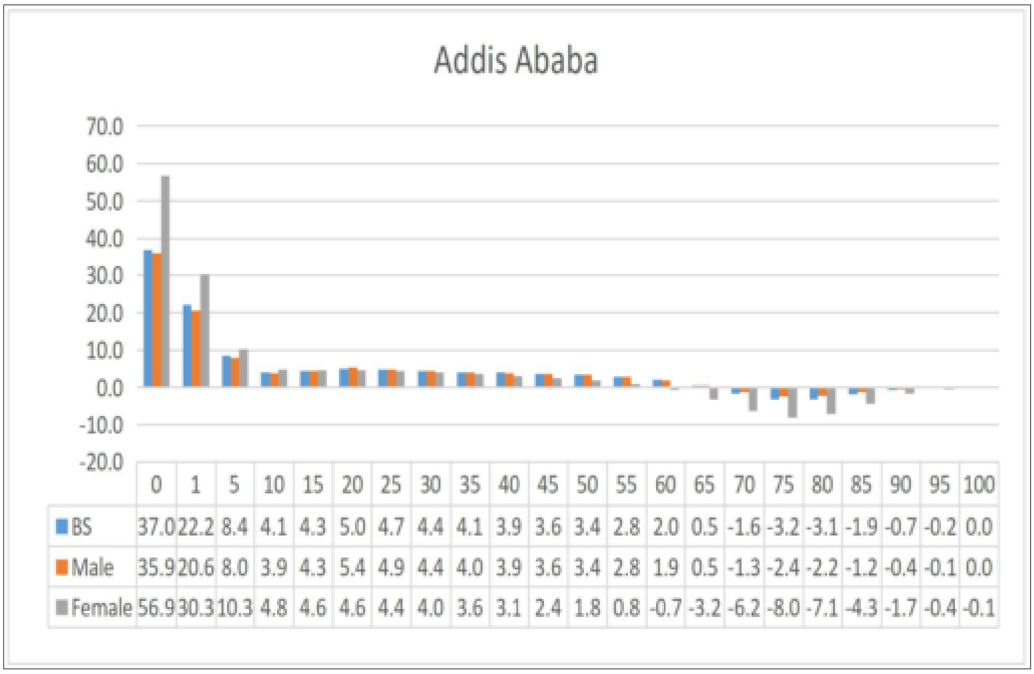

Figure 5 Percentage decomposed changes in Life Expectancy at birth (LEB) for both sexes, males, and females of Addis Ababa, 1990-2019

While the age group 0–5 accounted for more than half of the gains in LEB over the period in Ethiopia as a whole and in nearly all of its regional states, Addis Ababa had achieved an exceptional feat in contributing 59.2% in both sexes, 56.5% in males, and 87.2% in females to the total gain from infants alone. This demonstrates that efforts to lower the death rate among children under five were successful and had a substantial positive impact on the population's LEB. However, the elderly (60+) age group had a negative impact on LEB gains, and interventions for mortality reduction in this age group must also be worked on.

4. Conclusion

This study decomposed the life expectancies of Ethiopia and its regional states into direct and other effects age-wise to assess the relative contributions of age groups using Arriaga method over 1990-2019. The results disclosed that the other effect was the main positive contributor to changes in life expectancy in Ethiopia and in all of its regional states except in few extreme old age groups. Age-wise, infants and under five children positively contributed the most to the overall life expectancy transformation of Ethiopia and its regions consistently.

However, changes in mortality patterns in old ages contributed minimally, and in many cases negatively, to this overall trend. The other effect of mortality reductions in the age groups 65 years and above was negligible, while the direct effect, probably reflecting weak age specific medical interventions, was negative.

The results show that the elderly bear the brunt of life expectancy losses caused by disparities in the country's healthcare system, which could have been avoided with the support of appropriate age-specific interventions and beneficial public health initiatives.

Therefore, more investigation is necessary to pinpoint and resolve the issues limiting longevity in the oldest demographic groups.

Compliance with ethical standards

Disclosure of conflict of interest

The authors report that there are no competing interests to declare.

Data availability statement

Data available within the article and its supplementary materials are found in the sites given here https://journals.plos.org/globalpublichealth/article?id=10.1371/journal.pgph.0001471

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