DEVELOPING A SYSTEM OF MODEL LIFE TABLES FOR ETHIOPIA TO IMPROVE MORTALITY ANALYSIS: A BRASS' LOGIT APPROACH

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By: Hailay Mebrahtom Gebreegziabiher

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A PhD dissertation submitted to the Center for Population and Development, Institute of Population Studies of Mekelle University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in Population Studies

By:

Hailay Mebrahtom Gebreegziabiher

Supervisor: Professor Kinfe Abraha (PhD)

Co - Supervisor: Dr. Girmatsion Fisseha (PhD)

Mekelle University, Institute of Population Studies, Center for Population and Development

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Acronyms and Abbreviations

ASDR	Age Specific Death Rate
CDR	Crude Death Rate
CIESIN	Center for International Earth Science Information Network
CMR	Child Mortality Rate
CRVS	Civil Registration and Vital Statistics
DHS	Demographic and Health Survey
DSS	Demographic Surveillance System
EDHS	Ethiopian Demographic and Health Survey
GBD	Global Burden of Disease Study
HDSS	Health and Demographic Serveillance System
HMD	Human Mortality Database
IGME	United Nations Inter - Agency Group for Child Mortality Estimation
IMR	Infant Mortality Rate
INDEPTH	International Network for the continuous Demographic Evaluation of Population and their Health
IPoSt	Institute of Population Studies, Mekelle University, Tigray, Ethiopia
IUSSP	International Union for the Scientific Study of Population
LEB	Life Expectancy at Birth
LT	Life Table
MLT	Model Life Table
MORTPAK	Software Package for Mortality Measurement
U5MR	Under 5 Mortality Rate
UN	United Nations
US	United States
VRS	Vital Registration System
WHO	World Health Organization

List of Mathematical Notations

μ_x	Force of mortality at age x
m_x	Central death rate at age x
q_x	Probability of dying at age x
l_x	Probability of surviving at age x
e_0	Life expectancy at birth
e_x	Remaining life expectancy at age x
l_x^s	Probability of surviving at age x of a standard population
α	A measure of level of mortality
β	Shape of mortality pattern
γ_x	A correction factor for the upward or downward tilt of l_x
θ_x	Adjustment level of adult survivorship relative to the standard
ψ	Measure of curving the standard survival curve
χ	Measure of twisting the standard survival curve
ω	The oldest age considered beyond which no one survives
$p\,(a)$	The probability of surviving from birth to age a
i^{DE_x}	Direct Effect to LEB change on the age range x to $x+i$
DE_{x^+}	Direct Effect to LEB change on an open ended interval of age x and beyond
i^{IE_x}	Indirect Effect to LEB change on the age range x to $x+i$
i^{OE_x}	Other Effect to LEB change on the age range x to $x+i$
i^{I_x}	Interaction Effect to LEB change on the age range x to $x+i$

Abstract

Ethiopia does not a have a functional vital registration system for its mortality analysis and the model life tables that exist today have been criticized for not capturing mortality experiences of the country because they did not include mortality data from the developing world while created. This study, therefore, aims to construct a mortality analysis tool - a system of model life tables - that addresses the issue of mortality analysis in Ethiopia using Brass' logit approach. Infant Mortality Rates (IMRs) and Under - Five Mortality Rates (U5MRs) collected from the Global Burden of Disease Study (GBD) 2019 were combined with survivorship functions derived from Ethiopian empirical life tables from the UN World Population Prospects (WPP) 2022. By averaging thirty years of UN survivorship functions for Ethiopia and its regions, tailored standard survivorship functions were developed. The original l_x and the standard l_x^s survival functions were related via their logit transformations allowing for the computations of age specific mortality rates on the basis of the available data - IMRs and U5MRs.

Finally, a complete set of model based abridged life tables was generated by fitting the parametric model to the transformed survival functions.

The results indicate that the newly developed system of model life tables produced fairly comparable results to those found in the literature concluding its robustness and applicability. With a 7.7% increase in the likelihood of survival at birth, life expectancy increased by 16.977 years. IMRs and U5MRs decreased by 69.5% and 66% respectively and they differed from 12.88 deaths per 1000 live births in Addis Ababa to 43.94 in Benshangul - Gumuz; and from 28.16 deaths per 1000 live births in Addis Ababa to 77.32 in Benshangul - Gumuz respectively.

Even though Ethiopia's survival rate has improved over the previous three decades, more work is still demanded to lower the persistently high level of mortality, reach the global average life expectancy, and satisfy the Sustainable Development Goals set by the United Nations to the greatest extent viable.

Key words: Brass' logit model, Ethiopia, Life expectancy, Life table, Mortality

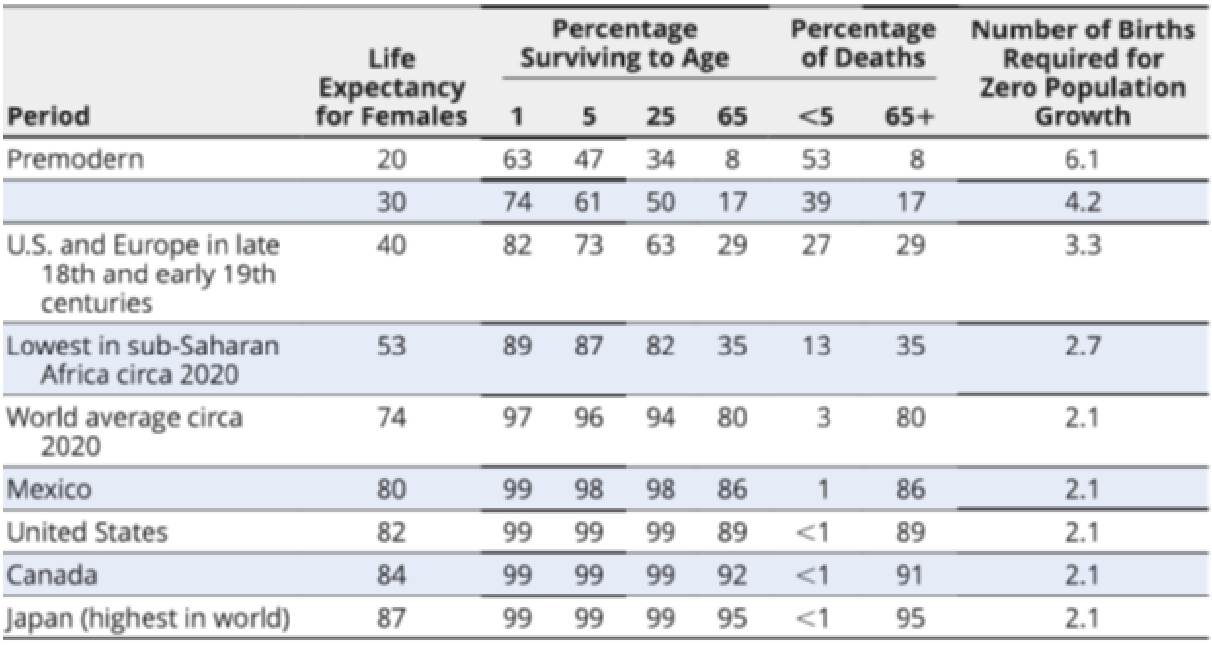
1 Introduction

1.1 Background of the Study

According to Pol and Thomas (2001), mortality refers to the measurement of death rates including its causes and characteristics of those who are dead. It is, therefore, the frequency of death occurrence and the its pace is determined by the frequency of its relevant event, death (Lundquist et al., 2014).

Studying mortality - the unavoidable end of life and its impact on individuals and society - holds immense significance for a number of reasons, including understanding the life cycle, improving health care and quality of life, understanding its ethical and social implications, facing our own mortality, planning and making informed decisions for the future, and ultimately leading more meaningful and purposeful lives in the face of our inevitable end. There have been attempts to measure and quantify mortality since antiquity, according to a variety of sources. According to Impagliazzo (2012), Babylonia was concerned about mortality as early as 3800 B.C. One of the earliest records of mortality dates to the Stone Age, when it was discovered from stone etchings that only 54% of people lived to be five years old. Curiously, however, only 3% of people lived to be seventy. According to various sources, the maximum age that people used to live during the Bronze age was not better than fifteen; on the other hand, reaching 65 was a rare event in pre - modern societies with only about 10% of them lived that long (Weeks, 2020). For much of human history, people were used to living a short life span usually twenty to thirty years (Weeks, 2020; Newbold, 2021). But after a few thousand years, improvements in housing, sanitation, nutrition, and health intervention programs led to a decline in mortality and an increase in life expectancy (Cutler et al., 2006; Bhusal and Khanal, 2022; Muttarak and Wilde, 2022). A table summarizing human mortality from pre - modern times to the present is provided below, along with an explanation of what longer life expectancies mean:

Table 1: Death Summary and the meaning of improvements in life expectancy



Period	Life Expectancy for Females	Percentage Surviving to Age				Percentage of Deaths		Number of Births Required for Zero Population Growth
		1	5	25	65	<5	65+	
Premodern	20	63	47	34	8	53	8	6.1
	30	74	61	50	17	39	17	4.2
U.S. and Europe in late 18th and early 19th centuries	40	82	73	63	29	27	29	3.3
Lowest in sub-Saharan Africa circa 2020	53	89	87	82	35	13	35	2.7
World average circa 2020	74	97	96	94	80	3	80	2.1
Mexico	80	99	98	98	86	1	86	2.1
United States	82	99	99	99	89	<1	89	2.1
Canada	84	99	99	99	92	<1	91	2.1
Japan (highest in world)	87	99	99	99	95	<1	95	2.1

Source: (Weeks, 2020), p.141.

Although people were curious about understanding and tracking death throughout their lives, it was only in the 17th century that they began studying it scientifically(Coale et al., 2013). Though death is inevitable to everyone, factors such as age, sex, race, occupation, and social standing influence its occurrences and its rates can tell much about the living standard and health care system of a population (Haupt et al., 2011).

Mortality is, therefore, worth of being studied and quantified in that it helps properly understand the overall wellbeing of the human race and act accordingly.

1.2 Measuring Mortality

In measuring mortality, we are attempting to estimate the force of mortality, the extent to which people are unable to live to their biological maximum age (Weeks, 2020). The most basic way to measure mortality is simply to count the number of deaths (Pol and Thomas, 2001). According to Rau (2013); Shryock et al. (1980); Yusuf et al. (2014), and others, the simplest and most widely used measure of mortality is the Crude Death Rate (CDR). This rate is the weighted average of age-specific death rates, where the weights are supplied by a population's proportionate age distribution (Preston and Guillot, 2001). Because of differences in age structure, crude death rates are not suitable for comparing the populations of several countries over time and in space (Gaimard, 2013). This disadvantage becomes apparent when the CDR is used as a common measure to compare the mortality experience of several communities (Chiang et al., 1978). Even death experiences of the same population cannot be well explained and nor can they be compared using Crude Death Rates (CDRs) at different periods of time that would bring about changes in the age structure.

Poston Jr and Bouvier (2010) note that because death varies so considerably with age, Age Specific Death Rates (ASDRs) and not Crude Death Rates should be used to compare the mortality experiences of countries with known differences in the age composition of their populations. Although age – specific death rates are preferable to crude death rates in comparing mortality experiences of different populations and even of the same population at different times with different age compositions because they are not influenced by the population's structure, no single rate but many of them have to be in use to depict the mortality experiences of the given population (Lundquist et al., 2014).

Rau (2013) then reminds that it will be convenient to look for a measure that avoids the limitations of both the crude and the specific death rates and present a single figure that is not influenced by the age-sex structure of the population and emphasizes that life expectancy at birth is such a measure. This measure is, therefore, explained through a statistical model called life table (Weeks, 2020).

1.3 Life Tables

An important extension of the tools of mortality analysis is the model called the life table; a life table is a statistical table describing the course of mortality and survivorship of a hypothetical birth cohort through the life cycle (Rau, 2013). It is the demographer's way of representing the effects of mortality (UN, 1990).

Two main systems of mortality measurements are in use; the first includes crude and age (and sex) specific death rates, and the second is derived from the life-table concept and its various functions (UN, 1955).

Mortality rates give an indication of the chances of survival of populations. However, as age-specific mortality rates show, the chances of survival vary from one age to another at different stages of the life span. In general terms, there are also differences in mortality between males and females. Therefore, crude deaths rates are poor indicators of survival and the length of life, on average, because of disparities in the age composition of different populations (Yusuf et al., 2014).

While crude death rate is the most readily available measure of mortality, it is generally a poor indicator of mortality as it does not take age structure into account (Srinivasan, 2011). Indeed, other than as a component of population growth, it is a measure to be avoided (Carmichael et al., 2016).

Etikan et al. (2017) indicated that life table is used to overcome these problems because it best expresses the pattern of human mortality and presents a detailed sketch of a population that systematically gets depleted through death at each age. Since the expectation of life at birth or its reciprocal, the life table death rate is the single measure of mortality derived from the age specific death rates of a population and since this measure does not depend upon the existing age distribution of the population, it is totally free from the weaknesses of the crude rate (UN, 1983).

Shryock et al. (1980) also explain that life tables are primarily used to calculate the population's mortality rate; one of their main advantages over other methods of calculating mortality is that they do not take into account an actual population's age distribution and do not demand the use of a reference population in order to make valid comparisons between the mortality rates of various populations. Moreover, Keyfitz et al. (2005) add that the life table answers questions concerning individuals: what is the probability that a man aged 30 will survive until he retires at 65? But it also answers questions concerning cohorts, groups of individuals born at the same time: what fraction of the births of this year will still be alive in the coming year, or how many of them will live to the age of retirement? Third, it answers population questions: if births were constant from year to year in a closed population of constant mortality, what fraction of the population would be 65 and over? Accordingly, the life table is couched in terms of probabilities for individuals, but for populations it is a deterministic model of mortality and survivorship.

It is, therefore, to exploit these advantages and at the same time to cope with the limitations of crude rates as measures of mortality that we are going to use the life table as a mortality analysis tool taking the advantage of it not being affected by age distributions in a sense that it will be a display of life expectancy at birth.

A life table is a statistical model which combines the mortality rates of a population at different ages into a single set-up (Srinivasan, 2011). It is also "a tabular display of life expectancy and the probability of dying at each age (or age - group) for a given population, according to the age-specific death rates prevailing at that time (Chander Shekhar, 2011).

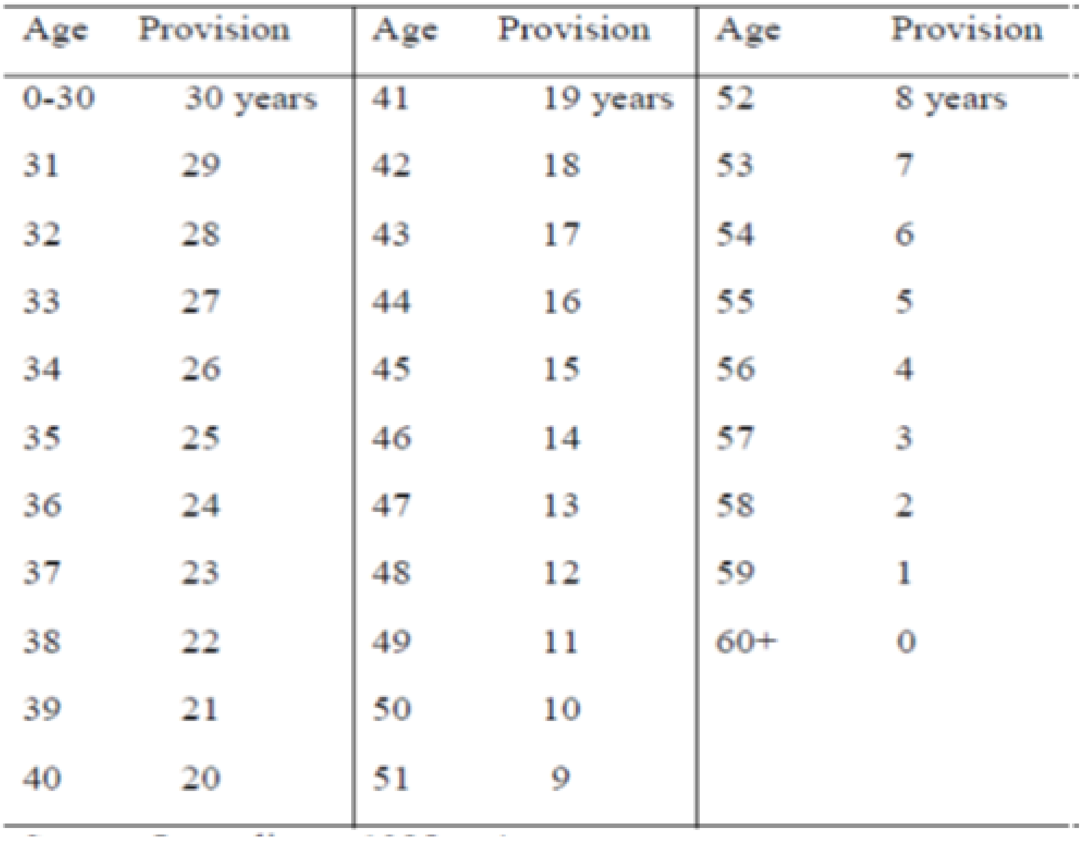
1.3.1 Historical development of Life Tables

It was the Roman Juris - consulate, Emilius Macer, who published a table of mortality or life expectancies in order to capitalize annuities about the year 225 A.D for the first time (Etikan et al., 2017; Impagliazzo, 2012). According to Impagliazzo (2012), this table was simple and arbitrary so that Macer sanctioned the use of another improved and more correct schedule whose authorship was credited to Ulpian; this later table was considered accurate since it reflected actual life expectancies.

In 1570, Girolamo Cardano estimated the first mathematical formula that related age x ,and life expectancy e, and said that the expectancy of life was a linear decreasing function of age $e = k(x - \omega)$, where ω is the final age. This formula was not however based on real mortality data. John Graunt in 1662 and Edmund Halley in 1693 developed sketches of what we call today life tables based on observed real mortality data (Impagliazzo, 2012; Coale et al., 2013; Preston and Guillot, 2001; Gaimard, 2013; Poston Jr and Bouvier, 2010). Bacaër (2011) summarizes the processes of the early developments and the contributions of the pioneers as:

The first life table had been published in London in 1662 in a book entitled Natural and Political Observations Made upon the Bills of Mortality. This book is considered as the founding text of statistics and demography and has strange particularities: people still wonder if it was written by John Graunt, a London merchant and author indicated on the book cover, or by his friend William Petty, one of the founders of the Royal Society. In any case the life table contained in the book tried to take advantage of the bulletins that had been regularly reporting the burials and baptisms in London since the beginning of the seventeenth century. These bulletins were mainly used to inform people on the recurrent epidemics of plague. This is the reason why they indicated the cause of death and not the age at which people died. To obtain a life table giving the chance of survival as a function of age, Graunt or Petty had to guess how different causes of death were related to age groups. So their life table could be subject to large errors. The book was nevertheless very successful, with five editions between 1662 and 1676. Several cities in Europe had started to publish bulletins similar to that of London. Bacaer also notes Halley published the first modern life table based on numerical data births and funerals at the city of Breslau.

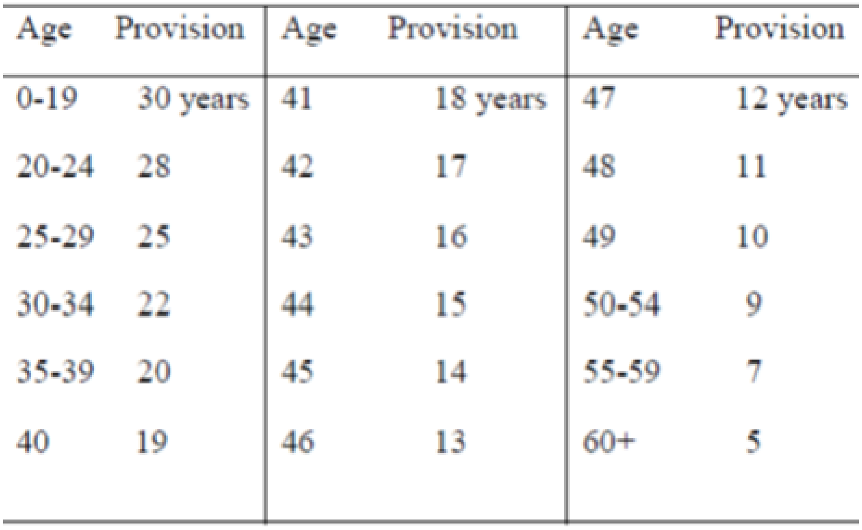
Table 2: Macer's first published table of mortality



Age	Provision	Age	Provision	Age	Provision
0-30	30 years	41	19 years	52	8 years
31	29	42	18	53	7
32	28	43	17	54	6
33	27	44	16	55	5
34	26	45	15	56	4
35	25	46	14	57	3
36	24	47	13	58	2
37	23	48	12	59	1
38	22	49	11	60+	0
39	21	50	10		
40	20	51	9		

Source: (Impagliazzo, 2012) , p.4.

Table 3: Ulpian's table



Age	Provision	Age	Provision	Age	Provision
0-19	30 years	41	18 years	47	12 years
20-24	28	42	17	48	11
25-29	25	43	16	49	10
30-34	22	44	15	50-54	9
35-39	20	45	14	55-59	7
40	19	46	13	60+	5

Source: (Impagliazzo, 2012) , p.4.

1.3.2 Types of Life Tables

Life tables differ in several ways, including the reference year of the table, the age detail, and the number of factors comprehended by the table (Rau, 2013).

Based on their reference years, life tables are categorized into two types as Cohort (Generation) life tables and Period (Current) life tables (Chander Shekhar, 2011).

1.3.3 Cohort (Generation) life tables

Cohort (Generation) life tables are constructed based on all the mortality experiences observed from the very beginning to the end of a real population, that is, until all the members of the population die (Shryock et al., 1980). These types of life tables are, however, not practical as it takes long time for their construction and consequently would be impossible to observe, study, and answer related questions of the population accordingly (Carmichael et al., 2016; Caselli et al., 2005). They may be of some historical interest, but are not useful in answering current life - expectancy questions (Chander Shekhar, 2011).

1.3.4 Period (Current) life tables

The period life tables assign to a hypothetical cohort the age-specific risks of dying observed in a given period (Caselli et al., 2005). They are derived from the age-specific death rates for one year, or an average of three or five years (Chander Shekhar, 2011). According to Shryock et al. (1980), these life tables do not represent the mortality experience of an actual cohort but they assume a hypothetical cohort that is subject to the age specific death rates observed in the particular period.

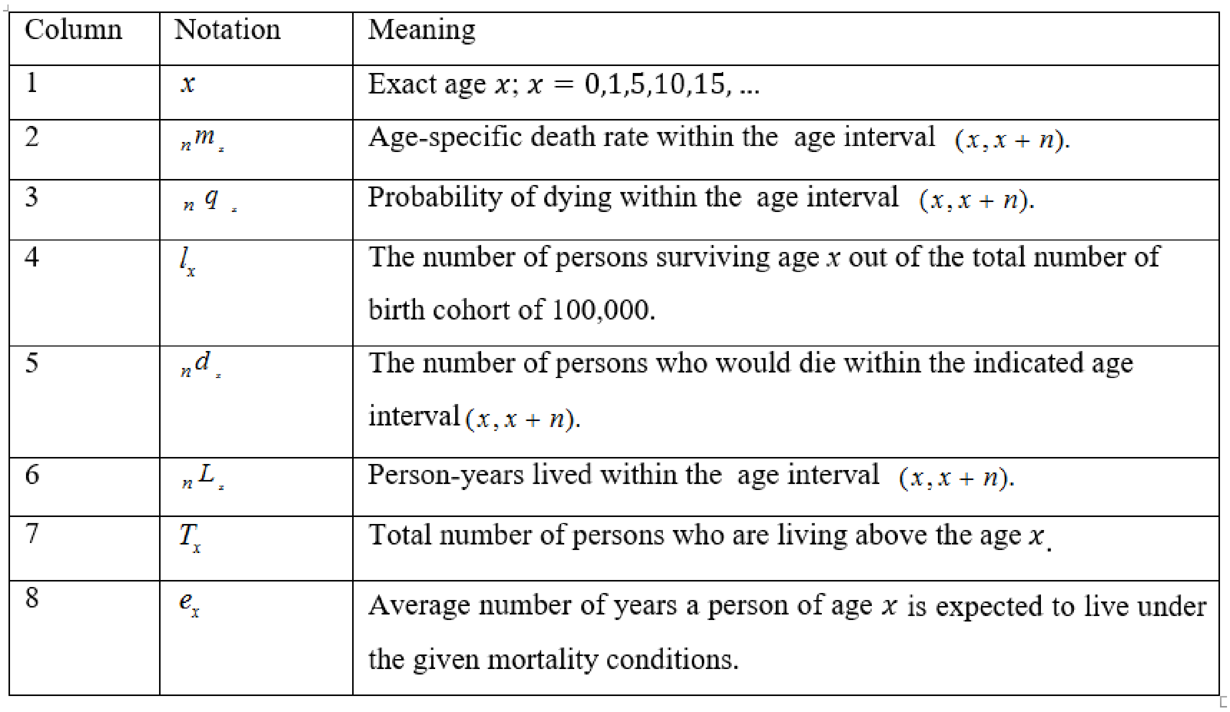
Referring to the length of the age interval used to present data for their construction, life tables are also classified into complete and abridged; complete life tables are constructed by single years of age while abridged life tables are constructed by age groups (Shryock et al., 1980; Carmichael et al., 2016; Chander Shekhar, 2011). Here in this work, by life table it would mean period abridged life table.

1.3.5 Components of a Life Table

The life table is a tool “depicting the lifetime mortality experience of a single cohort of newborn babies, who are subject to the age-specific mortality rates on which the table is based.” (Shryock et al., 1980). For simplicity of computations, the cohort of the new born babies of a given life table is assumed to be 100,000 (Shryock et al., 1980; Carmichael et al., 2016; Chander Shekhar, 2011).

The definition of each element or function of a period abridged table is summarized as follows:

Table 4: Column entries of a life table and their meanings



Column	Notation	Meaning
1	x	Exact age x; $x = 0,1,5,10,15,\ldots$
2	${}_nm_x$	Age-specific death rate within the age interval $(x, x+n)$.
3	${}_nq_x$	Probability of dying within the age interval $(x, x+n)$.
4	l_x	The number of persons surviving age x out of the total number of birth cohort of 100,000.
5	${}_nd_x$	The number of persons who would die within the indicated age interval $(x, x+n)$.
6	${}_nL_x$	Person-years lived within the age interval $(x, x+n)$.
7	T_x	Total number of persons who are living above the age x.
8	e_x	Average number of years a person of age x is expected to live under the given mortality conditions.

Source: Carmichael et al. (2016), p.134.

1.4 Statement of the Problem

It had been documented that roughly half the countries in the world did not have at least a partial vital registration system that tracks age - specific mortality while approximately 39% of all countries had some information on at least child mortality from which a complete set of age - specific mortality rates could be estimated using model life tables (Sharrow, 2013) ten years ago. Some countries in the developing world, particularly in Africa, do not yet have civil registration and vital statistics systems that function well enough to report accurately on either fertility or mortality (Clark, 2019). While it is intuitive that improvements have to be due through time, Africa has still been stuck in a stalemate. In the near time, it was found that the percentage of registered deaths ranged from 98% in WHO European region to only 10% in African region (WHO, 2020a) and specifically, none in Ethiopia (ECA, 2019).

Even the model life tables based on numerical data that have been created thus far, to substitute the role of vital registration systems, have been seriously criticized for only using mortality data from the developed world and thus neglecting to include and failing to accurately reflect the mortality experiences of Sub - Saharan Africa (Shryock et al., 1980; Rau, 2013; Preston and Guillot, 2001; INDEPTHNetwork, 2002; Ouedraogo, 2020; UN, 1983). Demographic Surveillance Systems (DSS) have been established with the goal of examining the mortality experiences of the populations of Sub - Saharan Africa longitudinal study sites (Caselli et al., 2005; INDEPTHNetwork, 2002).

There are at least 19 such research facilities in the area, and their data have been extremely helpful in determining age-specific mortality estimates as well as model life tables that demonstrate how the age distribution of mortality in Africa differs from that of the model life tables created by Coale and Demeny and also by the United Nations (INDEPTHNetwork, 2002; Sharrow, 2013).

Although the primary goal of the new model life table system created by the INDEPTH Network was to address issues with other model life tables' inclusivity of Sub - Saharan Africa, it also failed because the data it used were either insufficiently or entirely unrepresentative of the region. The life tables are based not on national populations but on sub - populations (Bracher, 2006) and as a result, they are no longer as representative of the populations for which they were designed. Data from DSS sites are frequently disregarded because they were only drawn from small areas, which is assumed to render the mortality measures that result neither accurate nor representative (INDEPTHNetwork, 2002). Both the region of Sub - Saharan Africa and the countries in which they are located are not adequately represented by the sites' locations, which are neither deliberately chosen to do so (Jamison et al., 2006).

The census, which counts the population by age and sex at a specific time point, the death registration, which records deaths by sex and age in a specific period, and the sample survey, which could gather data on both deaths and population but only covers a small portion of the population in a country, are the sources of empirical data used in estimating life tables (Li, 2015; WHO, 2020b). Annual death registrations, however, are either unavailable or unreliable for the majority of developing counties (Li et al., 2019).

While the most effective and efficient source of reliable vital statistics is a civil registration system that covers the whole population and that generates statistics on a continuing basis (WHO, 2013), African countries lack continuous, permanent and universal sources of mortality data, and face considerable challenges in providing reliable and essential data for tracking health trends and establishing sound identity management systems (Mr. Oliver Chinganya and Tesfaye., 2017).

Ethiopia, a country that does not have functioning civil registration and vital statistics system, CRVS, (ACS, 2009) and many of its records tend to be inconsistent, incomplete, and poorly recorded, resulting in low quality statistics (Central Statistical Agency Addis Ababa, 2016) relies exclusively on population censuses and sample surveys to generate basic vital statistics. Sample surveys can provide trustworthy indicators of mortality for some age groups when death is not a rare event or when the age group is wide enough, despite the fact that they frequently only collect data from a small portion of the population and therefore cannot produce life tables (Li, 2015; Li et al., 2019). Despite the fact that a model based on actual life tables would be acceptable, for most developing countries, actual life tables have not been calculated, and only model life tables exist (Caselli et al., 2005). Ethiopia is also one of those countries that do not produce life tables but use model life tables instead (WHO, 2020b). Consequently, there are two sides to the mortality analysis issue in Ethiopia. First, actual life tables cannot be produced due to the above mentioned limitations; second, Ethiopia as a member of the developing world is not represented by the model life tables that are in use today.

This study, therefore, aims to create a new system of model life tables for Ethiopia to address these issues of mortality analysis.

1.5 Rationale of the study

The focus of this study has been on the challenges that Ethiopia faces in obtaining accurate age specific mortality rates due to the absence of functional vital registration system and due to the fact that existing model life tables are inadequate to reflect the actual mortality experiences of its population.

Given these issues, the study intends to develop a system of Brass' logit model life tables for Ethiopia using a set of home based data and provide clear insights into age specific mortality rates thereby enabling the explanation of mortality trends and the calculations of life expectancies.

Subsequently, this study has been deemed necessary because it develops a mortality analysis tool that would contribute to closing the methodological and age specific mortality data gaps and proves itself locally relevant.

1.6 Review of the Literature

1.6.1 Model Life Tables

A trustworthy set of age - specific death rates gathered using direct statistical methods is needed for the computation in order to attempt to describe the human mortality experiences using life tables (Hu and Yu, 2014; Sharrow, 2013). However, the methods used to collect these types of data have a significant impact on them, and it is rarely found that they are accurate and reliable enough to serve the intended purpose (Sharrow, 2013; Rau, 2013; UN, 1983). They are also limited (Preston and Guillot, 2001; Yusuf et al., 2014; Caselli et al., 2005; Wachter, 2014). Demographic data are frequently inaccurate; they may be incomplete, as when there is a significant lack of participation in a census or survey, when vital events are not recorded, or when an administrative source only covers a portion of the population (Carmichael et al., 2016; Chander Shekhar, 2011). These restrictions serve as both the main argument for and the main flaw in attempts to create life tables that reflect widespread experience (Coale et al., 2013). Coale and Demeny also stress that the restrictions apply to the material's geographic and historical coverage in addition to its quality.

Observations show that despite numerous attempts to create life tables from empirical data from one country in order to explain the mortality experiences of a different country that is thought to be in a similar general state of mortality and survival conditions, the efforts have not been successful. This may be due to the fact that mortality determinants behave differently depending on the population and even the age strata within the same population.

The analysis of mortality in developing populations, for which reliable mortality data were frequently lacking, was a primary initial motivation for the development of model life tables (Carmichael et al., 2016). Model life tables summarize regularities in how mortality varies by age in human populations and they allow the estimation of arrays of age - specific mortality rates or probabilities on the basis of only one or two mortality indicators chosen as entry parameters (Guillot et al., 2022).

In this case, it makes sense to look for an average mortality pattern that is largely devoid of individual variations and roughly but generally reflects a particular level of general mortality (UN, 1955). It is for this purpose that model life tables are developed. The model life tables' goal is to replace unknown aspects of mortality in populations where there is a dearth of reliable or adequate mortality data (Hannerz, 2001) because they are based on at least two shared assumptions about human life tables: first, that there is a general path of mortality evolution and that real populations' life tables follow this path closely; and second, that human populations' life tables are remarkably similar (Vassin, 1994).

In order to estimate death rates when accurate and reliable data are lacking, are scarce, or are flawed, model life tables—which describe typical age patterns of human mortality—are created (Coale et al., 2013; Rau, 2013; Carmichael et al., 2016; Keyfitz et al., 2005; Hu and Yu, 2014; Murray et al., 2000). Using the scant information currently available, these models take advantage of the strong positive correlation between mortality levels at various ages to predict mortality levels for all ages (Preston and Guillot, 2001; Hu and Yu, 2014). As a result, the fundamental goal in the creation of any model life table is to construct a system that gives schedules of mortality by sex and age, defined by a small number of parameters that capture the level as well as the age pattern of mortality (Murray et al., 2000).

Model life tables are exactly like real life tables, with the exception that they don't pertain to any specific location or time (Srinivasan, 2011).

1.6.2 Different Models of Age Patterns of Mortality

Preston and Guillot (2001) state that model age patterns come in one of three options: Mathematical, empirical, and the combination of the two - relational.

A mortality law is a mathematical expression that describes mortality as a function of age (Hannerz, 2001). Although the search for a "law of mortality" that describes the characteristic age pattern of death observed within populations of sexually reproducing organisms dates back to the pioneering work of the British actuary Benjamin Gomperz (Carnes et al., 1996), DeMoivre first proposed an arithmetic progression law for the life table's survivorship function (Spain, 2018).

In 1825, Gompertz cited by (INDEPTHNetwork, 2004) criticized this law, arguing that after a certain age, the survivorship function follows rather a geometric progression law and suggested representing the force of mortality as an exponential function of age, $\mu(x) = \alpha e^{\beta x}$, which gives $ln(\mu(x)) = ln(\alpha) + \beta x$. This equation tells that the logarithm of the death rate is a linear function of age. Such a relationship, however, fails to model the overall mortality because it merely is “underlying” mortality, that is, mortality that does not encompass deaths from accidents and infectious diseases (Preston and Guillot, 2001; Sharrow, 2013; Ghana et al., 2004a).

In 1860, Makeham Cited by (Preston and Guillot, 2001) and by (Sharrow, 2013) added a constant to Gompertz’s model to include the other causes of mortality $\mu(x) = \alpha e^{\beta x} + \gamma$. This model also overpredicts mortality because the logarithm of the force of mortality is also a linear function of age with this model, but at older ages death rates frequently rise at a decreasing rate (Preston and Guillot, 2001).

It has been impossible to completely capture the age variations in mortality experiences of the human population using only mathematical models, despite the development of numerous other models that are similar but with some additional improvements and adjustments. Due to the unavoidably high number of parameters required to describe the age pattern of mortality, many mathematical models can only adequately describe a small portion of the age range (Sharrow, 2013). Additionally, the previously mentioned mathematical models, along with a great number of others, failed to accomplish their objectives because, despite mortality being stochastic and continuously evolving, these models attempted to describe it at a fixed point in time (Spain, 2018). In general, it is impracticable to capture all of the potential shapes in a single law for all populations because the shape of mortality risk across the age spectrum is determined by an epidemiological profile (Sharrow, 2013).

Shryock et al. (1980) point out that different approaches to model construction have been used because it is challenging to find straightforward mathematical functions to represent the entire life span. One of these is the development of empirically based models, in which typical patterns are drawn from a set of tables from real - world data.

There are many different types of model life tables, but the most popular ones are listed below:

1. The United Nations Model Life Tables
2. The Coale - Demeny Model Life Tables
3. The United Nations Model Life Tables for Developing Countries
4. The Lederman’s System of Life tables

5. The Brass Logit System of Model Life Tables

The data underlying these model Life tables vary in the range of human experience they encompass (Murray et al., 2000).

1.6.3 The United Nations Model Life Tables

Empirical life tables were proposed in the 1950s to address the lack of trustworthy data sources for mortality estimation in the majority of developing countries (Ouedraogo, 2020). Based on a collection of 158 tables for each sex, the Population Branch of the United Nations published a series of model life tables in 1955 (Coale et al., 2013). This was a relatively simple one-parameter system indexed on infant mortality levels (Murray et al., 2003). The key assumption was that the level of mortality in any age group was closely correlated with the level of mortality in an adjacent age group (Shryock et al., 1980).

In this model (UN, 1955), it was assumed that the likelihood of passing away within a specific age range was a quadratic function of the likelihood of passing away within the previous age range. By repeatedly regressing on the data corresponding to the 158 life tables, the coefficients were calculated.

According to (UN, 1955; Coale et al., 2013; Rau, 2013; Preston, 2000; Sharrow, 2013; INDEPTHNetwork, 2004), the coefficients were then used to generate the actual life table by starting from a specified level of infant mortality; by continuously using the regressions, all the probabilities of dying were calculated. Knowledge of only one mortality parameter such as infant mortality enables to determine a complete life table and thus, this model is said to be a single parameter system (Murray et al., 2000; INDEPTHNetwork, 2004).

Given the issue of considering this system of model life tables as the first brilliant attempt to capture all the mortality experiences of the human race and model them accordingly, it has gone far to do with being a base knowledge for explanations and for further developments of other models. Yet, some limitations have been observed of it.

Murray et al. (2000) states that there are three major criticisms of the original one-parameter UN model life tables. First, the fact that they are one-parameter systems makes them relatively inflexible. Such a single parameter model cannot adequately describe the complex mortality patterns available. In some cases, they have failed to describe adequately life tables that were known to be accurate. Second, because the estimate of mortality in each age group is ultimately linked to the infant mortality rate through the chaining process, measurement errors are easily accentuated. The third criticism concerns the poverty of developing country life tables in the original design of the model. Additionally, some of the empirical tables included were of dubious quality. Preston and Guillot (2001) also explain that the life tables used to construct the models were not subjected to thorough data quality check.

1.6.4 The Coale - Demeny Model Life Tables

Coale et al. (2013) produced a system of model life tables based on 192 empirical life tables. By creating various sets of models that took into account regional variations in the relationship between the level and the age pattern of mortality, they improved upon the United Nations system by using a larger, better-screened empirical basis (Preston and Guillot, 2001).

After 326 life tables were collected for each sex based on age specific death rates over different geographical locations and periods of time in the process of construction, the values of the probabilities of dying at each age were ordered from highest to lowest at each age; by putting together mortality rates that had got the same rank, preliminary model tables were formed and consequently deviations of individual life tables from the preliminary tables were examined (Preston and Guillot, 2001; Coale et al., 2013). Of the original 326, those that exhibited large deviations from the norm were dropped; only life tables derived from registration data and from the complete enumeration of the populations to which they refer were included (Rau, 2013).

Coale et al. (2013) emphasize that because the pattern of deviations is often similar among life tables expressing the mortality of the same population at different times, and because several groups of geographically linked populations exhibited similar patterns of deviations, they were led to the construction of four separate families of model tables namely North, South, East, and West according to the geographical location of many of the countries that constituted each family.

According to Coale et al. (2013); Rau (2013); Preston and Guillot (2001); INDEPTHNetwork (2004), the four families are characterized as follows: The North family model which exhibits low infant mortality, relatively high child mortality, and low mortality after age fifty was derived from a total of nine tables: four were from Sweden during 1851 - 1890, four from Norway during 1856 - 1880, and one from Iceland during 1941 - 1950. The South family model is characterized by high under age five mortality, low adult mortality of ages 40 - 60, and high old age mortality of over 65. It was based on five tables for Italy during 1876 - 1910, eight tables for Portugal during 1919 - 1958, one table for Sicily in 1951, three tables for South Italy during 1921 - 1957, and five tables for Spain during 1900 - 1940, which sum up to twenty two tables. The East family model with characteristics of high infant mortality and very high mortality at ages beyond fifty was developed from a total of thirty one tables from Germany, Austria, Poland, Czechoslovakia, and from North and Central Italy. The West family model was developed from one hundred thirty life tables and is considered to represent the most general pattern of mortality because it was derived from the largest number and the broadest variety of cases.

This model, like all model life table systems, cannot fit mortality conditions that lie outside the scope of the original data, which includes low child mortality and high adult mortality (Sharrow, 2013). Preston and Guillot (2001) also explain that the result is sensitive to the choice of a regional model. The Coale and Demeny tables are not entirely suitable for demographic research in developing countries because recent evidence suggests that age patterns of mortality in many developing countries differ systematically from those of historical European experience (UN, 1982). Additionally, the system's flexibility is limited by the discrete nature of one of its parameters - the family - especially when compared to other systems where both parameters are continuous (Murray et al., 2000).

1.6.5 The United Nations Model Life Table Systems for Developing Countries

Similar to Coale and Demeny, the United Nations released an updated set of model life tables in 1981 in an effort to build regional models using data from developing nations deemed suitable for inclusion in the empirical dataset (Murray et al., 2003). Coale and Demeny's model life tables, which are currently the most widely used, were almost entirely based on European populations; recent evidence that age patterns of death may differ systematically from those of Coale and Demeny's four groups suggests the need for a new set of model life tables that will be more applicable to demographic analysis in developing countries (UN, 1982).

Five mortality patterns named Latin American, Chilean, South Asian, far Eastern, and General emerged when the analysis was carried out on 286 original tables that finally came into only 72. The average of all the other families resulted into the General model.

This model shares the limitations of the former United Nations model life tables. Their main criticism is that the strict selection criteria reduced the underlying set of empirical life tables from 286 retaining only 72; and this relatively small number of the tables limits the applicability of the models to other populations (Murray et al., 2003). While Murray et al. (2000) pass judgment on these models that they are outdated, Preston and Guillot (2001) also adds that many of the tables were of poor quality.

1.6.6 The Lederman System of Model Life Tables

This system is based on a factor analysis of some 157 empirical tables (Murray et al., 2000; Rau, 2013). When analysis was done to determine and to explain variations in mortality among the life tables, five factors were found out. They were general mortality level, child-adult mortality ratio, old age mortality, under-five mortality, and male-female mortality differences in the ages of 5-70 years.

As to Murray et al. (2000), the main criticism of this model is its complexity that impedes its use in the developing countries; again, as the independent variables that were used to derive the model refer to parameters obtained from data on both sexes combined, male-female mortality ratio is to be accepted as is embodied in the model no matter how the differences behave. These models are still not free from the limitations of the other empirical based model life tables in their representations. A limitation to these models is that they are almost exclusively empirically based on the experiences of developed countries (Preston and Guillot, 2001).

1.6.7 The Brass' Logit Model Life Table System

The very common limitation of all the empirically based model life tables is that they fail to represent all the possible human mortality experiences because they depend upon the nature of the data that each of them were generated from (UN, 1983; Murray et al., 2000). Due to this restrictive nature of the data involved in the construction of model life tables, the mortality pattern of some countries may not fit very well into them (Shryock et al., 1980). To solve this problem, Brass in 1971 (Brass, 1971; Dodd et al., 2018; Murray et al., 2000) proposed a two - parameter logit system to construct model life tables. This is a relational model that combines features of both the tabular approach of model life tables and the mathematical approach (Preston and Guillot, 2001). In this regard, the Brass logit system offers considerable advantages by being essentially independent of historical data;

such flexibility could be harnessed in extending its application to situations of extreme data poverty, specifically in Africa and in parts of South East Asia (Murray et al., 2000). It is an expression that relates mortality in one population to that in others (Hannerz, 2001).

This relational model is built on the basis that two different age patterns of mortality can be related by linear transformations of the logits of their respective survivorship probabilities (Murray et al., 2000). This is because the survivorship probability indicator is a decremental index over age so that the age-specific values cannot vary independently (Bergeron-Boucher et al., 2019).

Given any two series of survivorship probability values l_x and l_x^s, where l_x^s stands for the survivorship value of the standard life table, constants α and β can be determined from the equation

$$logit(l_x) = \alpha + \beta logit(l_x^s) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

, where the first parameter α is a measure of the variations of mortality levels of the standard and the observed populations; and the second parameter β is the measure of mortality ratio of children to adults. Because $logit(l_x) = \frac{1}{2}ln\left(\frac{1-l_x}{l_x}\right)$, the above equation can be written as

$$\frac{1}{2}ln\left(\frac{1-l_x}{l_x}\right) = \alpha + \frac{1}{2}\beta ln\left(\frac{1-l_x^s}{l_x^s}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (2).$$

Again, if Y_x and Y_x^s represent $logit(l_x)$ and $logit(l_x^s)$ respectively, then

$$Y_x = \alpha + \beta Y_x^s \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3).$$

If a single life table that is said to be standard and that satisfies equation (2) above exists, one can generate as many number of life tables as one wishes by varying the ordered pair values of α and β (Murray et al., 2003). Once a standard life table is selected and values for the parameters, α and β are calculated, a set of life tables can be generated (Rau, 2013) by obtaining another l_x series for any series of l_x^s values defining the standard life table

(Moultrie et al., 2013).

1.7 Methods of constructing the Brass' Relational Model Life Tables

Rau (2013) adds that the main procedures for creating model life tables based on a standard life table are as follows:

1. Calculate $logit(l_x^s) = \frac{1}{2} ln \left(\frac{1 - l_x^s}{l_x^s} \right)$ from the standard life table .... (4)
2. Calculate
   $logit(l_x) = \frac{1}{2} ln \left(\frac{1 - l_x}{l_x} \right)$ from the life table for the study population .... (5)
3. Determine the values of α and β in equation (3) by inserting values of Y_x^s and Y_x from the standard table and from the various life tables in the set.
4. Compute values of Y_x with the estimated values of α and β in the model equation by inserting values of l_x^s .
5. Transform the computed values of Y_x into l_x values using the following equation:
   $l_x = \frac{1}{1 + exp \left(2 \left(\alpha + \beta \left(\frac{1}{2} ln \left(\frac{1 - l_x^s}{l_x^s} \right) \right) \right) \right)}$ .... (6)

According to (Preston and Guillot, 2001), the appropriateness of the standard chosen for the population in question and the appropriateness of the rule that specifies how mortality in the standard is related to mortality in other populations belonging to the same "family" are the two separate features of relational models that determine their success.

1.7.1 Advantages of Brass' relational model over the other model life tables

The approach of this model makes it possible to avoid generating life tables directly from an empirical age pattern of mortality; In addition, if accurate information on child mortality is available, it allows for better adjustment of the overall mortality level compared to the standard (Ouedraogo, 2020). It also gives a greater degree of flexibility in that it enables to relate two different life tables as far as they share the same "family". Model Life Tables derived by Brass' method are also expected to be of better fit than national life tables because they are based on averages (Vassin, 1994).

1.7.2 Choosing the standard Model Life Table

Since this model is used to generate life tables from a reference table known as the standard, something needs to be said about how the standard is chosen. By a standard life table, we mean a table that contains mortality experiences of populations that resemble those whom the new life tables are to be developed for, in their overall social status. There has, however, been no systematic way of choosing a "special" standard up till now (Zaba, 1979; Murray et al., 2000). Therefore, one can potentially choose as a standard any life table that seems appropriate (Moultrie et al., 2013; Rau, 2013).

1.7.3 Effects of varying the parameters α and β

These parameters of the Brass' relational model life table α and β respectively measure the level and the shape of the produced model life table (Zaba, 1979; ZABA and PAES, 1995; Brass, 1971). If β is to be kept constant and α is made to vary, then the life tables to be produced would essentially be the same in shapes as the life table used to generate them but whose overall levels would change (UN, 1983). Moreover, the survival curves form a set of non-overlapping curves (Shryock et al., 1980). Nonetheless, if α is kept constant and β is made to vary, the resulting life tables do not show the same shape as the original one (Zaba, 1979; Preston, 2000); and also the survival curves form a set of intersecting curves (Rau, 2013).

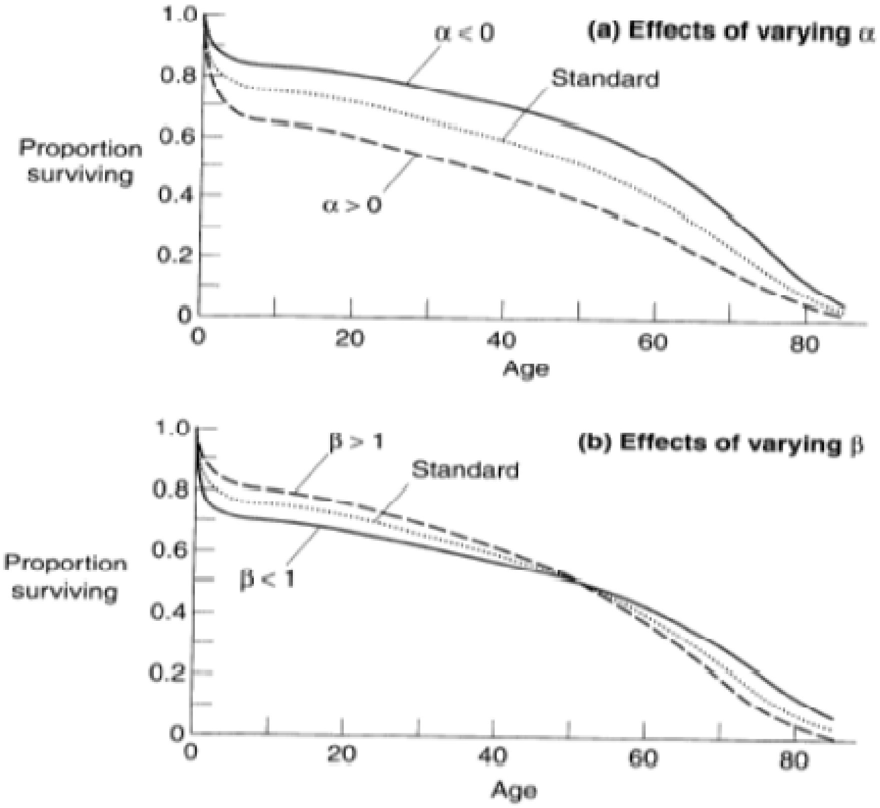


Figure 1: Effects of varying the parameters α and β in Brass' Logit Model, Preston, p271.

The parameter α allows one to vary the 'level' of the standard, β allows variation of the 'slope' of the standard -i.e., it controls the relationship between child and adult mortality (Zaba, 1979).

A higher value of α implies higher mortality, i.e., a lower probability of surviving to any age x as well as a lower probability of surviving between any two ages x and y (Preston and Guillot, 2001).

Positive α means the level of mortality is higher than the standard (Carmichael et al., 2016; IUSSP, 2020); negative α is the reverse (Wachter, 2014). Changes in β have a different impact at different ages: a higher β increases the slope of the survivorship function, i.e., accelerates the decline with age (Preston and Guillot, 2001).

It is remembered that Brass' formula of relating two life tables where one of them is a standard is given by $logit\,(l_x) = \alpha + \beta logit\,(l_x^s)$, and thus the model serves as a standard if $(\alpha, \beta) = (0, 1)$ (Brass, 1971). Brass (1974) has proven if Y_x^s is calculated as an overall average of life tables, such that the central value of β is 1, it is found that the central value remains 1 at different levels of mortality as α varies.

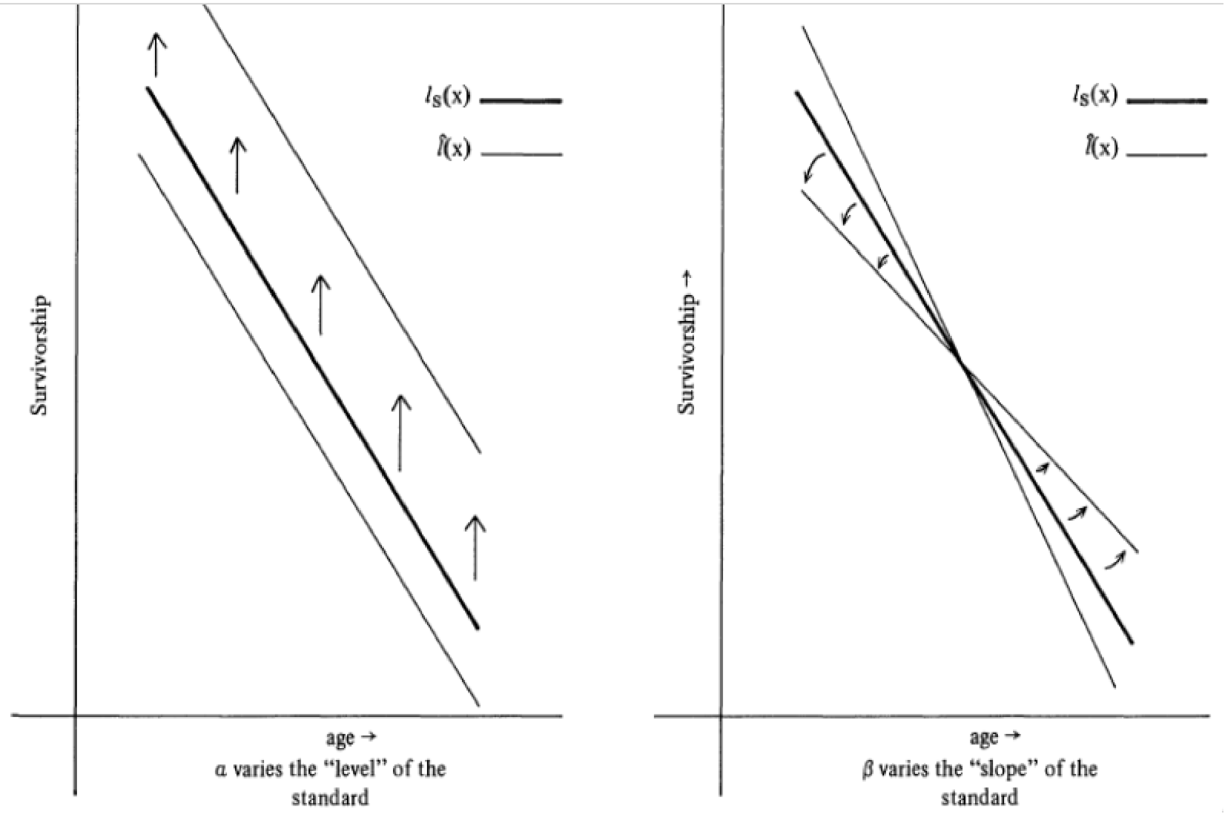


Figure 2: Effects of varying the parameters α and β in Brass' Logit Model, Basia Zaba, p81.

1.7.4 Criticisms of Brass' logit Model Life Table System

Despite all of the benefits that Brass' logit model has over the other model life tables, it is not without flaws. The relationship between two logit survivorship functions is not always linear in this model, and deviations from linearity appear to be especially large when the observed mortality of a population deviates significantly from the standard. Therefore, the logit model does not adequately represent the complexity of variations in levels and age patterns of mortality (Murray et al., 2000). This observation, then, led others to modify the model by incorporating additional parameters that allow for bends in the survivorship function (Zaba, 1979; Ewbank et al., 1983). Zaba Adds fits from the Brass Logit System generally compare well to fits from other sources, such as the Coale - Demeny regional model life tables. However, there are sometimes noticeable differences between the observed and the fitted values at the extremes of the age distribution, such as ages under 5 and over 70.

To correct these discrepancies, (Zaba, 1979) added two more parameters ψ and χ such that

$logit[l\,(x)] = \alpha + \beta logit[l^s\,(x) + \psi k\,(x)] + \chi t\,(x)]$ where $l^s(x)$ are the survivorship values for age x of the general standard, and $k(x)$ and $t(x)$ are schedules of deviations from this general standard altering mortality patterns in infancy and in old age. The shapes of the functions $k(x)$ and $t(x)$ of Zaba's modified model introduce variety into the shape of the standard curve at the youngest and at the oldest ages (Ewbank et al., 1983).

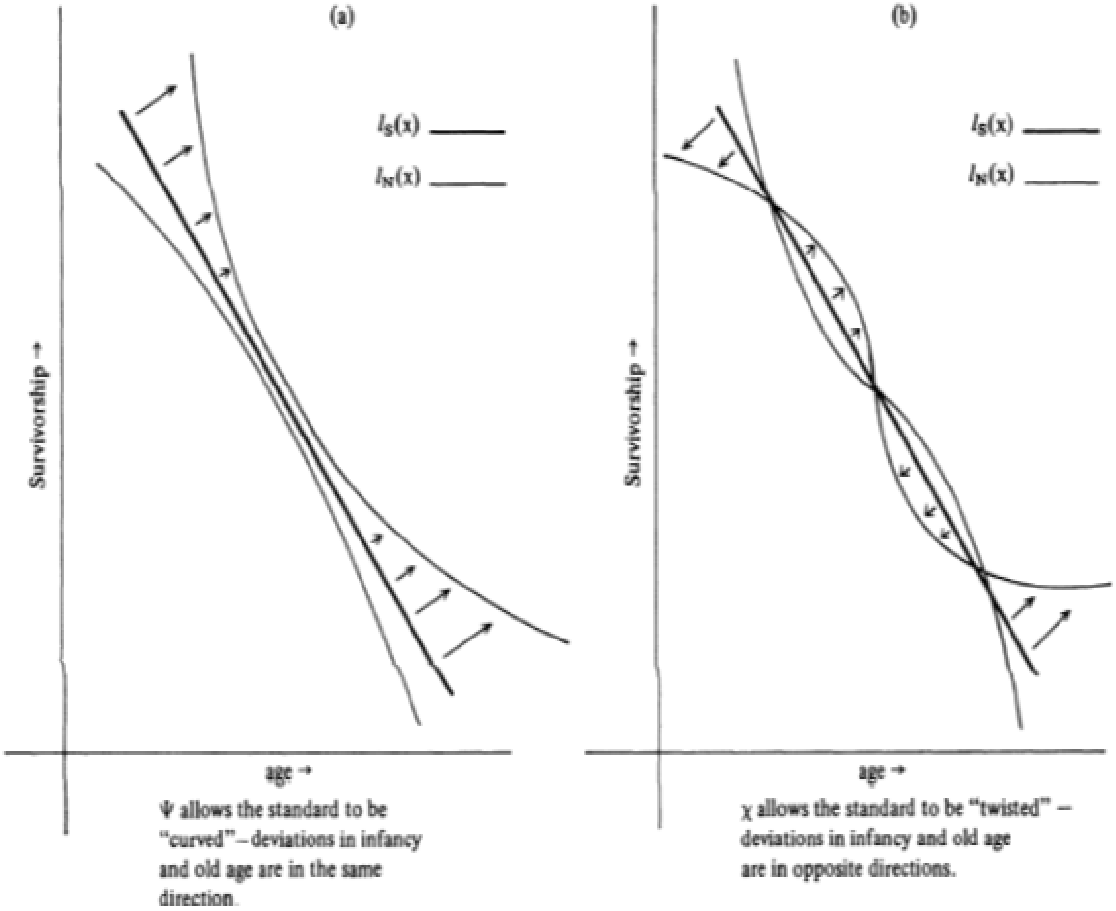


Figure 3: The effects of the third and the fourth parameters on the standard, Baisa Zaba, p86.

Nevertheless, this and the other four parameter modifications are of limited practical use because the additional parameters are difficult to estimate empirically and they complicate the application of the models (IUSSP, 2020; Murray et al., 2003). Furthermore, elaborate models requiring many constants to be determined are useless (Brass, 1971).

1.8 The Modified Brass' logit Model Life Table System

Since the generation of Brass' relational model life table system, modifications (Zaba, 1979; Ewbank et al., 1983) have been attempted to correct the problem of its linearity in connecting survivorship functions. However, of all the modifications, the one developed by (Murray et al., 2003) is found to be relatively simple extension of the Brass' logit system and is adopted by the United Nations (Hu and Yu, 2014; IUSSP, 2020). They state that deviations from linearity in the original Brass' model are linked to the relative difference between the mortality rate of the standard and the mortality rate of the actual life table being estimated; based on this observation, they proposed the following modified alternative logit transformation based on a single global standard life table by incorporating two additional age – specific correction factors γ_x and θ_x based on mortality levels among children and adults relative to the standard,

$$\Gamma(l_x) = logit(l_x) + \gamma_x[1 - \left(\frac{logit(l_5)}{logit(l_5^s)}\right)] + \theta_x[1 - \frac{logit(l_{60})}{logit(l_{60}^s)}]$$

where l_x^s, γ_x and θ_x are standard functions that are age and sex specific but invariant across populations (Murray et al., 2003).

This study used the original version of Brass' logit method rather than the modified one because data on IMRs and U5MRs were easily accessible and flactuations at very old ages were not a top priority.

1.9 Comparison of the original and the modified Brass'logit models

Numerous authors have noted that the original Brass' logit model life table system exhibits disparities in capturing the overall mortality trend of populations because the logit transformation's linearity is not due specifically at the extreme ends of the age distribution schedule (Ewbank et al., 1983; Zaba, 1979; UN, 1962; John Hobcraft and Preston, 1982; Preston and Guillot, 2001; Murray et al., 2003). Even though these authors had attempted to address the issues by adding new parameters and functions to the original Brass' logit model, only the one created by (Murray et al., 2003) was found to be promising.

Tests of predictive validity reveal that this new modified system predicts age - specific mortality rates that are 15 to 40% lower than those indicated by the original Brass' method (Murray et al., 2003).

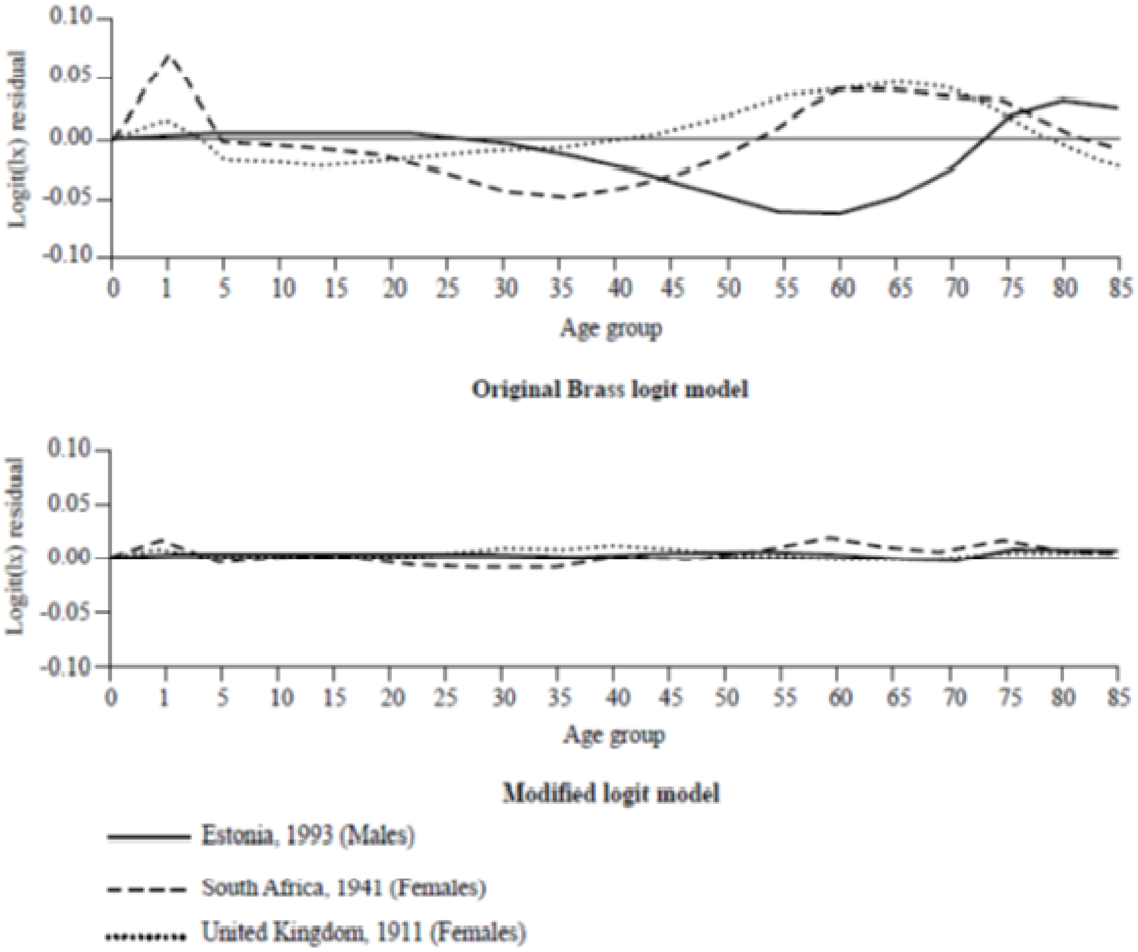


Figure 4: Deviations between observed and predicted logits by age, selected countries, Murray et al., p173.

1.10 Dissertation theoretical and conceptual Perspectives

Beyond their use in demographic accounting, mortality data are significant markers of socioeconomic and health advancement; they also assist in determining a nation's current demographic state and its immediate demographic future (UN, 1982). Mortality was the main obstacle facing the medical professions, and the main goal of social legislation and public health professionals, among many other organizations and institutions, was to prevent early death (Chiang et al., 1978).

Based on death statistics, there exist a multitude of measures of mortality that differ in terms of the aspect of mortality they describe, the level of elaboration or refinement, whether they are specific or summary measures, and whether they are measures of mortality in and of themselves or just measures related to mortality (Shryock et al., 1980). The crude death rate is the most basic metric, but its usefulness is limited because it lumps all deaths together, even though not every person has the same risk of dying (Pol and Thomas, 2001) and therefore, this measure is generally a poor indicator of mortality as it does not take age structure into account (Srinivasan, 2011).

Rather than just looking at the overall number of deaths and the crude death rate, we also need to take into account the range of age-specific numbers and rates for analytical purposes (Rau, 2013). This is due to the fact that age-specific death rates are more accurate indicators of mortality since death varies with age so greatly (Poston Jr and Bouvier, 2010).

Mortality modeling was first limited to attempts to forecast the risk of dying by age using a mathematical function, and it was primarily utilized in the actuarial sciences (INDEPTH-Network, 2002; Ghana et al., 2004b). The mortality curve's shape indicates that a variety of parameters would be needed to represent the risks of death at all ages (Preston and Guillot, 2001). The history of mathematical models is further complicated by the significant complexity with which analysts tried to develop a single law of mortality to capture the entirety of human mortality experiences (Sharrow, 2013).

People such as Girolamo Cardano in 1570 as in (Impagliazzo, 2012); john Graunt in 1662, Edmond Halley in 1693, Deparcieux in 1746, Gompertz in 1865, Makeham in 1860, Perks in 1932 in (Preston and Guillot, 2001); Siler in 1979, Heligman and Pollard in 1980 in (Sharrow, 2013) a few among many others were the pioneers who exerted great effort to develop mathematical models that could explain the overall mortality experiences of populations. However, because different causes of death cause variations in the age pattern of mortality in different populations, it is challenging to develop and identify a valid law of mortality that is applicable to different populations (Preston and Guillot, 2001; INDEPTHNetwork, 2002).

This challenge has led to a shift in mortality modeling toward empirical models known as Model Life Tables (INDEPTHNetwork, 2002; Shryock et al., 1980; Preston and Guillot, 2001).

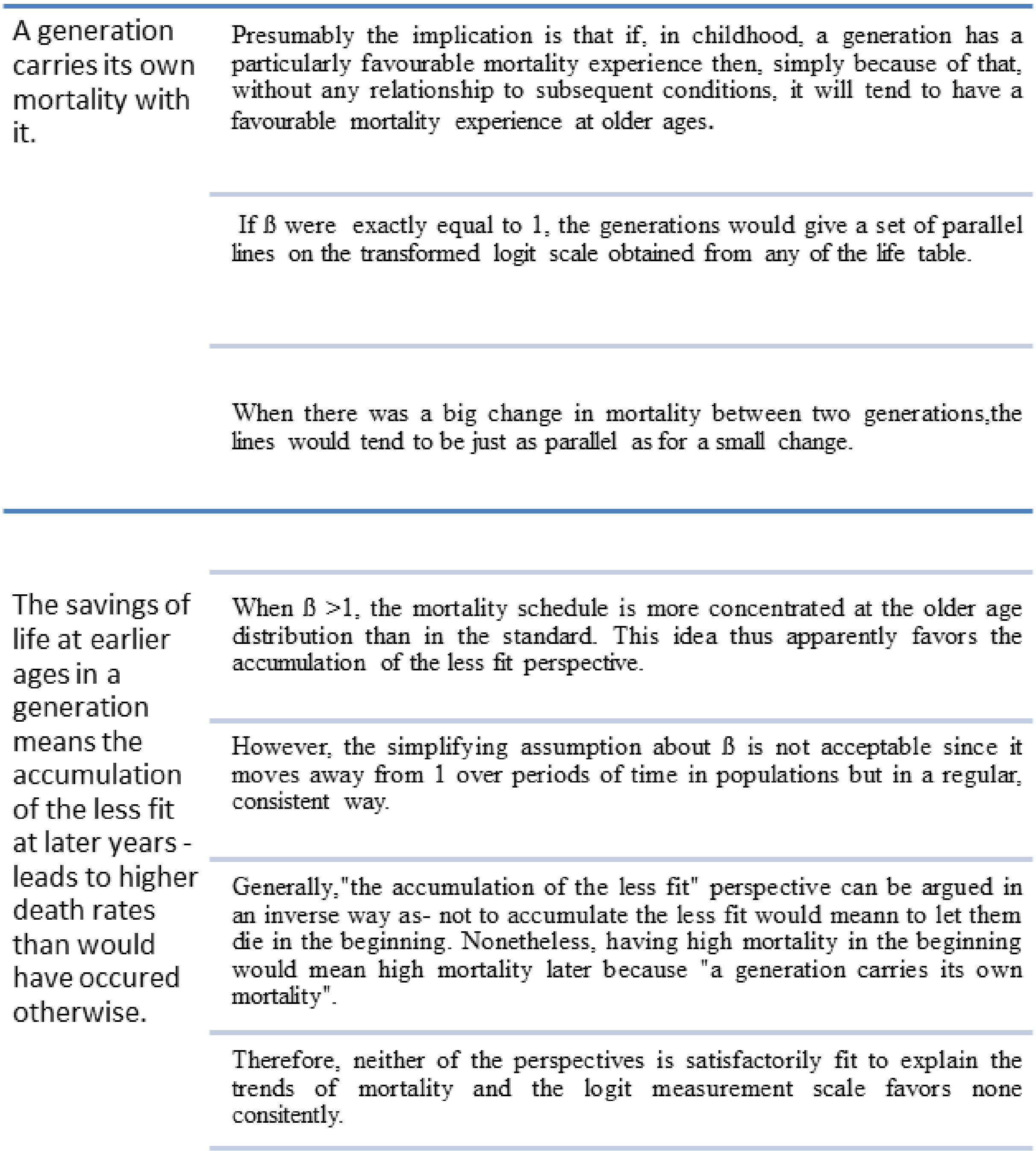
Model life tables are inevitably meant to be used, primarily in circumstances in which trustworthy direct information is unavailable (Coale et al., 2013; Carmichael et al., 2016), where little is known (Murray et al., 2000, 2003; Brass, 1971), or when the data are defective (Moultrie et al., 2013). All of these models were regrettably built using data from the developed world, where mortality data is relatively proper and complete. As a result, they are unable to accurately represent the experiences of human mortality in many developing nations, even though their goal was to capture the overall mortality experiences of populations with incomplete, defective, and unreliable mortality data.

William Brass developed a slightly different type of system in 1971 to address this issue. In this system, an empirically expressed relationship between mortality and age is transformed into other relations that can function as a set of model life tables by means of an explicit mathematical function (Brass, 1974).

Others altered Brass' model by adding extra parameters that allow for bends in the survivorship function in response to concerns about the linearity of the relationship between two logit survivorship functions (Zaba, 1979; Ewbank et al., 1983).

Thus, a system of model life tables for Ethiopia has been generated here using the original version of Brass' logit system.

Conflicting perspectives of mortality



A generation carries its own mortality with it.

Presumably the implication is that if, in childhood, a generation has a particularly favourable mortality experience then, simply because of that, without any relationship to subsequent conditions, it will tend to have a favourable mortality experience at older ages.

If ß were exactly equal to 1, the generations would give a set of parallel lines on the transformed logit scale obtained from any of the life table.

When there was a big change in mortality between two generations,the lines would tend to be just as parallel as for a small change.

The savings of life at earlier ages in a generation means the accumulation of the less fit at later years - leads to higher death rates than would have occured otherwise.

When ß >1, the mortality schedule is more concentrated at the older age distribution than in the standard. This idea thus apparently favors the accumulation of the less fit perspective.

However, the simplifying assumption about ß is not acceptable since it moves away from 1 over periods of time in populations but in a regular, consistent way.

Generally,"the accumulation of the less fit" perspective can be argued in an inverse way as- not to accumulate the less fit would meann to let them die in the beginning. Nonetheless, having high mortality in the beginning would mean high mortality later because "a generation carries its own mortality".

Therefore, neither of the perspectives is satisfactorily fit to explain the trends of mortality and the logit measurement scale favors none consitently.

Figure 5: Theoretical perspectives related to the Study

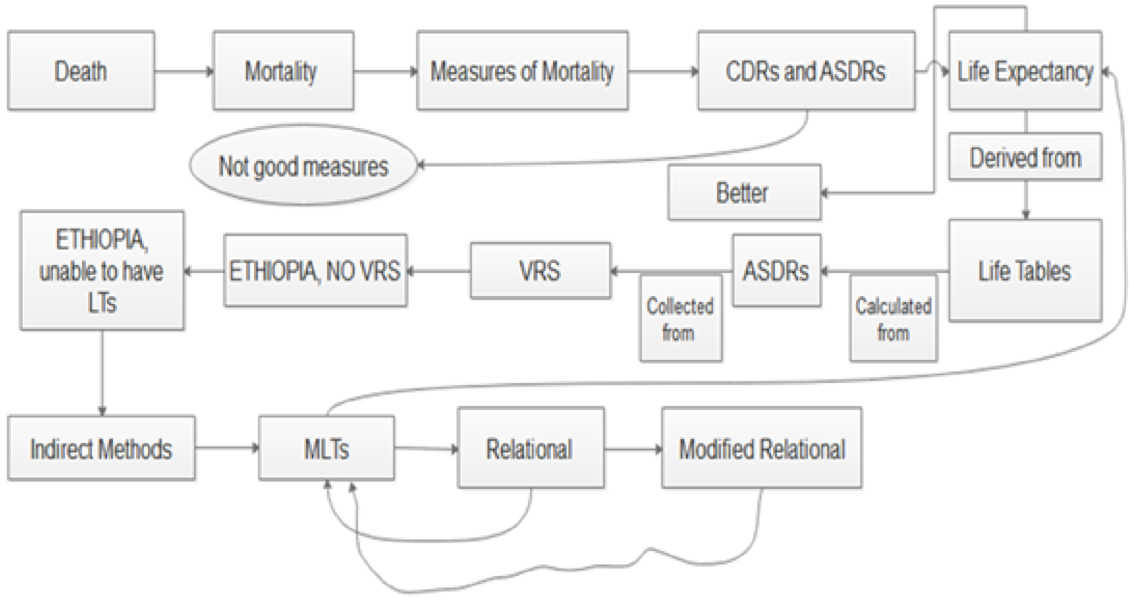


Figure 6: Conceptual schematic flow of the Study

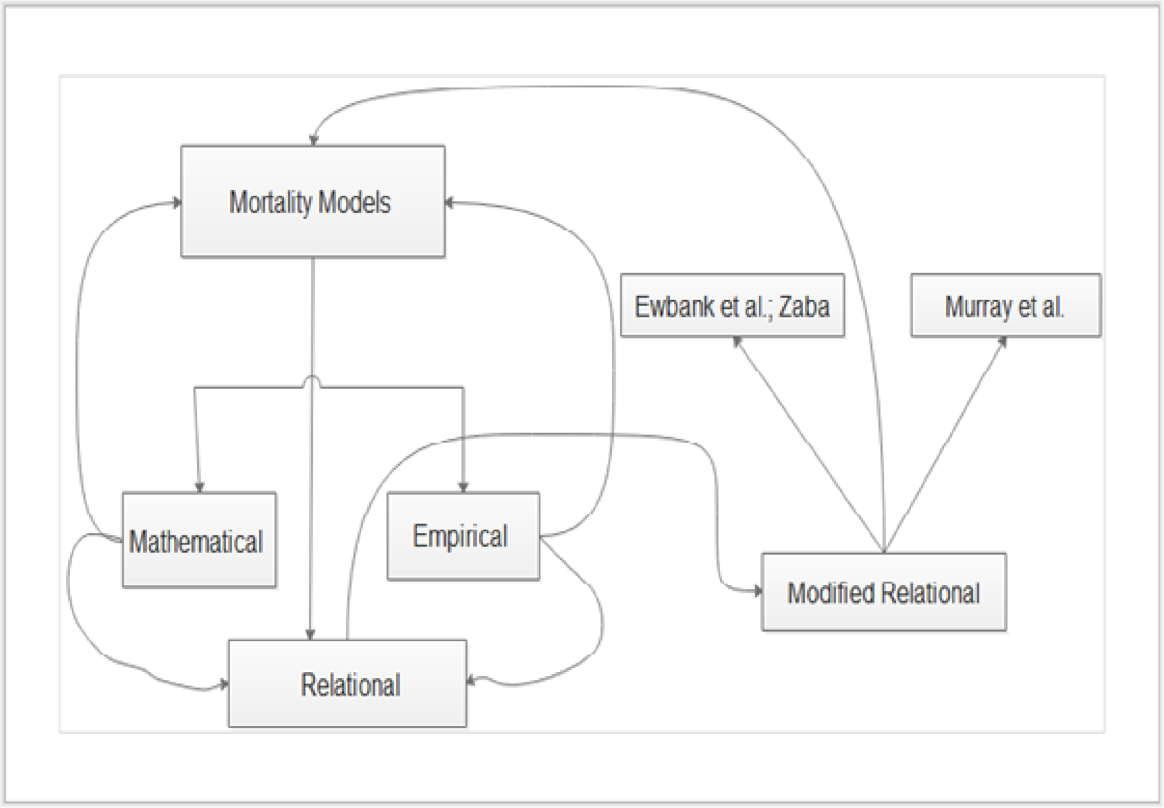


Figure 7: Theoretical schematic flow of the Model

2 Objectives

2.1 General Objective

This study aimed to improve mortality analysis by developing a Brass' logit system of model life tables for Ethiopia.

2.2 Specific Objectives

1. To estimate Brass' model based abridged life tables for Ethiopia and its regional states
2. To comparatively analyse mortality trends and life expectancies in Ethiopia on the basis of insights from the model based abridged life tables over 1990 - 2019
3. To decompose the change in life expectancies of Ethiopia and its regional states age - wise: 1990 - 2019
4. To measure the decomposed change in life expectancies of Ethiopia and its regional states age - wise: 1990 - 2019

3 Methods and Materials

3.1 Data

Official statistics must be produced in a way that is objective, transparent, and professionally independent in order to attract and keep the public's interest (CEPAL, 2022). The United Nations safeguarded these and other additional principles in 1994 and 2014 when it adopted a list of ten Fundamental Principles of Official Statistics at its general assembly (Pierson, 2015). These fundamental principles of official statistics are still as relevant today as they were in the past and they have become an integral part and a common reference in the statistical systems at global and national level (Rozkrut et al., 2021).

Population data is collected and disseminated by agencies or organizations like the World

Health Organization (WHO), the UN, and nation - specific statistical agencies. The Center for International Earth Science Information Network (CIESIN) also has interesting data applications, such as a census by satellite (Newbold, 2021).

Therefore, abridged life tables' survival functions l_x of Ethiopia were extracted from the United Nations World Population Prospects 2022 web source (United Nations and Social Affairs, 2022) for this study. That source was deemed appropriate because it offered empirical life tables covering Ethiopia's wide range mortality experiences from 1950 - 1954 through 2095 - 01. Those tables supplied survivorship functions that were in turn used to derive model mortality standards by sex for the model based abridged life table system that was produced. The main inputs to the system, Infant Mortality Rates (IMRs) and Under Five Mortality Rates (U5MRs), were also collected from the Global Burden of Disease Study (GBD) for 1990 and 2019 from (Tessema et al., 2023). Those input data were also selected due to the reason that they contained IMRs and U5MRs of Ethiopia and its regional states from 1990 to 2019.

3.2 Study Design

Research design refers to the overall structure or plan of the research (Bowling, 2014). It sets out the specific details of your enquiry (Ranjit, 2011). Ranjit also adds that the quantitative designs are more suitable if the researcher's goal is to quantify the extent of variation in values, such as to determine how many people have a particular value, belief, etc. In order to explain phenomena, quantitative research gathers numerical, detailed data that is constant and is then analyzed using mathematical techniques, particularly statistics that answer the questions "who, what, when, where, how much, how many, and how" (Mohajan et al., 2020). Mohajan again stresses that Creating and applying mathematical models, theories, and propositions about phenomena is the aim of quantitative research. Usually, it studies the relationships between these variables and conceptualizes the world in terms of quantifiable variables (Punch, 2000).

There are numerous definitions of a research paradigm in the literature. A paradigm is a set of beliefs that molds a person's perspective on the world (Robbins, 2008); a paradigm is a philosophical way of thinking (Kivunja and Kuyini, 2017); a paradigm is a way of organizing information so that fundamental, abstract relationships can be clearly understood (Gall et al., 1996); A paradigm is an approach to studying or observing phenomena, a worldview, an understanding of what constitutes legitimate scientific knowledge or methodology, or simply an accepted model or pattern (Cohen et al., 2017); to sum up, a paradigm is a basic set of beliefs that guide action (Creswell and Creswell, 2017). Each branch of scientific enquiry is, therefore, based on a set of these theoretical perspectives, or paradigms (Bowling, 2014).

The systematic, scientific, or positivist approach is the name of the paradigm that has its roots in the physical sciences (Ranjit, 2011). Objectivism and reality are positivists' ontological and epistemological stances, respectively; and its methodology is experimental (Rehman and Alharthi, 2016).

Rehman and Alharthi assert once more that post-positivism, the positivist paradigm's derivative, emerged as a result of criticism of the positivist paradigm. Post positivists contend that reality is fallible and that truth is probable rather than absolute; they also permit observations to be made without conducting experiments or developing testable hypotheses (Kivunja and Kuyini, 2017).

Non - experimental methods are more appropriate for the study of naturally occurring phenomena, such as reactions to parental discipline, gender - specific behavior, thorough examination of attitudes and prejudice, regular health behavior, and so on (Coolican, 2018).

Data that the researcher has not created especially for the purpose but has instead gathered them from trustworthy public or private sources are said to be existing data (Mohajan et al., 2020).

As a result, this study was conducted using Quantitative approach because it used numerical data and statistical analysis and retrospective longitudinal design - not in the sense that it followed and tracked the same subjects over time - but in the sense changes were analyzed in mortality patterns across different years allowing for the creation of multiple life tables that reflect trends over time.

Moreover, Brass' logit system of model life table development emphasizes on context accommodation, pragmatic utility, and admitting model limitations. Besides, though mainly rooted in quantitative methods, it still opens a space not to rigidly follow objectivity and to prioritize practical visions over universal laws. For this reason, it is the post positivist world view that leads this study.

3.3 Source Population

The source population for this study was the entire Ethiopian population, using data from the United Nations World Population Prospects 2022 online web source and from the Global Burden of Disease Study (GBD): 1990 - 2019.

3.4 Data Collection

Secondary data are those that are already available or those that have already been collected, analyzed, and documented (Kothari, 2004; Walliman, 2021). Technical publications like manuals, handbooks, data sheets, and standards, books and journals, official publications from the federal government, state and local governments, private data services, and computer databases are some places where they can be gathered (Pandey and Pandey, 2021).

Quantitative research involves gathering data, which is usually numerical, and the researcher's goal is to analyze the data using mathematical models (Walliman, 2021; Mohajan et al., 2020).

Consequently, secondary data from the United Nations World Population Prospects 2022 database and the the Global Burden of Disease Study (GBD): 1990 - 2019 were used in this study.

3.4.1 Staement of Data Clarification

1. Empirical life tables for Ethiopia were collected from UN - WPP 2022, which age - specific survivorship probabilities (l_x) were extracted from. Those l_x functions were averaged over 30 years (1990 – 2019) to derive Ethiopia - specific standard survivorship functions, l_x^s.

2. Infant Mortality Rates (IMRs) and Under - Five Mortality Rates (U5MRs) were collected from the Global Burden of Disease Study (GBD) 2019, which served as input data for the Brass' logit system of model life tables.

3. After each l_x value was extracted from each annual life table, they were averaged over the study period to produce an average survivorship value at each age, smoothing

out yearc - to - year variability due to epidemics, data quality issues, or other short - term effects clearing all noises.

4. The resulting set of averaged l_x values forms a standard survivorship function. This standard represents the typical mortality pattern for the population over the 30 - year period and serves as a reference or benchmark for the Brass' logit modeling. Eventually, The Brass' logit transformation $(logit\,(l_x) = \alpha + \beta logit\,(l_x^s))$ was applied to relate the observed population's survivorship functions (l_x) to the Ethiopia - specific standard functions (l_x^s) enabling estimation of tailored model life tables.

3.5 Operational definitions and measurements

Operational definitions are terms that are used by the researcher solely for the purpose of the study and are utilized in the research problem or in the study population in a measurable form (Ranjit, 2011). They are crucial to research because they make abstract ideas more measurable (Marczyk et al., 2010). Researchers must operationally define all variables - those measured, the dependent variables, and those manipulated, the independent variables (Jackson, 2009).

Hence, the following standard definitions apply to concepts that will be heavily utilized in this study:

Mortality – the rate at which deaths occur within a population

Model Life Table – A series of reference life tables that can be used to estimate mortality when only a few indicators are known

Brass' logit method – a relational method developed by William Brass that combines empirical and mathematical models based on the assumption that two distinct age patterns of mortality can be related to each other by a linear relationship between the logits of their respective survivorship probabilities

Modified Brass' logit method – a method that adds some parameters to the Brass' logit method Relational method – a model age pattern of mortality that combines features of both the tabular approach of model life tables and the mathematical approach

Infant Mortality Rate, IMR, – the number of infants dying under one year of age in a year in a given geographical area per thousand live births in the same year and geographical area

Under Five Mortality Rate, U5MR – the probability of death before completing five years of age

Mortality differentials – Variations in mortality based on age group, sex, and other socio-economic measurements etc.

Life expectancy at birth (LEB) – The average number of years that members of a hypothetical cohort are expected to live if they have the same risks of dying throughout their lives as those indicated by the age specific death rates in the year of their birth

Decomposition – A process of breaking down a difference between two summary measures into components attributable to differences in population composition, and to differences in measures specific for compositional categories

Abridged life table – A life table constructed by using broader age groups

Survivorship function, l_x - the probability of surviving at least to age x

Standardization – with standardization we endeavor to eliminate from a comparison the influence of one or more compositional variables, so that the comparison becomes, as far as is practicable, uncontaminated by compositional differences

3.6 Data processing and management

In technical terms, data processing is the process of modifying, coding, classifying, and tabulating gathered data to make them suitable for analysis (Kothari, 2004).

In order to fit the logit method of generating a model life table system, data containing survival functions were collected from the United Nations World Population Prospects and they were further converted into standard survival functions that represented the entire population on average. Standardization of the survivorship functions will also be carried out in order to reduce the effects of differences resulting from age distributions in the populations under study.

3.7 Data Analysis

3.7.1 Assumptions of Brass' Logit Model Life Table System

1. Linearity: The two parameters of the model are used to treat the linearity that may be affected by mortality shocks.
2. Freedom of resembling standard model life table selection
3. The parameters alpha and Beta are independent of age groups.

3.7.2 Generation of a System of Brass' relational model life tables for Ethiopia

The standard survival function value l_x^s was derived from the values of each of the survival functions, l_x of the UN generated empirical life tables for Ethiopia extracted from the United Nations World Population Prospects 2022 online source by averaging. The averaged survivorship rates were then used to construct the standard survivor function, which represented the overall mortality experience of the entire population. The populations were grouped into three patterns sex - wise: male, female, and both sexes combined. Correction factors γ_x had been calculated for each group and they were applied to the observed mortality rates to obtain adjusted mortality rates that would better reflect the true mortality experience of the population. Then, a model life table system based on the original version of Brass' logit relational method was built for Ethiopia.

3.7.3 Standardization and calculation of correction factors

The standard survival function values, l_x^s were derived from the values of each of the survival functions, l_x of the UN generated empirical life tables for Ethiopia by averaging. Correction factors are required to narrow the gap that may be exhibited between each l_x value of the abridged life tables and l_x^s - that of the standard. Because general trends in mortality also show sex differentials favoring one sex over the other (Caselli et al., 2005; INDEPTHNetwork, 2002; UN, 1955), this study examined whether or not the general pattern continues using the three aforementioned sex based patterns. A compelling use of the relational logit model by Brass as per (Wachter, 2014) is to take the present - day life table of a country as the standard and tabulate Y_x values from that one.

3.7.4 Steps in deriving the survival function l_x from IMRs and U5MRs

1. Since q_x functions were readily available for IMRs and U5MRs from the GBD 2019, they were used to derive l_x functions using the life table function relationships $l_x+q_x = 1$. Then, l_1 and l_5 were computed as $l_1 = 1 -_1 q_0$, and $l_5 = 1 -_5 q_0$, where l_x is the probability that a person of age x survives to age $x+1$ and q_x is the probability that a person of age x dies before reaching age $x+1$.

2. Deciding the - Both Sexes Combined - pattern as the standard mortality table, and choosing l_1^s and l_5^s, α and β were computed using the following formulae:

$$\beta = \frac{logit(l_5) - logit(l_1)}{logit(l_5^s) - logit(l_1^s)}$$

$$= \frac{ln\left[\dfrac{(1-l_5)l_1}{l_5(1-l_5^s)}\right]}{ln\left[\dfrac{(1-l_5^s)l_1^s}{l_5^s(1-l_1^s)}\right]}$$

   From $l_x = \alpha + \beta l_x^s$, we have $\alpha = l_x - \beta {l_x}^s$. Thus, $\alpha = \frac{1}{2}ln\left(\frac{1-l_5}{l_5}\right) - \frac{1}{2}\beta ln\left(\frac{1-l_5^s}{l_5^s}\right)$.

3. The survival function l_x was generated using the pair (α, β) calculated above, l_x^s, and γ_x as :

$$l_x = \frac{1}{\gamma_x\left(1 + e^{2\alpha+\beta ln\left(\frac{1-l_x^s}{l_x^s}\right)}\right)}$$

4. Logit values of the above estimated function l_x and also that of the standard l_x^s were obtained as

$$logit(l_x) = \frac{1}{2}ln\left(\frac{1-l_x}{l_x}\right)$$

$$logit(l_x^s) = \frac{1}{2}ln\left(\frac{1-l_x^s}{l_x^s}\right)$$

5. The new values of the pair (α, β), namely (α', β') were calculated using the following linear regression equation:

$$logit(l_x) = \alpha' + \beta' logit(l_x^s)$$

6. After that the final and adjusted value of l_x was computed using the new pair (α', β') and l_x^s as

$$l_x = \frac{1}{1 + e^{2\alpha' + \beta' ln\left(\frac{1 - l_x^s}{l_x^s}\right)}}$$

7. Finally, following the appropriate procedures and extending the final estimated l_x column obtained in step 6) above to age 100, full set of life tables with all the usual columns was obtained. The final adjusted survivorship function computed above was used as an input in the UN's MORTPAK LITE software to generate the final model. Moreover, when any one of the life table functions l_x, ${}_nq_x$, or ${}_nm_x$ to be computed by the researcher are known, LIFTB program of MORTPAK LITE can be used to produce the abridged life tables.

3.7.5 Estimation of model based abridged life tables for Ethiopia and its regional states from the information on IMRs and U5MRs

Carey (1993) points out that there are two drawbacks to the full life table that can be overcome by creating an abridged version. First, it is impossible to track a cohort's daily mortality over the course of their lives; second, it is challenging to fully understand a table with $50 - 100$ age groups and $5 - 7$ life table functions (columns), many of which are unimportant details. (P.19). Abridged life tables are typically calculated for males and for females separately, as with other life tables; however, they can also be calculated for both sexes together (Yusuf et al., 2014).

Of all the functions of a life table, ${}_nq_x$ is pivotal from which all other life table functions are generally derived (Chander Shekhar, 2011). Therefore, taking l_x from the model life table to be constructed, and using ${}_nq_x = 1 - l_x$, the whole abridged life tables can be generated. Alternatively, MORTPAK LITE can also be used to generate them.

3.7.6 Comparative analysis of mortality trends and life expectancies of Ethiopia and its regional states using the model based abridged life tables

Full abridged life tables for Ethiopia and for its regional states were produced. A table (Table 17) containing life expectancy at birth of the period 1990 to 2019 for Ethiopia and all its regional states was also developed to complement the whole analysis. The findings suggest that there had been substantial progress in reducing mortality in Ethiopia over the past thirty years. They also revealed significant variations in mortality experiences across the regional states and between the sexes. This model produced abridged life tables for Ethiopia and for each of the regional states with estimates of life expectancy at birth ranging from 64.185 years in Benshangul - Gumuz to 69.483 years in Addis Ababa with a variation of 5.298 years, while the national average was 66.236 years.

3.7.7 Decomposing and measuring the change in life expectancies of Ethiopia and its regional states age - wise: 1990 - 2019

Demography's most fundamental technique is to break down population change into its constituent parts (Shryock et al., 1980) and look into each one separately. Decomposition analysis is a technique that finds the cumulative contributions of the effects of two populations' different compositional or rate factors to the differences in their overall rates (GUPTA, 1994).

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 and Guillot, 2001) because an increase or a 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 mortality reductions are translated into gains in life expectancy at birth and can be attributed to specific age groups (Aburto et al., 2022).

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). 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 demographers such as Andreev (1982) in (Andreev et al., 2002; Shkolnikov et al., 2001), Pollard (1982, 1988), Pressat (1985), and Arriaga (1984) independently developed various methods for the purpose of decomposing life expectancies and measuring relative age specific contributions to the overall change in the 1980s. Because all these methods lead to similar results (Pollard, 1988; Ponnapalli, 2005), the decomposition method developed by Arriaga (1984) was used 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 in this study. The choice of Arriaga's decomposition method was based on the fact that it gives reliable and consistent results (Zafeiris, 2020).

Andreev (1982) in (Andreev et al., 2002; Shkolnikov et al., 2001), Arriaga (1984), Pressat (1985) 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).

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

$$e_0 = \int_0^{\omega} p\left(a\right) da$$

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

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

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

Combining the two equations given above, we see that

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

Now, when $\mu\left(u\right)$ 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 $\mu\left(u\right)$ 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 $\mu\left(u\right)$ 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):

Direct Effect,

$$i^{DE_x} = \frac{l_x^t}{l_a^t}\left(\frac{T_x^{t+n} - T_{x+i}^{t+n}}{l_x^{t+n}} - \frac{T_x^t - T_{x+i}^t}{l_x^t}\right)$$

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.

Direct Effect for the open ended interval,

$$DE_{x^+} = \frac{l_x^t}{l_a^t}\left(e_x^{t+n} - e_x^t\right) = \frac{l_x^t}{l_a^t}\left(\frac{T_x^{t+n}}{l_x^{t+n}} - \frac{T_x^t}{l_x^t}\right)$$

Indirect Effect,

$$i^{IE_x} = \frac{T_{x+i}^t}{l_a^t}\left(\frac{l_x^t l_{x+i}^{t+n}}{l_{x+i}^t l_x^{t+n}} - 1\right)$$

Other Effect,

$$i^{OE_x} = \frac{T_{x+i}^t}{l_a^t}\left(\frac{l_x^t}{l_x^{t+n}} - \frac{l_{x+i}^t}{l_{x+i}^{t+n}}\right)$$

Interaction Effect,

$$i^{I_x} = i^{OE_x} - i^{IE_x}$$

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

$$i^{e_x} = \frac{T_x - T_{x+i}}{l_x}$$

Where x is the lower limit and i the upper limit of the age range considered $x >= 0, i < \omega$. Decomposition analyses were thus carried out in this study to quantify the contribution of each age group to the variations in life expectancy at birth for each population in Ethiopia and its regional states between 1990 and 2019.

Data quality, as a concept, is meaningful only when it relates to the intended use of the data (US, 2000). Before utilizing secondary data, the researcher should exercise caution and ensure that they have the following qualities (Kothari, 2004): reliability, suitability, and adequacy.

On the thing that has been mentioned, this study has used secondary data from the Global Burden of Disease Study, another reasonably trustworthy source, as well as the United Nations data source, which is the most reliable source ever. Care was taken to make sure the data were not used at face value in regards to their appropriateness and sufficiency. This was accomplished by using the right techniques to transform the data into the relevant variables of interest, such as converting raw death rate figures into probabilistic survivorship functions, deriving standard survival probabilities using moving averages, transforming them via their logits, and making the necessary adjustments.

3.8 Ethical Considerations

Research ethics was not historically taken seriously as a primary component of the entire research work until the Second World War ended and US wartime investigators established tribunals to try Nazi criminals for the heinous crimes they had committed against the victims of the concentration camps.

The ethical guidelines we use today have their basis in the Nuremberg Code (Jackson, 2009).

Cooper et al. (2009) state:

The horrors carried out by Nazi researchers conducting experiments in concentration camps contributed to the rise in concern over the moral treatment of research subjects. 23 Nazi researchers—the majority of whom were doctors—were put on trial before the Nuremberg Military Tribunal at the close of World War II. It was crucial for the prosecution to make a distinction during the trial between the methods employed by US wartime investigators and those used in Nazi experiments. The judges decided on ten fundamental guidelines for human subjects research in order to accomplish this. It's interesting to note that many of the fundamental ideas, like informed consent, were reminiscent of German laws that were in effect both before and during the Nazi era. These laws included clauses that forbade the use of dying people, gave special consideration to cases involving minors, and prohibited the exploitation of the poor. The Nuremberg Code is the name given to the set of rules developed by the Tribunal. Many of the tenets of the Nuremberg Code—such as the opportunity for research participants to withdraw, the avoidance of needless suffering or injury, voluntary consent of the human subject, and restrictions on the level of risk permitted—remain the cornerstone of ethical procedures employed today. (pp. 127 - 8).

The Nuremberg Code was, therefore, the first major international document to provide guidelines on research ethics (Marczyk et al., 2010).

Ethical research concerns what researchers ought and ought not to do in their research and research behavior (Cohen et al., 2017).

The different parties involved in a research activity are the funding agency, the researcher, and the research subjects or participants. Each of these stakeholders may have personal goals and interests that have an impact on the research's overall methodology and the way its conclusions are communicated. As a result, it's critical to make sure that research is conducted without regard to anyone's self-interest or in a way that could harm them (Ranjit, 2011).

As such, it is essential to evaluate the ethical concerns of each stakeholder in isolation.

3.8.1 Ethical issues regarding the Subjects

Regarding study participants, Bowling (2014); Robbins (2008); Creswell and Creswell (2017); Marczyk et al. (2010); Jackson (2009) say the following:

The ethical guideline that governs research states that participants should not suffer any negative consequences from their participation, and that they should sign an informed consent form after being fully informed about the study's objectives, confidentiality, and anonymity. It is imperative that participants are made aware of their freedom to withdraw from the study at any point, and that the investigator is available to address any queries they may have. This voluntary consent lessens the researcher's legal liability and protects the participant's right to decide whether or not to participate in the study.

However, this study has not used any human subjects and has not been subject to any of the ethical concerns regarding research subjects that have been previously mentioned.

3.8.2 Ethical issues regarding the Institution

Sometimes there may be direct or indirect controls exercised by sponsoring organizations and there can also be misuse of information – which are both unethical (Ranjit, 2011). This study has been, nevertheless, free of such institutional predispositions.

3.8.3 Ethical issues regarding the Researcher

The ethical issues that a researcher can generally abuse are deliberate bias, providing or withholding a treatment, using inappropriate methodology, incorrect reporting, and inappropriate use of the information (Ranjit, 2011).

The researcher has not been concerned about and has been relieved of ethical concerns because there was no manipulation of the study's variables. Rather, for use in deterministic mathematical models, only numerical values were collected from the United Nations, the most dependable open public domain source of data, and they were converted into functions using life table function relationships.

3.9 Dissemination of findings

Research's impact depends on how carefully it is disseminated; if it is done too little, its message will go unnoticed, but if it is done too much, decision - makers will become confused and cynical due to data overload (Cohen et al., 2017).

As a result, efforts were made to disseminate the deconstructed portions of the study's primary work to readers in an understandable and feasible way through the following publications, seminars, and conference presentations.

1. A paper was presented in The International Union for the Scientific Study of Population (IUSSP) conference that was held on 5 - 10 December 2021 in Hyderabad, India (one can get to this by the link https://ipc2021.popconf.org/abstracts/210687).
2. Four related articles were submitted to different publishers of which two are now published, and two are accepted. Evidences were produced to the IPoSt.
3. Two papers have been accepted for presentation in international conferences in America, and Australia.
4. A variety of related seminar works were presented and discussed in a series of programs organized and coordinated by the IPoSt.

4 Results

4.1 Description of the Developed System of Model Life Tables

The Brass' logit model has been proven rigorous for its statistical reliability and flexibility in accommodating various data types in the literature. Results obtained from specific Ethiopian age structures and mortality rates used as input data in this model were then deemed statistically sound.

To check the demographic representation of the produced system of model life tables, specific mortality rates and life expectancies were compared with those from other reliable sources and they were proven comparably reasonable indicating that the model captures unique local mortality patterns.

Evaluating regional differences and similarities in mortality has also shown contextual relevance in that it provided localized insights.

Outputs were cross checked among themselves and with the literature for the purpose of validating with local data and with benchmarks from reliable sources such as the UN to confirm the model's accuracy.

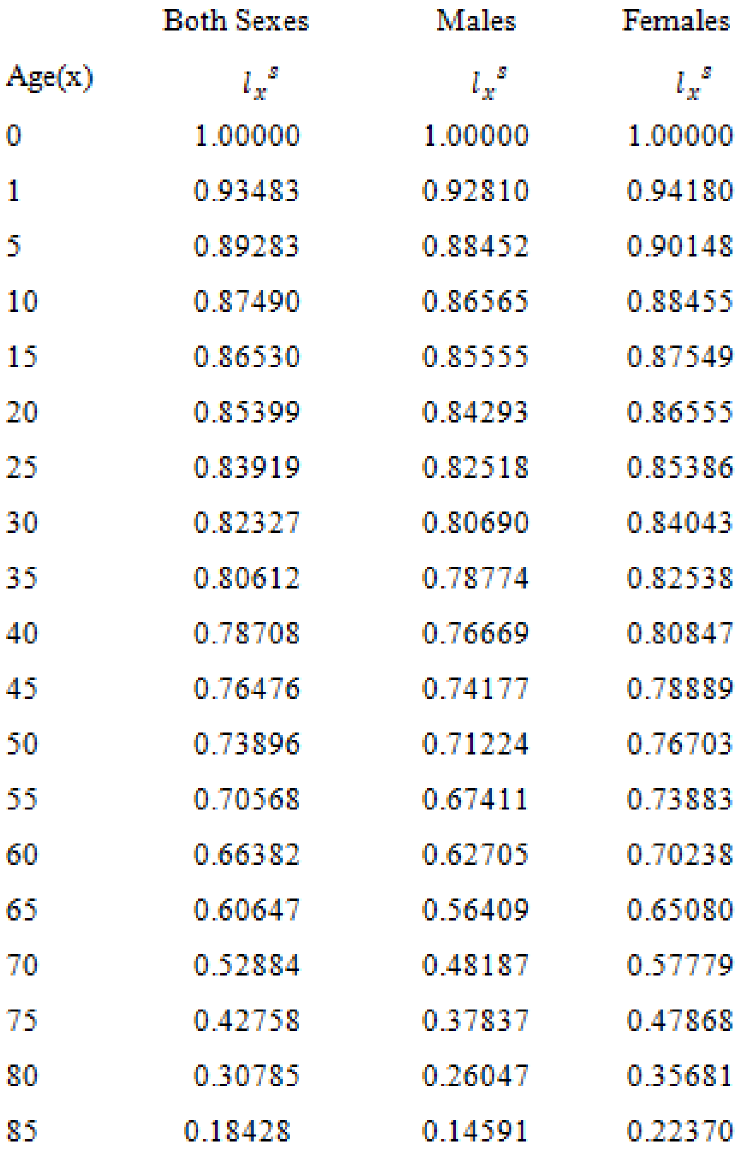
This study has provided results that are different from those found in other sources, consistent among themselves, and comparable with benchmark results from reliable global sources indicating the study has come up with improved methodological rigor and relatively better outputs.

These processes and results have been point by point discussed in the subsequent Result and Discussion sections.

4.2 Constructing model based abridged life tables for Ethiopia and its regional states

Abridged life tables based on the logit model by Brass provide significant insights into mortality at different ages. Therefore, using Brass' logit model - based abridged life tables, this study sought to compare changes in mortality, survival probabilities, infant mortality rates, and sex differentials in Ethiopia from 1990 to 2019. To create these life tables, information from the Global Burden of Disease Study 2019 and the United Nations World Population Prospects 2022 online resource was used. The results showed that Ethiopia's healthcare system made remarkable improvements in general between 1990 and 2019. With a 7.7% increase in the likelihood of survival at birth, life expectancy increased by 16.977 years, from 49.259 to 66.236 years. Between 1990 and 2019, the rate of infant mortality decreased by 69.5%, from 107.19 per thousand live births to 32.68. The difference in life expectancy at birth based on sex decreased significantly from 7.706 years in 1990 to 4.491 years in 2019. According to the study, there has been a noticeable decrease in overall mortality over the past three decades. However, there are still gender differences in life expectancy at birth, and Ethiopia's mortality and life expectancy rates could still be improved.

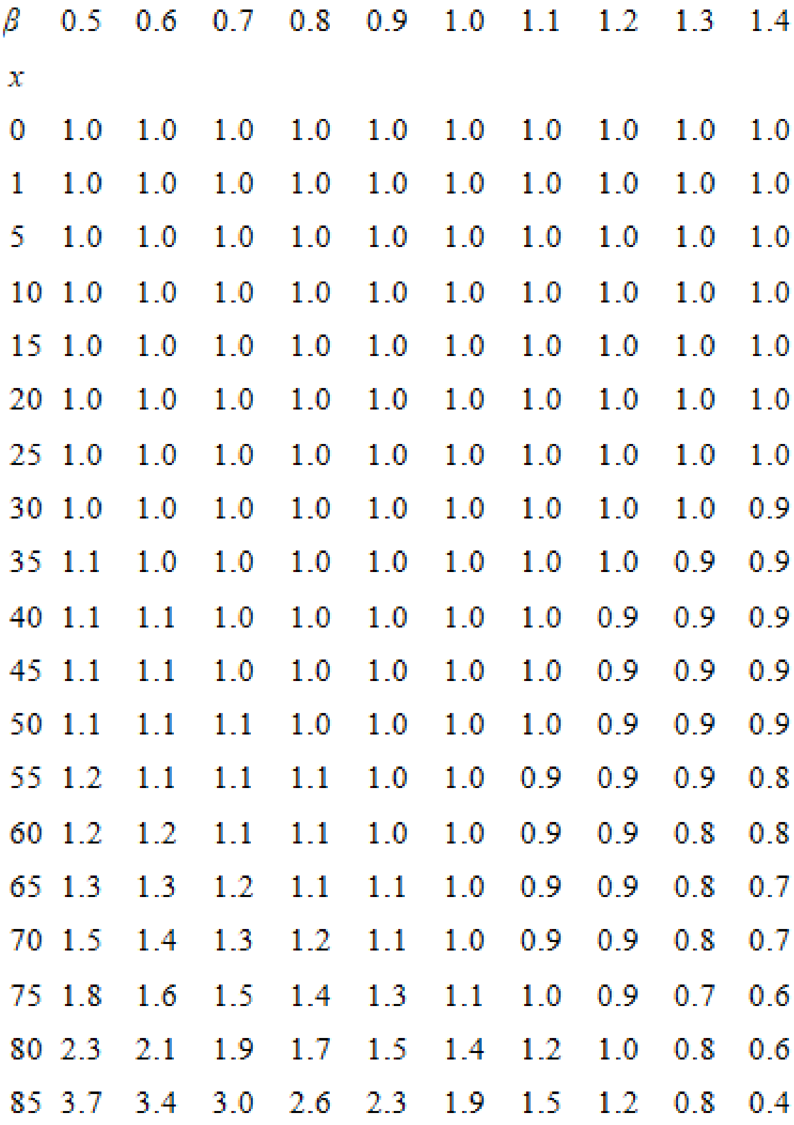
Table 5: Ethiopian standard survival functions: Both Sexes, Males, and Females



	Both Sexes	Males	Females
Age(x)	l_x^s	l_x^s	l_x^s
0	1.00000	1.00000	1.00000
1	0.93483	0.92810	0.94180
5	0.89283	0.88452	0.90148
10	0.87490	0.86565	0.88455
15	0.86530	0.85555	0.87549
20	0.85399	0.84293	0.86555
25	0.83919	0.82518	0.85386
30	0.82327	0.80690	0.84043
35	0.80612	0.78774	0.82538
40	0.78708	0.76669	0.80847
45	0.76476	0.74177	0.78889
50	0.73896	0.71224	0.76703
55	0.70568	0.67411	0.73883
60	0.66382	0.62705	0.70238
65	0.60647	0.56409	0.65080
70	0.52884	0.48187	0.57779
75	0.42758	0.37837	0.47868
80	0.30785	0.26047	0.35681
85	0.18428	0.14591	0.22370

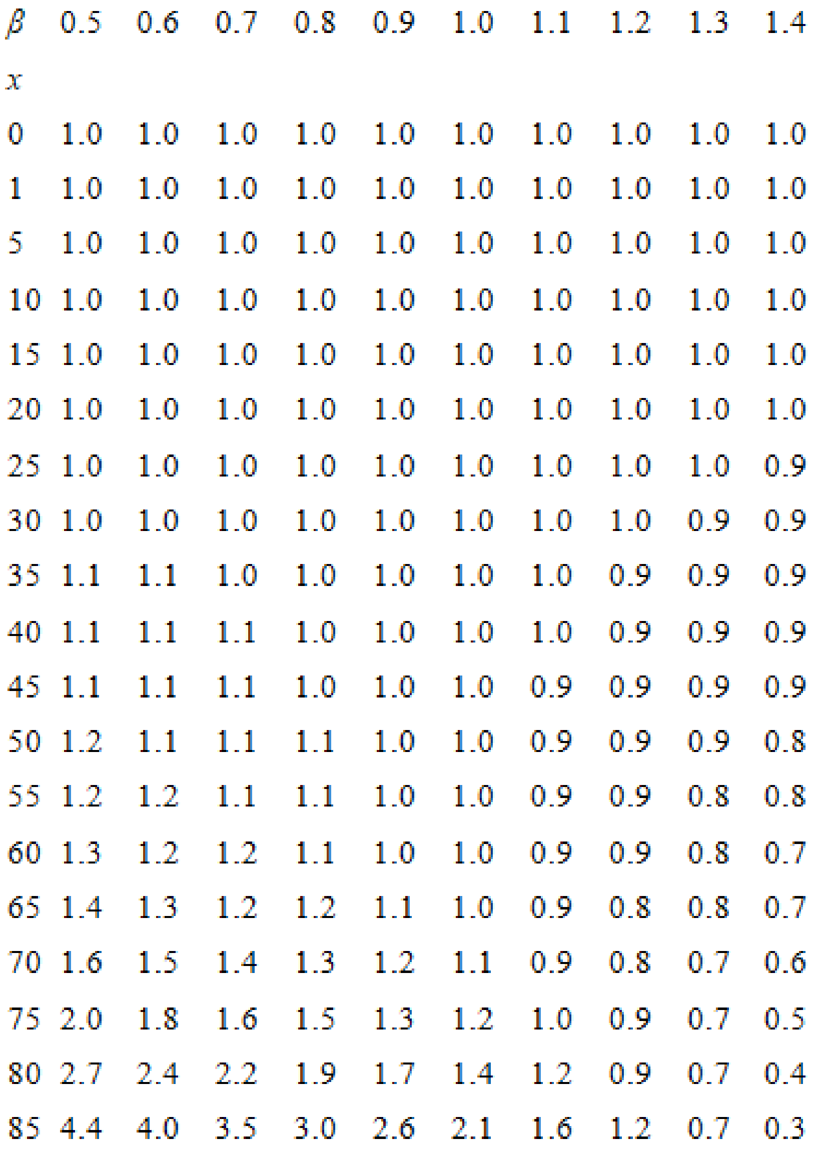
This is a table of standard survival functions that were produced for the Ethiopian population by sex. The survival functions were then used as mortality standards for the whole population in producing the model based abridged life tables (ALTs).

Table 6: Correction factors γ_x , Both Sexes combined



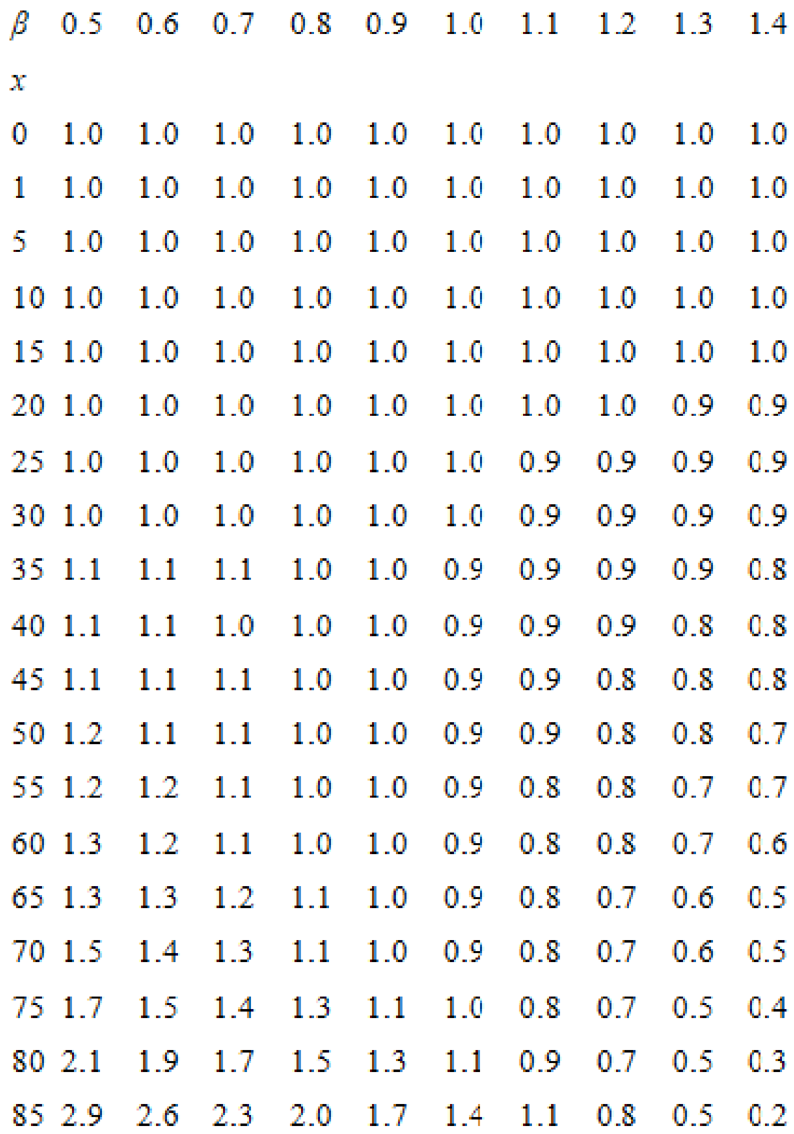
β	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
x										
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
30	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
35	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
40	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
45	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
50	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9
55	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
60	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
65	1.3	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.7
70	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.9	0.8	0.7
75	1.8	1.6	1.5	1.4	1.3	1.1	1.0	0.9	0.7	0.6
80	2.3	2.1	1.9	1.7	1.5	1.4	1.2	1.0	0.8	0.6
85	3.7	3.4	3.0	2.6	2.3	1.9	1.5	1.2	0.8	0.4

Table 7: Correction factors γ_x , Males



β	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
x										
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
30	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
35	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
40	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9
45	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
50	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
55	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
60	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.7
65	1.4	1.3	1.2	1.2	1.1	1.0	0.9	0.8	0.8	0.7
70	1.6	1.5	1.4	1.3	1.2	1.1	0.9	0.8	0.7	0.6
75	2.0	1.8	1.6	1.5	1.3	1.2	1.0	0.9	0.7	0.5
80	2.7	2.4	2.2	1.9	1.7	1.4	1.2	0.9	0.7	0.4
85	4.4	4.0	3.5	3.0	2.6	2.1	1.6	1.2	0.7	0.3

Table 8: Correction factors γ_x , Females



β	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
x										
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
25	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
30	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
35	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8
40	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
45	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8
50	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7
55	1.2	1.2	1.1	1.0	1.0	0.9	0.8	0.8	0.7	0.7
60	1.3	1.2	1.1	1.0	1.0	0.9	0.8	0.8	0.7	0.6
65	1.3	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5
70	1.5	1.4	1.3	1.1	1.0	0.9	0.8	0.7	0.6	0.5
75	1.7	1.5	1.4	1.3	1.1	1.0	0.8	0.7	0.5	0.4
80	2.1	1.9	1.7	1.5	1.3	1.1	0.9	0.7	0.5	0.3
85	2.9	2.6	2.3	2.0	1.7	1.4	1.1	0.8	0.5	0.2

Table 6, Table 7, and table 8 above contain the correction factors within the standard values of β varying between 0.5 and 1.4. These correction factors deviate from 1 either when $\beta > 1$ or when the age range is 35 years and above. Deviations from 1 of these correction factors are indications that overestimation or underestimation of life expectancies and the other life table function values might happen to exist. Given that secondary data were used in this study, along with all of their limitations, this is somewhat acceptable. Moreover, since higher values of β are in favor of the young, this is consistent with the model's characteristics that indicate deviations towards old age.

Although the model life table developed was used and would be used to produce abridged life tables for Ethiopia and for all its regional states overtime, in this section it was restricted to making inferences only for Ethiopia.

Finally, changes in general mortality rates, in average life span, and in infant mortality rates of the population over the last three decades (1990 - 2019) were treated and inferences were made accordingly.

4.2.1 Changes in mortality over the past three decades, Ethiopia

The model generated abridged life tables for Ethiopia by sex are displayed below for the years 1990 and 2019. The information from the tables was then used to conduct additional explanations on the country's mortality trend over the whole of thirty years.

Ethiopia has generally seen a significant decline in death rates since the 1990s across all age groups, with relative low rates of infant and child mortality. The death rate in 1990 was only declining up until the age of 15, after which it began to rise, indicating that earlier in life, a higher percentage of people died. Referring to the death trend curves provided below, in 2019 there was a discernible decrease in overall numbers of deaths in comparison to 1990; however, the pattern of rising mortality rates began to increase at the age of 20, and it persisted even after thirty years of overall improvements in survival.

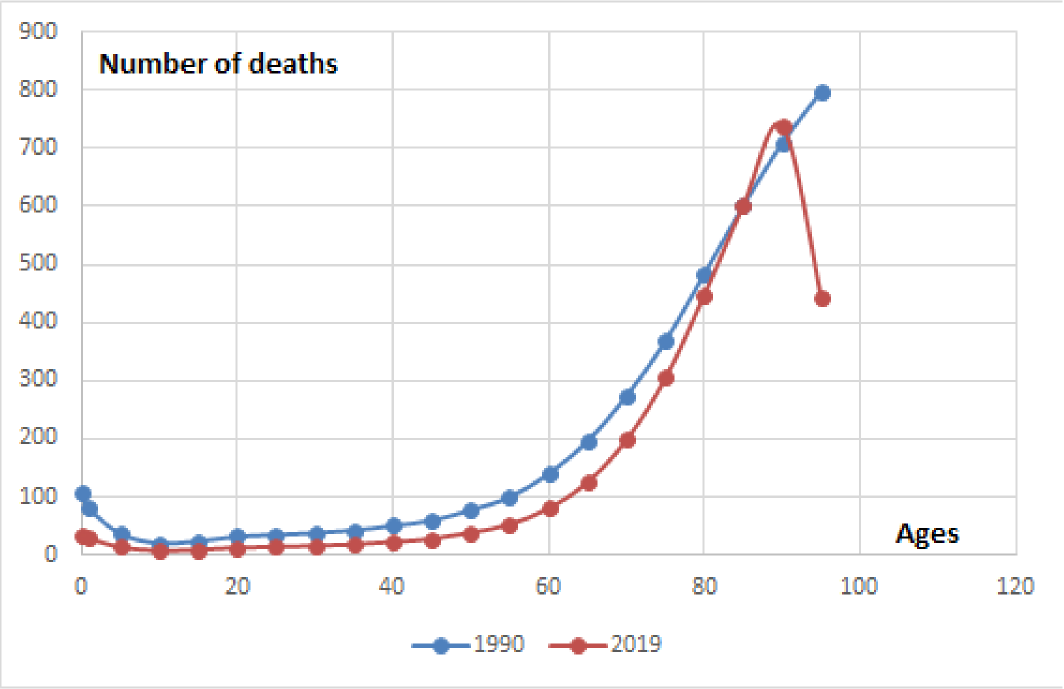


Figure 8: Ethiopia's death trend curves: 1990 - 2019

These two trend curves typically begin with high death rates, but they differ significantly in that the 2019 curve begins with a significantly lower rate than the 1990 curve, and the level difference between them illustrates the reductions in mortality that have been achieved over the specified time.

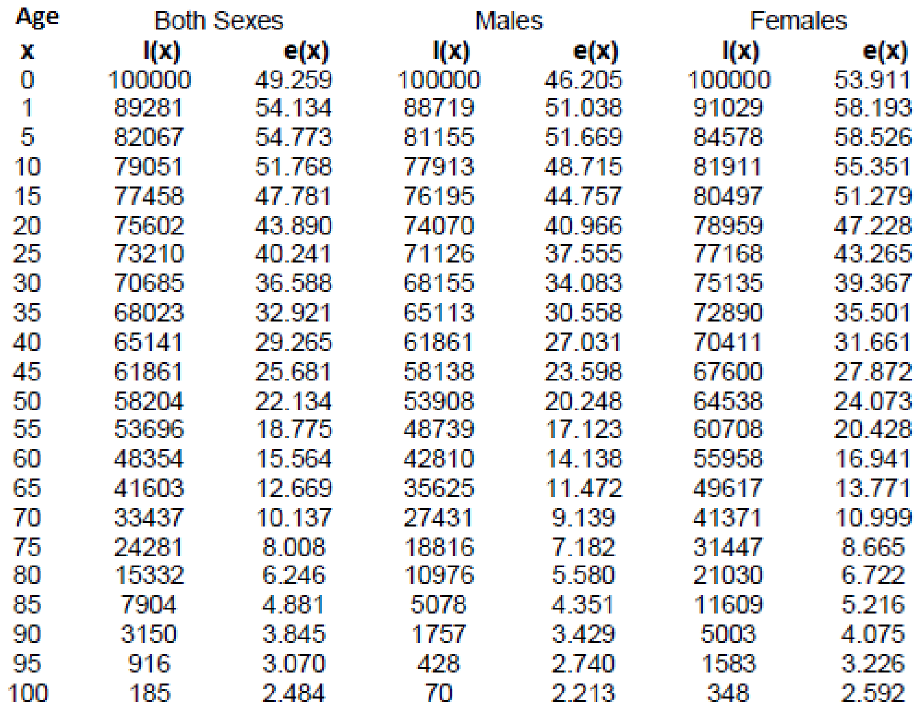
The beginning points' high values roughly indicate that the mortality rates for infants and children under five were high.

These curves indicate improvements in survival when they begin with high values and then gradually decrease over the age range of 0 to 15.

But after a short while, both curves start to rise at age 20 and keep going up with almost the same pace until age 60. This is due to a number of things, including middle - aged accidents and increased risk - taking behavior, as well as the fact that aging is associated with a constant rise in the risk of dying.

After the age of 60, both curves rise sharply, indicating high mortality risks linked to all potential hazards in very old age. They meet at 85 years old, and the 2019 curve sharply declines, highlighting the complex interactions between risk factors that occur throughout life. These two curves generally indicate a vulnerable time in early life that is followed by a risk - growing phase in young adulthood.

Table 9: Abridged life tables for Ethiopia, 1990



Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	49.259	100000	46.205	100000	53.911
1	89281	54.134	88719	51.038	91029	58.193
5	82067	54.773	81155	51.669	84578	58.526
10	79051	51.768	77913	48.715	81911	55.351
15	77458	47.781	76195	44.757	80497	51.279
20	75602	43.890	74070	40.966	78959	47.228
25	73210	40.241	71126	37.555	77168	43.265
30	70685	36.588	68155	34.083	75135	39.367
35	68023	32.921	65113	30.558	72890	35.501
40	65141	29.265	61861	27.031	70411	31.661
45	61861	25.681	58138	23.598	67600	27.872
50	58204	22.134	53908	20.248	64538	24.073
55	53696	18.775	48739	17.123	60708	20.428
60	48354	15.564	42810	14.138	55958	16.941
65	41603	12.669	35625	11.472	49617	13.771
70	33437	10.137	27431	9.139	41371	10.999
75	24281	8.008	18816	7.182	31447	8.665
80	15332	6.246	10976	5.580	21030	6.722
85	7904	4.881	5078	4.351	11609	5.216
90	3150	3.845	1757	3.429	5003	4.075
95	916	3.070	428	2.740	1583	3.226
100	185	2.484	70	2.213	348	2.592

These are model based abridged life tables with only the common and fundamental columns l_x and e_x given for Ethiopia in 1990. While it is possible to include all the usual columns of the life table functions, these ones are the most important elements to make analyses and also every other function of the life table can be derived from them.

Table 10: Abridged life tables for Ethiopia, 2019

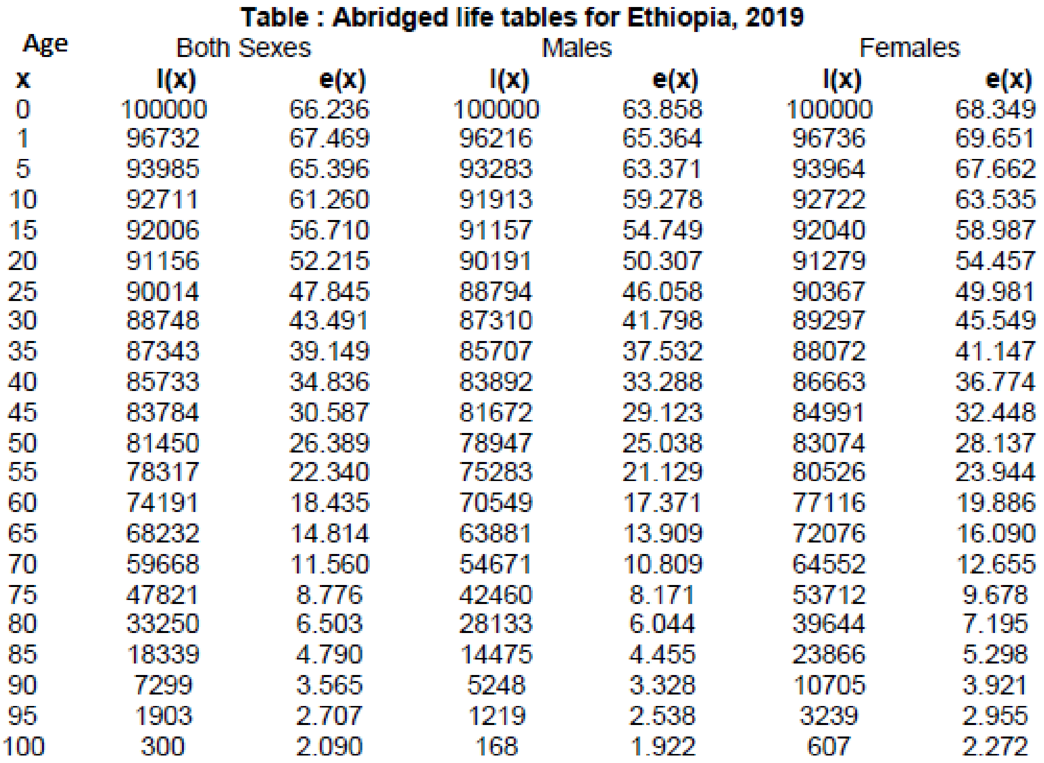
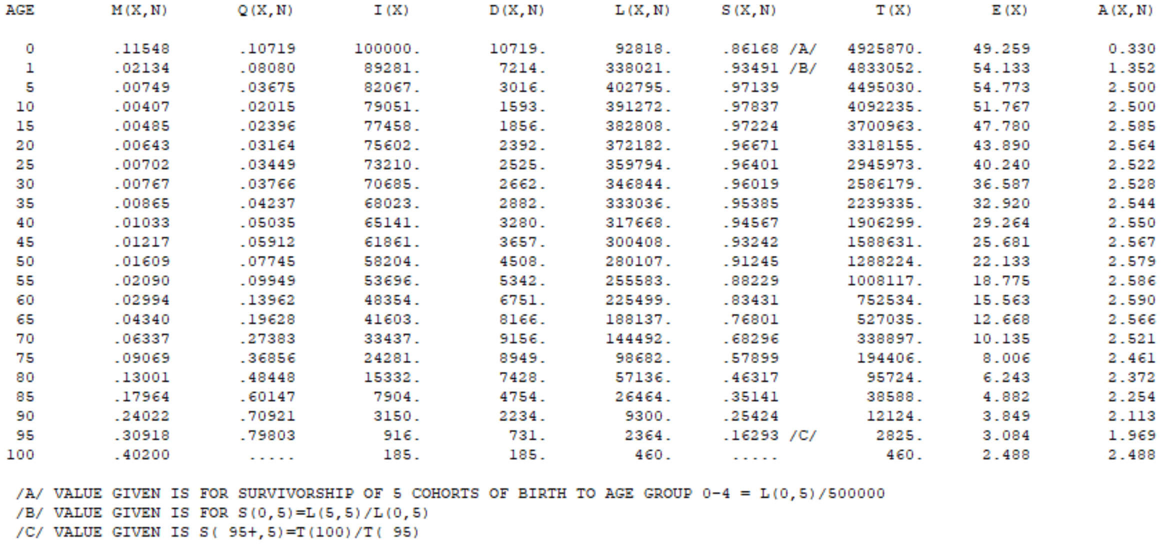


Table : Abridged life tables for Ethiopia, 2019

Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.236	100000	63.858	100000	68.349
1	96732	67.469	96216	65.364	96736	69.651
5	93985	65.396	93283	63.371	93964	67.662
10	92711	61.260	91913	59.278	92722	63.535
15	92006	56.710	91157	54.749	92040	58.987
20	91156	52.215	90191	50.307	91279	54.457
25	90014	47.845	88794	46.058	90367	49.981
30	88748	43.491	87310	41.798	89297	45.549
35	87343	39.149	85707	37.532	88072	41.147
40	85733	34.836	83892	33.288	86663	36.774
45	83784	30.587	81672	29.123	84991	32.448
50	81450	26.389	78947	25.038	83074	28.137
55	78317	22.340	75283	21.129	80526	23.944
60	74191	18.435	70549	17.371	77116	19.886
65	68232	14.814	63881	13.909	72076	16.090
70	59668	11.560	54671	10.809	64552	12.655
75	47821	8.776	42460	8.171	53712	9.678
80	33250	6.503	28133	6.044	39644	7.195
85	18339	4.790	14475	4.455	23866	5.298
90	7299	3.565	5248	3.328	10705	3.921
95	1903	2.707	1219	2.538	3239	2.955
100	300	2.090	168	1.922	607	2.272

Table 11: Abridged life tables with all the usual columns for Ethiopia, 1990

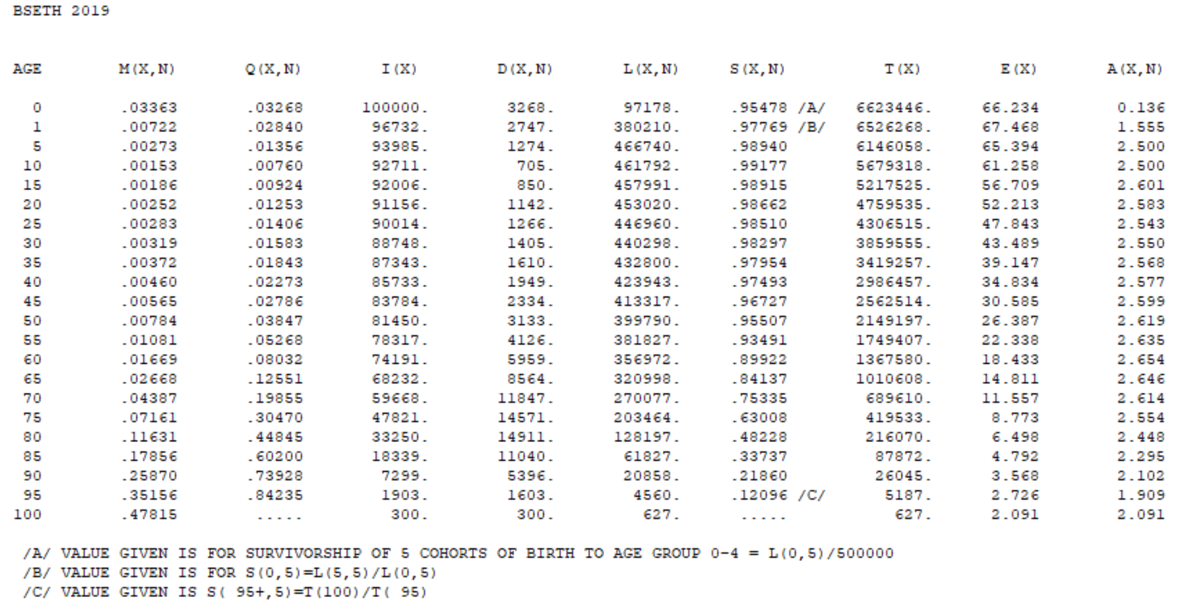


```
AGE        M(X,N)      Q(X,N)       I(X)      D(X,N)      L(X,N)    S(X,N)         T(X)      E(X)       A(X,N)

  0        .11548      .10719     100000.     10719.      92818.   .86168 /A/   4925870.    49.259      0.330
  1        .02134      .08080      89281.      7214.     338021.   .93491 /B/   4833052.    54.133      1.352
  5        .00749      .03675      82067.      3016.     402795.   .97139        4495030.    54.773      2.500
 10        .00407      .02015      79051.      1593.     391272.   .97837        4092235.    51.767      2.500
 15        .00485      .02396      77458.      1856.     382808.   .97224        3700963.    47.780      2.585
 20        .00643      .03164      75602.      2392.     372182.   .96671        3318155.    43.890      2.564
 25        .00702      .03449      73210.      2525.     359794.   .96401        2945973.    40.240      2.522
 30        .00767      .03766      70685.      2662.     346844.   .96019        2586179.    36.587      2.528
 35        .00865      .04237      68023.      2882.     333036.   .95385        2239335.    32.920      2.544
 40        .01033      .05035      65141.      3280.     317668.   .94567        1906299.    29.264      2.550
 45        .01217      .05912      61861.      3657.     300408.   .93242        1588631.    25.681      2.567
 50        .01609      .07745      58204.      4508.     280107.   .91245        1288224.    22.133      2.579
 55        .02090      .09949      53696.      5342.     255583.   .88229        1008117.    18.775      2.586
 60        .02994      .13962      48354.      6751.     225499.   .83431         752534.    15.563      2.590
 65        .04340      .19628      41603.      8166.     188137.   .76801         527035.    12.668      2.566
 70        .06337      .27383      33437.      9156.     144492.   .68296         338897.    10.135      2.521
 75        .09069      .36856      24281.      8949.      98682.   .57899         194406.     8.006      2.461
 80        .13001      .48448      15332.      7428.      57136.   .46317          95724.     6.243      2.372
 85        .17964      .60147       7904.      4754.      26464.   .35141          38588.     4.882      2.254
 90        .24022      .70921       3150.      2234.       9300.   .25424          12124.     3.849      2.113
 95        .30918      .79803        916.       731.       2364.   .16293 /C/       2825.     3.084      1.969
100        .40200      .....         185.       185.        460.   .....             460.     2.488      2.488

 /A/ VALUE GIVEN IS FOR SURVIVORSHIP OF 5 COHORTS OF BIRTH TO AGE GROUP 0-4 = L(0,5)/500000
 /B/ VALUE GIVEN IS FOR S(0,5)=L(5,5)/L(0,5)
 /C/ VALUE GIVEN IS S( 95+,5)=T(100)/T( 95)
```

Table 12: Abridged life tables with all the usual columns for Ethiopia, 2019



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BSETH 2019

AGE       M(X,N)      Q(X,N)      I(X)       D(X,N)     L(X,N)    S(X,N)         T(X)       E(X)       A(X,N)

  0       .03363      .03268     100000.      3268.      97178.   .95478 /A/   6623446.    66.234      0.136
  1       .00722      .02840      96732.      2747.     380210.   .97769 /B/   6526268.    67.468      1.555
  5       .00273      .01356      93985.      1274.     466740.   .98940       6146058.    65.394      2.500
 10       .00153      .00760      92711.       705.     461792.   .99177       5679318.    61.258      2.500
 15       .00186      .00924      92006.       850.     457991.   .98915       5217525.    56.709      2.601
 20       .00252      .01253      91156.      1142.     453020.   .98662       4759535.    52.213      2.583
 25       .00283      .01406      90014.      1266.     446960.   .98510       4306515.    47.843      2.543
 30       .00319      .01583      88748.      1405.     440298.   .98297       3859555.    43.489      2.550
 35       .00372      .01843      87343.      1610.     432800.   .97954       3419257.    39.147      2.568
 40       .00460      .02273      85733.      1949.     423943.   .97493       2986457.    34.834      2.577
 45       .00565      .02786      83784.      2334.     413317.   .96727       2562514.    30.585      2.599
 50       .00784      .03847      81450.      3133.     399790.   .95507       2149197.    26.387      2.619
 55       .01081      .05268      78317.      4126.     381827.   .93491       1749407.    22.338      2.635
 60       .01669      .08032      74191.      5959.     356972.   .89922       1367580.    18.433      2.654
 65       .02668      .12551      68232.      8564.     320998.   .84137       1010608.    14.811      2.646
 70       .04387      .19855      59668.     11847.     270077.   .75335        689610.    11.557      2.614
 75       .07161      .30470      47821.     14571.     203464.   .63008        419533.     8.773      2.554
 80       .11631      .44845      33250.     14911.     128197.   .48228        216070.     6.498      2.448
 85       .17856      .60200      18339.     11040.      61827.   .33737         87872.     4.792      2.295
 90       .25870      .73928       7299.      5396.      20858.   .21860         26045.     3.568      2.102
 95       .35156      .84235       1903.      1603.       4560.   .12096 /C/      5187.     2.726      1.909
100       .47815      .....         300.       300.        627.   .....            627.     2.091      2.091

  /A/ VALUE GIVEN IS FOR SURVIVORSHIP OF 5 COHORTS OF BIRTH TO AGE GROUP 0-4 = L(0,5)/500000
  /B/ VALUE GIVEN IS FOR S(0,5)=L(5,5)/L(0,5)
  /C/ VALUE GIVEN IS S( 95+,5)=T(100)/T( 95)
```

Overall life expectancy at birth of both sexes combined increased by 16.977 years, from 49.259 years in 1990 to 66.236 years in 2019. This increase was driven by improvements in mortality rates at all ages. The greatest increase in life expectancy occurred at birth. Infants and children have also shown increases in life expectancy of 13.335 and 10.623 years respectively. In the extreme old ages (85+ years), life expectancy decreased.

As indicated by the trend lines' negative slopes, life expectancy is declining with time in both scenarios. In addition, the slope of the red trend line - the upper line - is steeper than that of the blue (lower) trend line. This indicates that with every year of age that went by in 2019, life expectancy declined more swiftly than it did in 1990. The y – intercept for the trend line of the year 2019 is 72.006 means that the life expectancy at birth for 2019 was predicted to be 72.006 years by the trend line. The reality is however, it was 66.236 years. The variation has resulted from the fact that the distribution of the data points (life expectancies) were not evenly distributed; many factors such as life style, diet, access to healthcare, and many more factors that affect life expectancy were not included in the model and they likely skewed the trend lines.

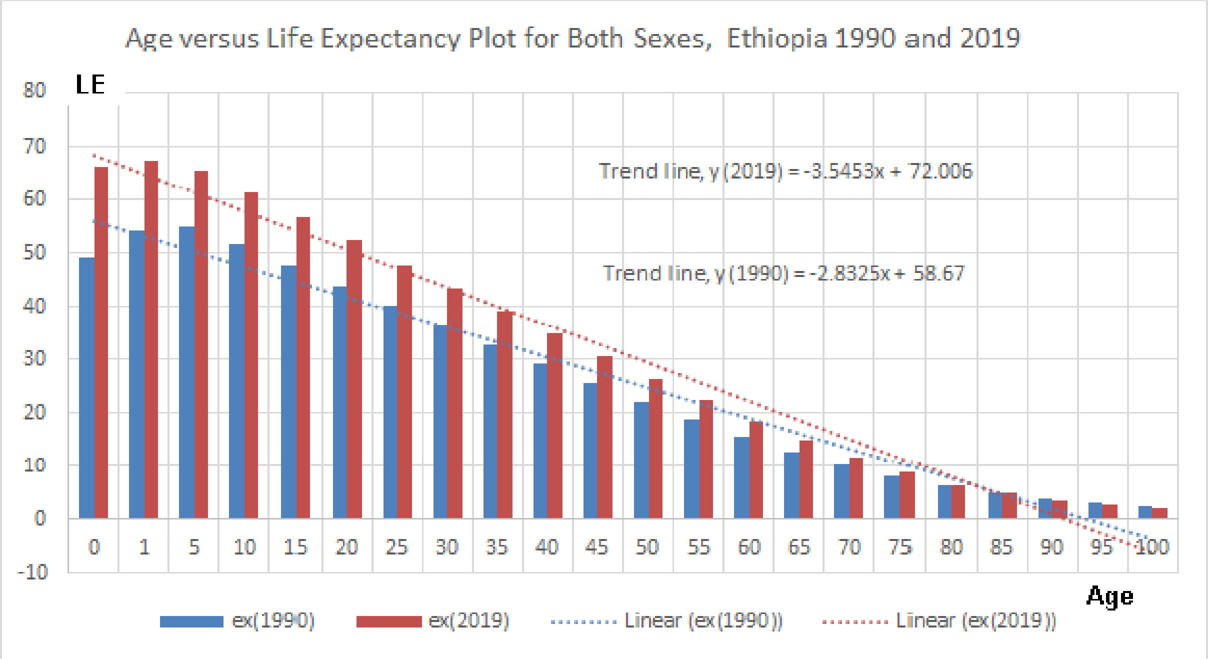


Figure 9: Age versus life expectancy plot for both sexes of Ethiopia for the years 1990 and 2019

4.2.2 Survival probabilities over the past three decades, Ethiopia

Survival probability at birth has increased by 0.07451, from 0.89281 in 1990 to 0.96732 in 2019. This indicates that the likelihood of a newborn surviving to reach age 1 has increased by 0.07451. Put another way, people in this age group who are experiencing this increase in survival probability are now 7.451% more likely to survive a given time or ordeal than they were previously.

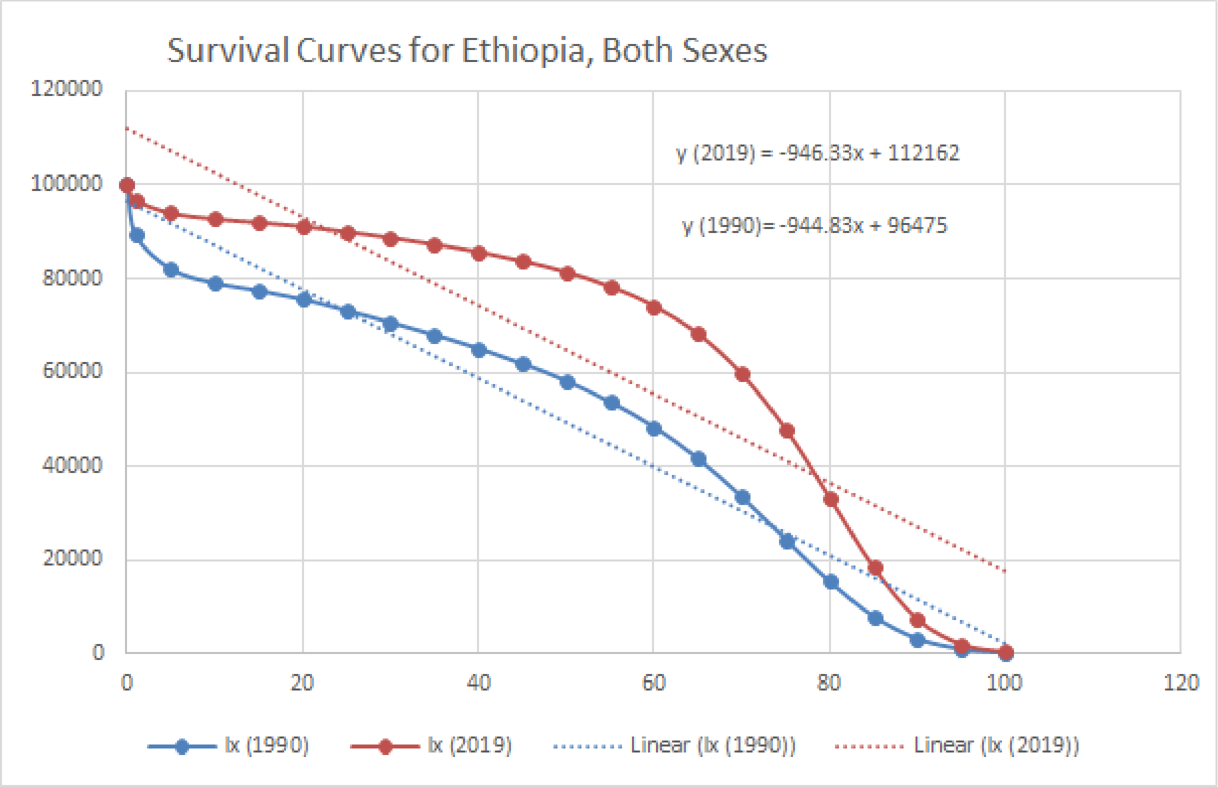


Figure 10: Age Vs Survivor Plot for Both Sexes of Ethiopia, 1990 and 2019

The y - intercept of the trend line of the 2019 survival curve at 112,162 is greater than the radix of 100,000. This implies that over a thirty - year period, Ethiopia had experienced a high overall mortality rate despite overall improvements in reducing mortality in relative terms.

Besides, Ethiopia's survival curve for 2019 has a trend line $y\,(2019)$ with a slope of -946.33, which is slightly steeper than that of the 1990 curve, $y\,(1990)$ which reads -944.83. This suggests that compared to 1990, the number of survivors decreased at a comparatively rapid rate in 2019.

4.2.3 Infant mortality rate comparisons over the past three decades, Ethiopia

In 1990, the infant mortality rate was 0.10719, or 107.19 infant deaths for every 1000 live births. Likewise, the infant mortality rate of the year 2019 was 0.03268 indicates that for every 1000 live births, there were 32.68 infant deaths. The IMR in Ethiopia decreased significantly from 107.19 per thousand in 1990 to 32.68 in 2019. This represents a reduction of approximately 69.5%. Here are some references gathered from the various

Ethiopian Demographic and Health Surveys (EDHS) conducted in the years 2000, 2005, 2016, and 2019 for additional analysis of the trends in infant mortality rates in Ethiopia's regional states.

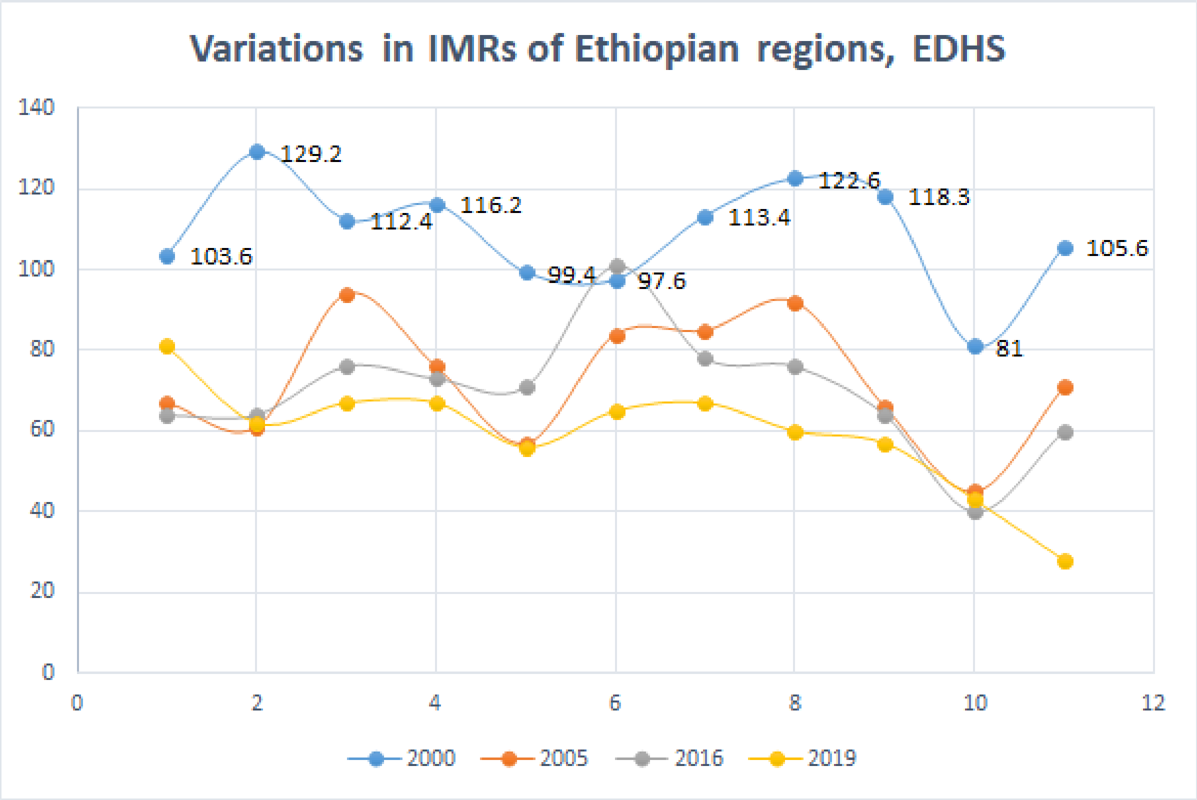


Figure 11: Region Vs IMR graph based on EDHS 2000, 2005, 2016, and 2019

The curves' alternating concavities show that there have been significant regional differences in infant mortality rates. The ages of 108.6, 112.4, 48.2, and 14.5 were the mean, median, range, and standard deviation in the 2000's curve, respectively.

4.1.3.1 Observations

The data distribution appears to have been reasonably symmetrical based on the close proximity of the mean and median IMRs. The 48.2 range in the 2000's curve indicates a notable difference in IMRs between the regions. The observed variability in the 2000's curve is supported by the 14.5 standard deviation.
The mean, median, and range ages are 51.45, 50, and 53, respectively, based on the 2019 IMR curve. The fact that the mean and median ages are nearly equal suggests that there may have been some symmetry. While there was an improvement in the level of lowering IMRs, the variability did not change over the period 2000 to 2019.

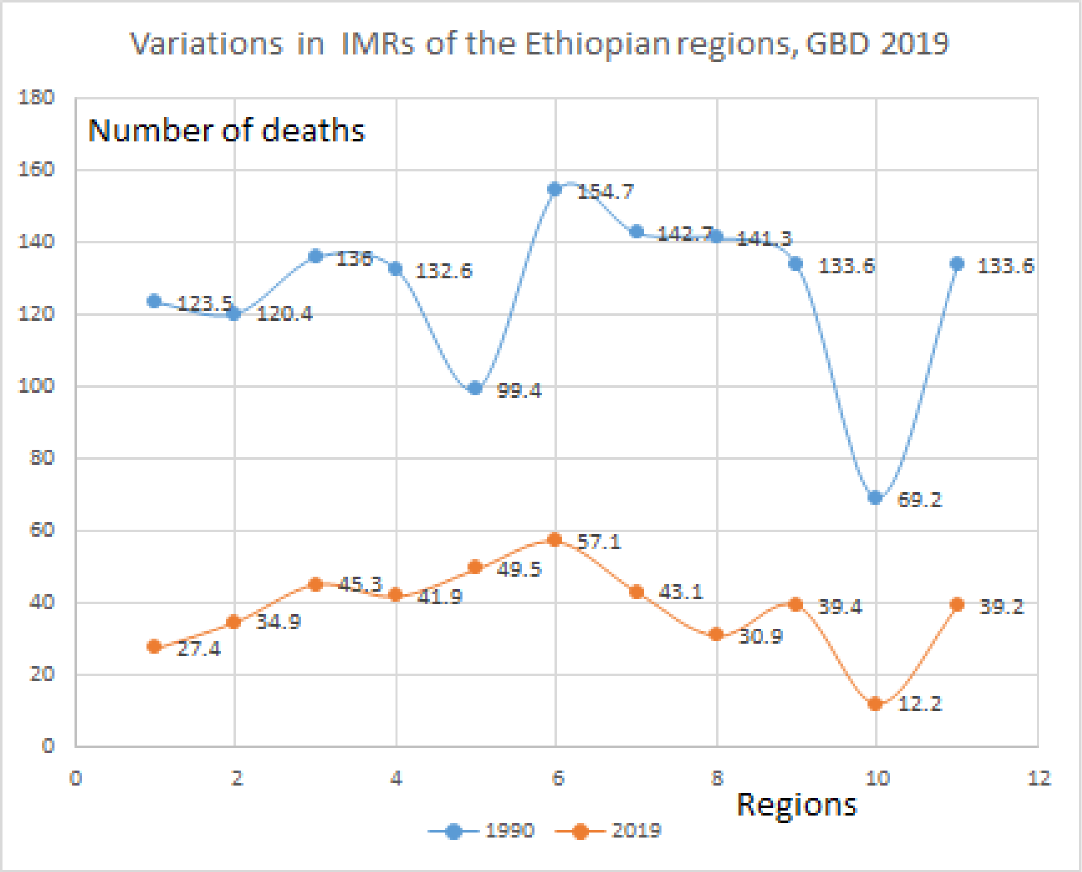
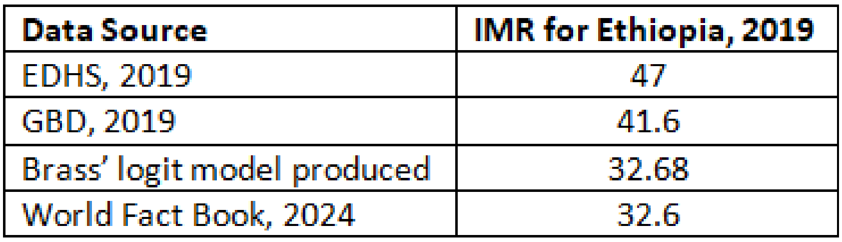


Figure 12: Region Vs IMR graph based on GBD, 2019

These two curves, which are based on the Global Burden of Disease Study 2019, depict the variations in IMRs that the various regions have attained over a thirty - year span. These IMR data saw mean and median changes of 90.5 and 94.2, respectively. The significant decline in the mean suggests that infant survival has significantly improved overall across the regions in 2019, and the decline in the median age suggests that the middle value of the distribution of infant mortality rates has considerably shifted downwards meaning that half of the regions have lower rates than in the past.

The IMRs of Addis Ababa and Tigray, represented by Regions 10 and 1, respectively, saw changes of -82.4% and -77.7%. Various sources reported varying rates of infant mortality for Ethiopia in 2019. One factor among many could be the fact that they employed various techniques and data sources. Here are some of the data that were collected from those sources and also the outcomes of the model that was created.

Table 13: IMRs for Ethiopia from different sources



Data Source	**IMR for Ethiopia, 2019**
EDHS, 2019	47
GBD, 2019	41.6
Brass' logit model produced	32.68
World Fact Book, 2024	32.6

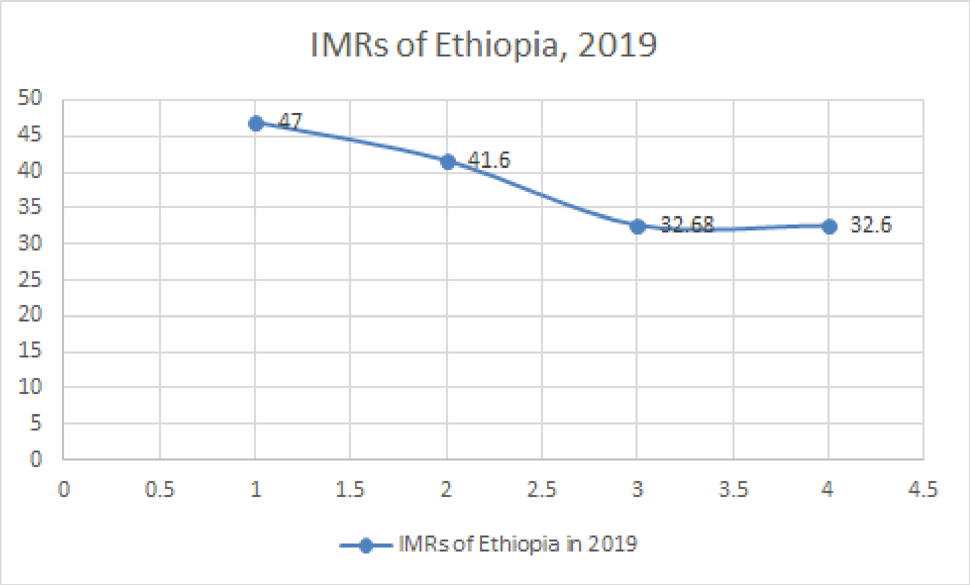


Figure 13: Data Source Vs IMR of Ethiopia, 2019

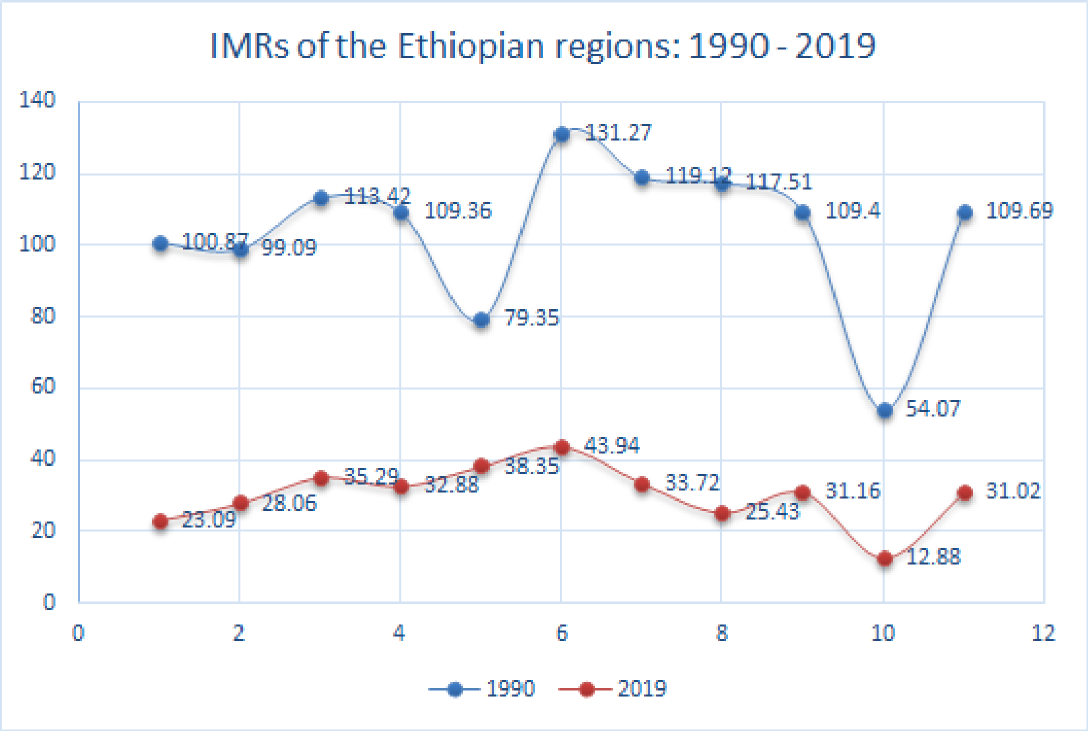


Figure 14: Region Vs IMR sketches based on The Brass' logit model produced: 1990 - 2019

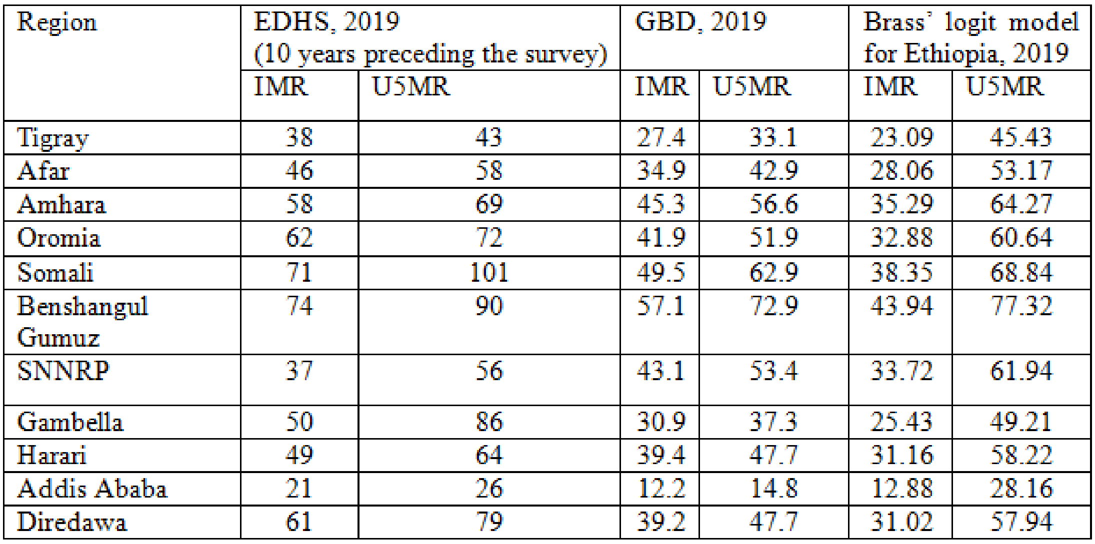
Over a thirty - year period, all regions saw a relatively significant decrease in infant mortality rates, as is easily observed and roughly understood only from the graphical observations. The fact that the 2019 curve is softer than the 1990 one is more proof that not only levels of infant mortality rates declined but also rate variability has improved over time.

In the 1990s, Somali's Region 5, as is represented by these data in order, had the second - lowest infant mortality rate in the nation. However, over the next thirty years, it lost its position and, worst of all, in 2019 it rose to the second - highest. Benshangul - Gumuz of region 6 had the highest infant mortality rate in the 1990s and it remained the highest after thirty years in 2019 despite a total change of -66.53%. In the beginning, Addis Ababa held the top spot with the lowest level and managed to hold onto it with a successful change of -71.73% until 2019.

Over the course of the thirty years, there have been some remarkably notable improvements in infant mortality rates, with the average percentage change across all regions being -72.96%. However, there are still high rates that require improvement, and there are variations among the regions.

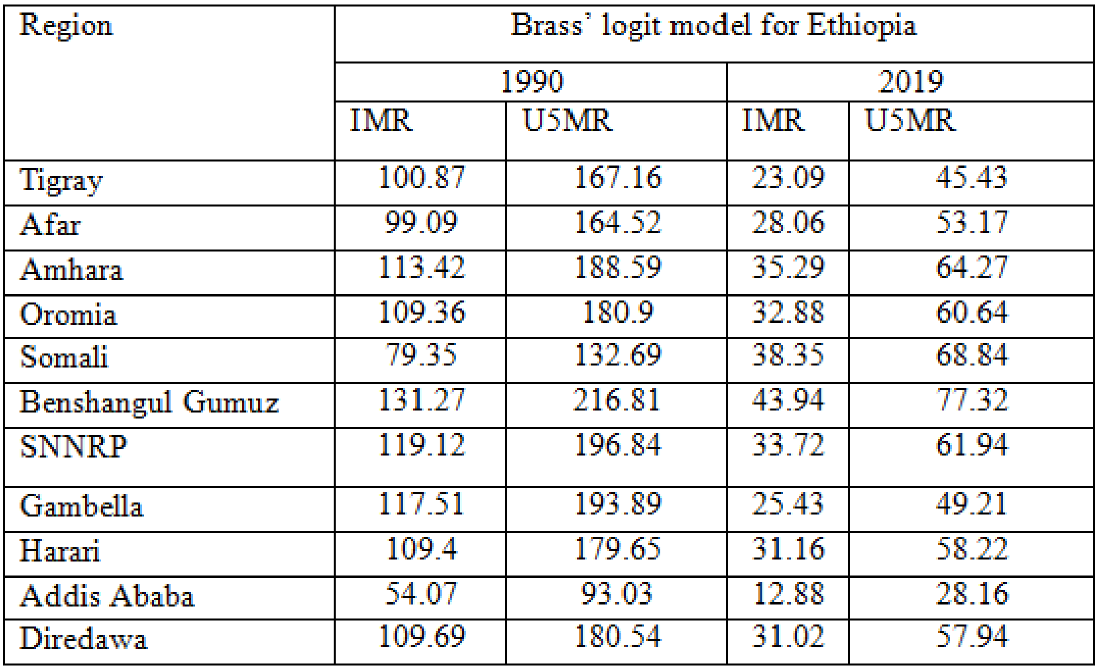
4.2.4 Under - five mortality rate comparisons over the past three decades, Ethiopia

Table 14: IMRs and U5MRs for the regions from EDHS 2019, GBD 2019, and The Brass' logit model produced



Region	EDHS, 2019 (10 years preceding the survey)		GBD, 2019		Brass' logit model for Ethiopia, 2019	
	IMR	U5MR	IMR	U5MR	IMR	U5MR
Tigray	38	43	27.4	33.1	23.09	45.43
Afar	46	58	34.9	42.9	28.06	53.17
Amhara	58	69	45.3	56.6	35.29	64.27
Oromia	62	72	41.9	51.9	32.88	60.64
Somali	71	101	49.5	62.9	38.35	68.84
Benshangul Gumuz	74	90	57.1	72.9	43.94	77.32
SNNRP	37	56	43.1	53.4	33.72	61.94
Gambella	50	86	30.9	37.3	25.43	49.21
Harari	49	64	39.4	47.7	31.16	58.22
Addis Ababa	21	26	12.2	14.8	12.88	28.16
Diredawa	61	79	39.2	47.7	31.02	57.94

Table 15: IMRs and U5MRs from the Brass' logit model produced: 1990 - 2019



Region	Brass' logit model for Ethiopia			
	1990		2019	
	IMR	U5MR	IMR	U5MR
Tigray	100.87	167.16	23.09	45.43
Afar	99.09	164.52	28.06	53.17
Amhara	113.42	188.59	35.29	64.27
Oromia	109.36	180.9	32.88	60.64
Somali	79.35	132.69	38.35	68.84
Benshangul Gumuz	131.27	216.81	43.94	77.32
SNNRP	119.12	196.84	33.72	61.94
Gambella	117.51	193.89	25.43	49.21
Harari	109.4	179.65	31.16	58.22
Addis Ababa	54.07	93.03	12.88	28.16
Diredawa	109.69	180.54	31.02	57.94

Ethiopia has achieved a noteworthy decrease in under - five mortality rate over the past few decades, going from 179.33 per 1000 live births in 1990 to 60.15 in 2019. This represents a remarkable 66% decline in 30 years. Although this country has made some impressive progress in reducing under - 5 mortality, it is still falling short of the global average, which in 2019 according to UN (2020) was 38 deaths per 1000 live births.

Observations based on regional specifics

Over the past three decades, there have been comparatively significant changes in all of Ethiopia's regional states regarding the decline in under - five mortality rates. In 1990, the average under - five death rate for all regions was 175.05, but in 2019 it was 57.69, representing a reduction of over 67%. This significant decline indicates a general improvement in the children's survival rate. The median of these mortality rates also declined from 180.54 to 58.22 over the given number of years. The fact that the mean and median of the updated data are nearly equal suggests that the regional mortality rates have decreased and are now concentrated around the central point, which is also another sign of improvement.

The range of the mortality rates dropped from 123.78 to 49.16 in terms of variability, which shows a decline in the variability of mortality rates over time. Additionally, the rates' distribution has gotten more symmetrical, indicating that the data points are nearly equally distributed on both sides of the mean and that most regions have attained comparable low death rates.

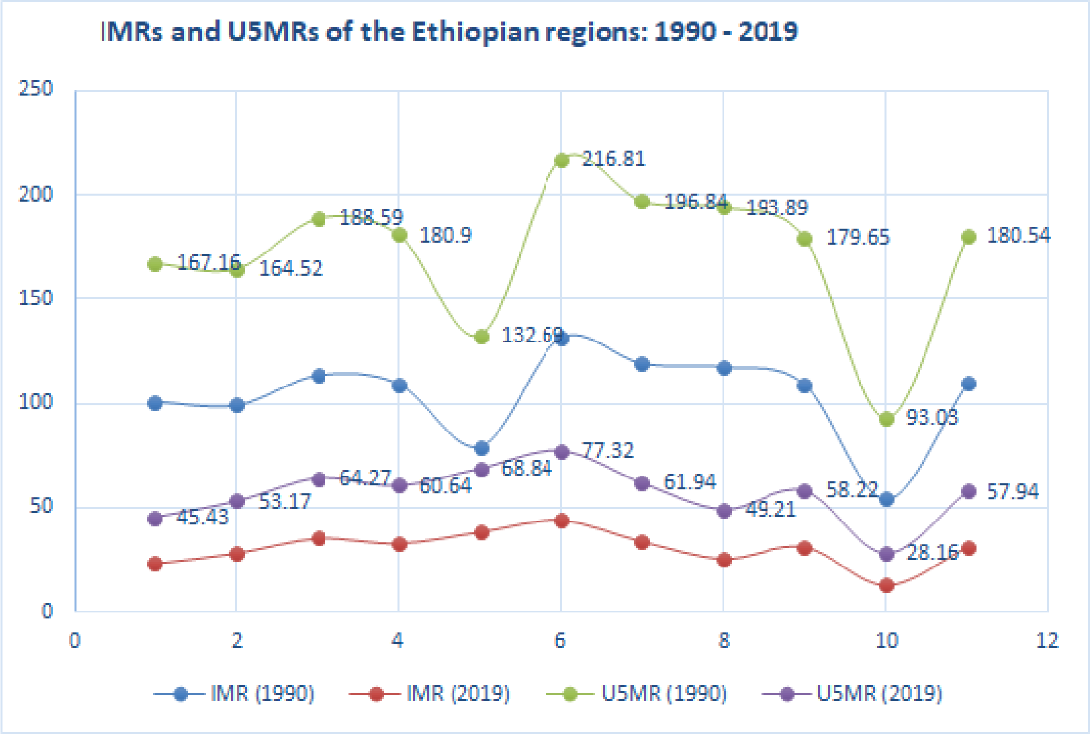


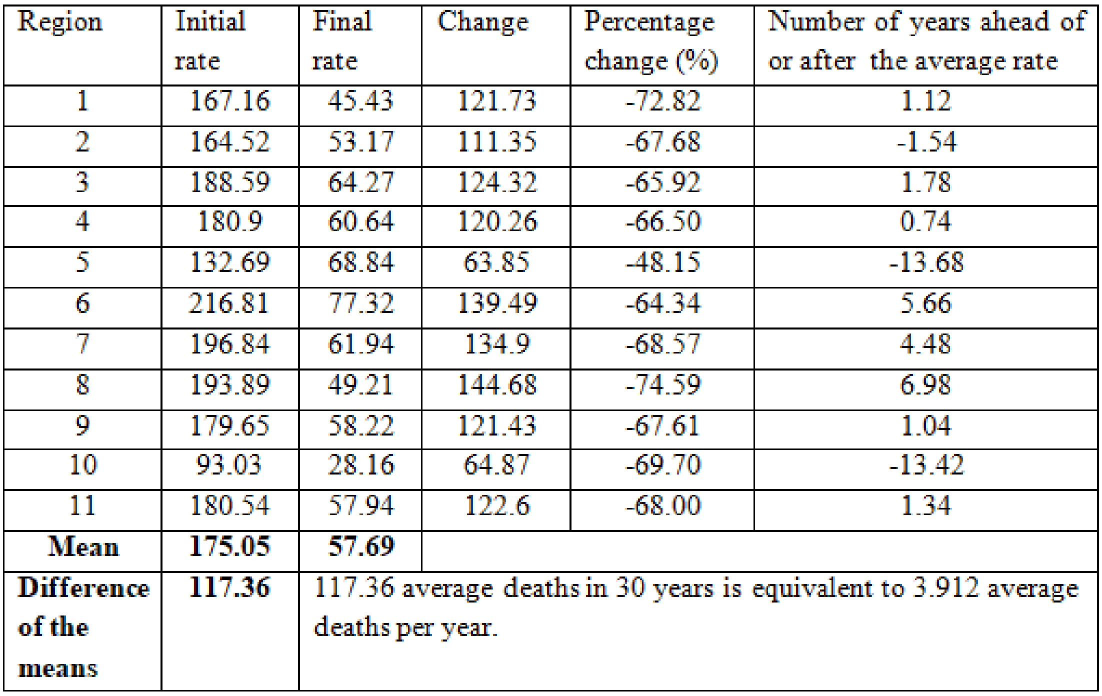
Figure 15: Region vs IMR and U5MR sketches from The Brass' logit model produced: 1990 - 2019

There appears to have been significant regional variation based on the sharply sloping ups and downs seen in the 1990s under - five mortality curve for different intervals or sets of values. Significant variation was observed in the rates, which ranged from 93.03 in Addis Ababa, region 10, to 216.81 in Benshangul - Gumuz, region 6. This represents an astonishing difference of 123.78 deaths per 1000 live births between two regions within the same nation.

Nevertheless, after thirty years, the overall curve pattern softened and had mild slopes between any two sets of values, indicating notable decreases in regional variability. Addis Ababa and Benshangul - Gumuz maintained their positions as the lowest and highest rates, ranging from 28.16 to 77.32 per 1000 live births, respectively, even after those all - around improvements in 30 years but with an improved difference of 48.16.

Over the past thirty years the average change in U5MR of the regions has been $175.05 - 57.69 = 117.36$. This means 3.912 deaths have been reduced each year on average.

Table 16: U5MR percentage change and annual average death rates of the regions of Ethiopia



Region	Initial rate	Final rate	Change	Percentage change (%)	Number of years ahead of or after the average rate
1	167.16	45.43	121.73	-72.82	1.12
2	164.52	53.17	111.35	-67.68	-1.54
3	188.59	64.27	124.32	-65.92	1.78
4	180.9	60.64	120.26	-66.50	0.74
5	132.69	68.84	63.85	-48.15	-13.68
6	216.81	77.32	139.49	-64.34	5.66
7	196.84	61.94	134.9	-68.57	4.48
8	193.89	49.21	144.68	-74.59	6.98
9	179.65	58.22	121.43	-67.61	1.04
10	93.03	28.16	64.87	-69.70	-13.42
11	180.54	57.94	122.6	-68.00	1.34
Mean	**175.05**	**57.69**			
Difference of the means	**117.36**	117.36 average deaths in 30 years is equivalent to 3.912 average deaths per year.			

This table of details shows that, in comparison to the national average of U5MRs, region 1 of the regional state of Tigray was 1.12 years ahead. This indicates that, over the course of thirty years, it had been successful in reducing $30 + 1.12 = 31.12 * 3.912 = 121.74$ deaths, as if it had been operating with the national average for 31.12 years. Comporably, region 2 was 1.54 years after the national average is meant that it had achieved reductions in U5MRs as if it were working for 28.46 years with the national average constantly.

Although region 10 had one of the lowest death rates, regions 5 and 10 were both more than 13 years behind the national average. Although this may seem contradictory, region 10 was the lowest from the start because of its stronger foundation rather than because its rates had consistently been comparable to or above the national average. The mortality rates in Regions 7 and 8 were remarkably lower than the national average, as if they had been operating for 34.48 and 36.98 years, respectively, at the national average rate all along.

4.2.5 Comparison of sex differentials over the past three decades, Ethiopia

In both the reference years 1990 and 2019, females had higher record of life expectancies than males at all ages. The largest sex differential in life expectancy was observed in the infancy stage, where females had a life expectancy of 7.706 years longer than males in 1990 and 4.491 years longer in 2019. This means the sex differential in life expectancy at birth decreased significantly from 7.706 years to 4.491 years over the period of thirty years. This may be a good indication that public health policies and interventions had been working on improving the health and well - being of both sexes and had succeeded in narrowing the gaps in life expectancies while general increment is there.

Overall sex disparity

Females consistently have lower mortality rates than males across all age groups. This suggests that, in this particular situation, females have an advantage over males in terms of survival.

Age - specific sex disparity

Infants: Based on the abridged life tables, the male and female IMRs were calculated to be 37.84 and 32.64, respectively. This means that there is a sex disparity in IMR of 5.2 deaths per 1000 live births, with males having a higher mortality rate.

Under - five children: The U5MRs for males and females were, respectively, 67.17 and 60.36. Thus, the gender disparity in U5MR is 6.81 deaths per 1000 live births, with males having a higher relative mortality rate once more.

Children: Male and female child mortality rates were 30.48 and 28.65, respectively. The child mortality rate (CMR) reveals a sex disparity of 1.83 deaths per 1000 live births, with males continuing to have a higher mortality rate.

Relative sex disparity

$IMR : (37.84/32.64) - 1 = 0.16$

$U5MR : (67.17/60.36) - 1 = 0.11$

$CMR : (30.48/28.65) - 1 = 0.06$

Based on the age groups chosen, these values show a small to moderate sex disparity in mortality rates, with males having a 16% to 6% higher risk of dying than females.

However, there still remains a sex differential in life expectancy at birth that needs to be addressed. The smallest sex differential occurred in the extreme old ages.

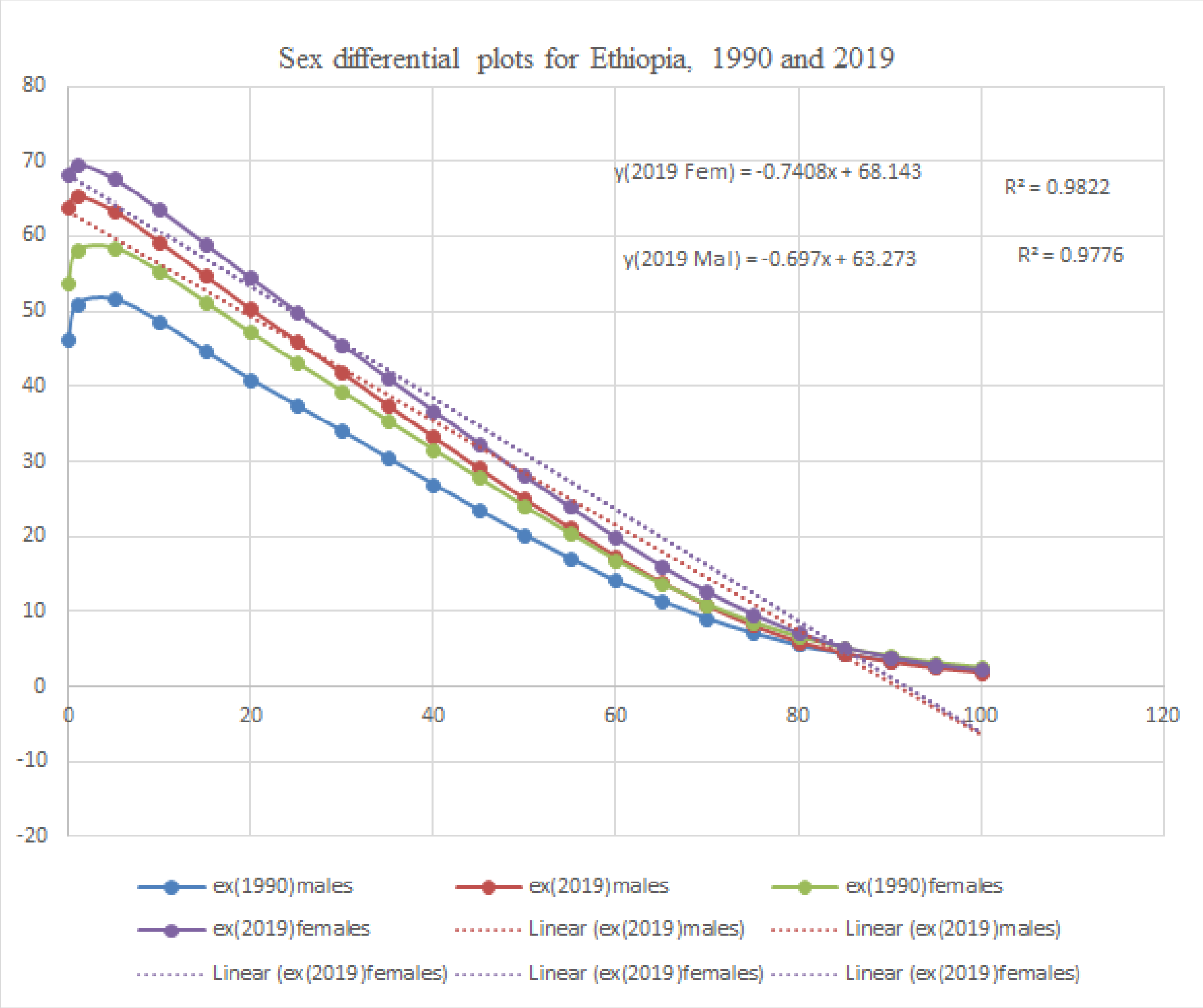


Figure 16: Age Vs Life Expectancy Plot by Sex of Ethiopia for the years 1990 and 2019

The trend lines here are regression lines that best fit their respective data points (life expectancies at different ages) in a straight line. The trend lines predicted that the life expectancies at birth for males and for females in 2019 were respectively 63.273 and 68.143 years. The actual calculated values were respectively 63.858 and 68.349 years. Because the trend lines were good estimates of the actual data points, inferences made from the trend lines meant inferences made for the actual data points. Life expectancy decreased by 0.74 years for every year of age for males and by 0.70 years for every year of age for females. The R^2 values show that the trend lines for males and for females explain 98.2% and 97.76% of the variations in the data – which is a good fit.

4.3 Comparative analysis of mortality trends and life expectancies in Ethiopia: insights from the model – based abridged life tables

Essential information regarding population dynamics and health outcomes can be obtained from life tables. Directly creating abridged life tables is not feasible in Ethiopia due to the absence of accurate and current mortality data. Therefore, a useful substitute for estimating mortality experiences is to use model - based abridged life tables. The purpose of this section of the study was to estimate the mortality experience of Ethiopia's regional states by creating model - based abridged life tables. Information from the Global Burden of Disease Study 2019 and the United Nations World Population Prospects 2022 web source was used. The abridged life tables were produced using the UN Population Division's MORTPAK LITE software and Brass' logit method. The findings indicated that during the previous three decades, life expectancy at birth had significantly increased in all regional states, and age - specific mortality rates had dropped for both sexes and all age groups. The study came to the conclusion that disparities in mortality patterns still exist among the regions and that they will take decades to catch up to the current global average life expectancy standard of 73 years.

Full abridged life tables for Ethiopia and for some selected regional states were produced. A table containing life expectancy at birth of 1990 and 2019 for Ethiopia and for all its regional states was also developed to complement the whole analysis. The findings suggest that there had been substantial progress in reducing mortality in Ethiopia over the past thirty years. They also revealed significant variations in mortality experiences across the regional states and between the sexes. Addis Ababa and Tigray had the highest life expectancies at birth, while Benshangul - Gumuz and Somali had the lowest.

The estimated infant mortality rates (IMRs) ranged from 12.88 deaths per 1000 live births in Addis Ababa to 43.94 in Benshangul - Gumuz. Under - five mortality rates (U5MRs) also exhibited sizeable variations among the regional states with the lowest in Addis Ababa (28.16 deaths per 1000 live births) and the highest rates in Benshangul - Gumuz (77.32 deaths per 1000 live births).

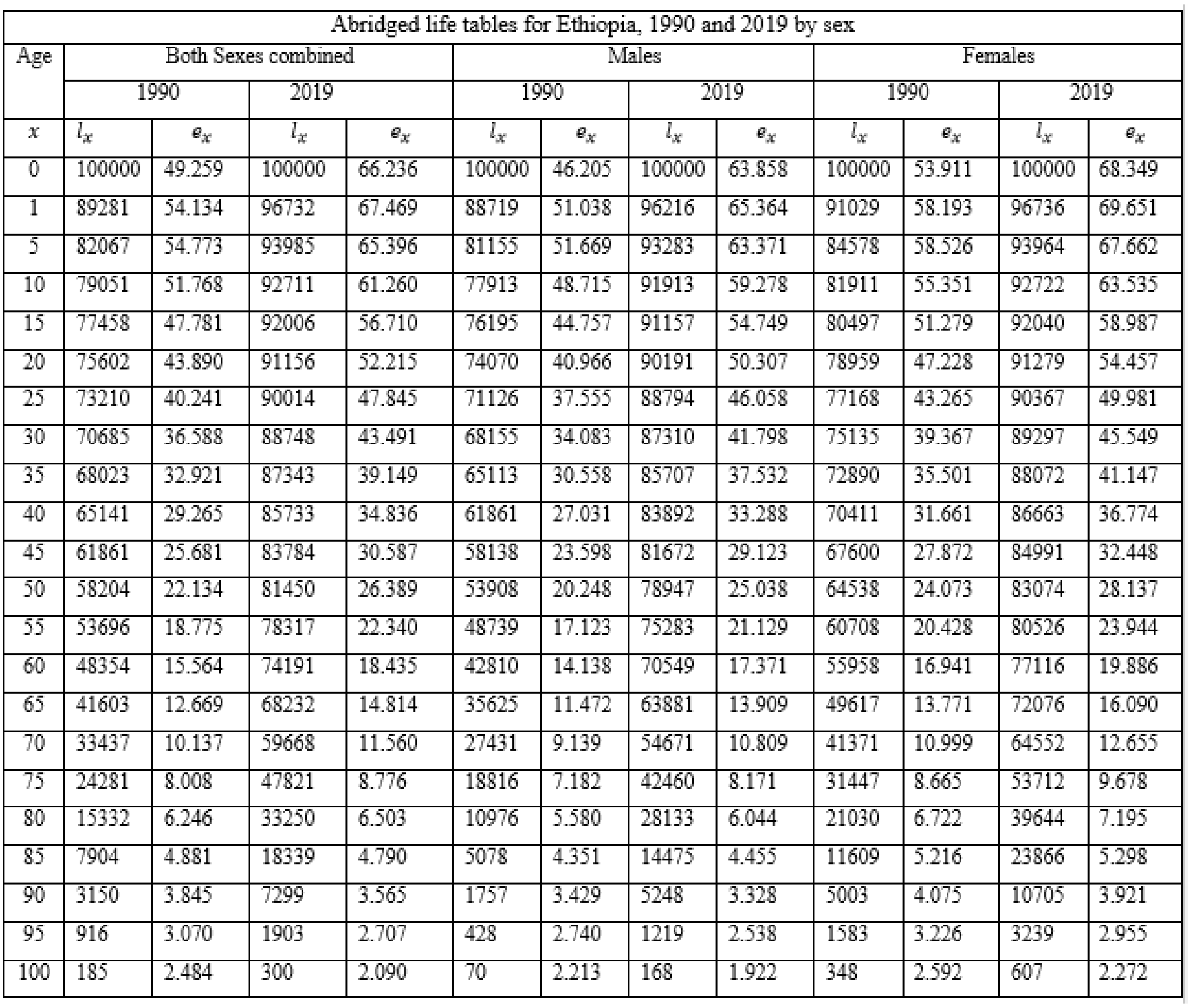
Because the continuous decline in child mortality is regarded as one of the most important achievements in public and population health of the past three decades (Ezbakhe and

Pérez-Foguet, 2020), these significant reductions in infant and under - five mortality rates over the past thirty years in Ethiopia, and specifically in each of its regional states, have been in agreement with the levels and trends of child mortality reduction achievements in the world.

The Brass' logit model produced abridged life tables for Ethiopia and for each of the regional states with estimates of life expectancy at birth ranging from 64.185 years in Benshangul - Gumuz to 69.483 years in Addis Ababa while the national average was 66.236 years.

The abridged life tables also provide estimates of mortality rates at various ages allowing for a detailed analysis of mortality patterns and disparities within each region.

Table 17: Abridged life tables for Ethiopia by sex: 1990 - 2019

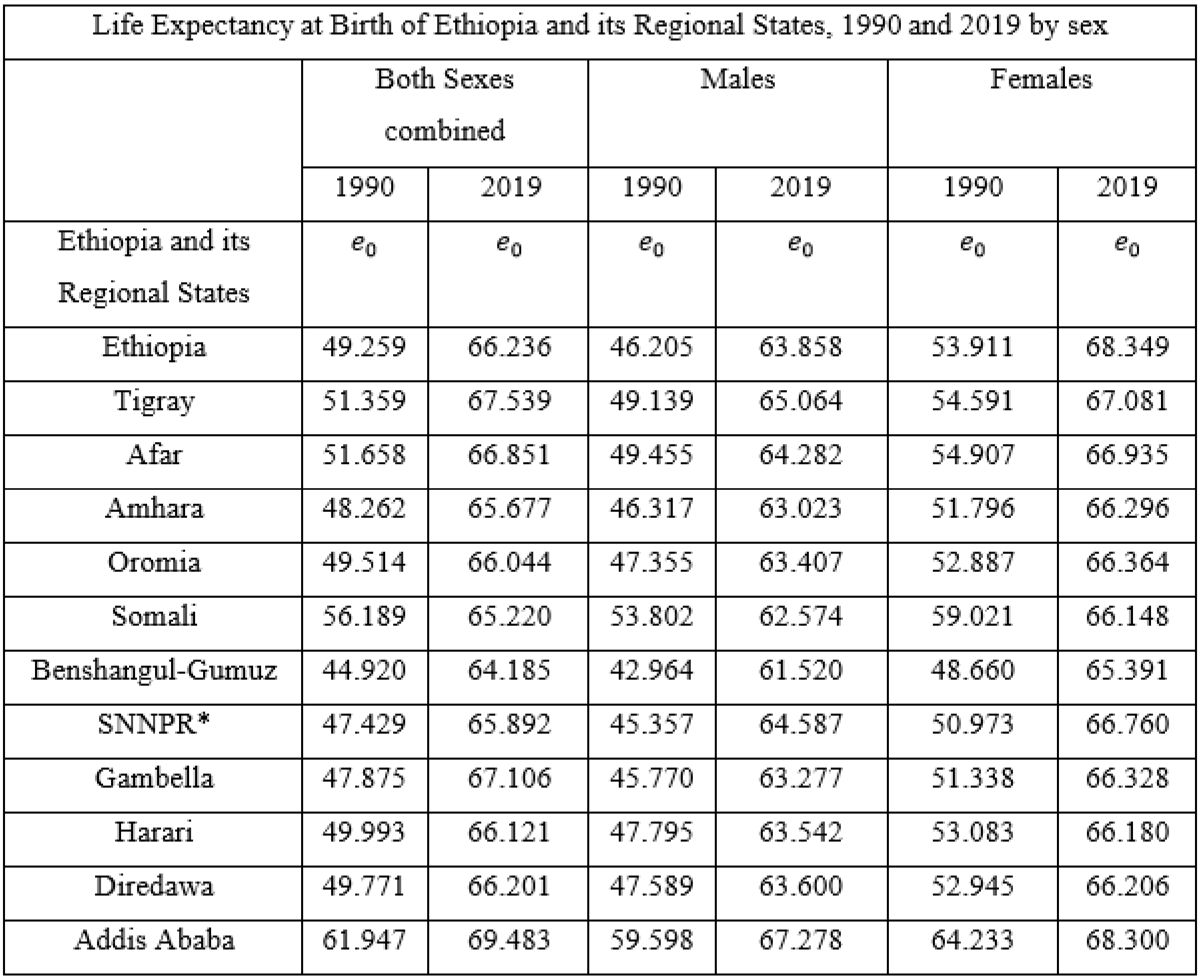


Abridged life tables for Ethiopia, 1990 and 2019 by sex

Age	Both Sexes combined				Males				Females			
	1990		2019		1990		2019		1990		2019	
x	l_x	e_x	l_x	e_x	l_x	e_x	l_x	e_x	l_x	e_x	l_x	e_x
0	100000	49.259	100000	66.236	100000	46.205	100000	63.858	100000	53.911	100000	68.349
1	89281	54.134	96732	67.469	88719	51.038	96216	65.364	91029	58.193	96736	69.651
5	82067	54.773	93985	65.396	81155	51.669	93283	63.371	84578	58.526	93964	67.662
10	79051	51.768	92711	61.260	77913	48.715	91913	59.278	81911	55.351	92722	63.535
15	77458	47.781	92006	56.710	76195	44.757	91157	54.749	80497	51.279	92040	58.987
20	75602	43.890	91156	52.215	74070	40.966	90191	50.307	78959	47.228	91279	54.457
25	73210	40.241	90014	47.845	71126	37.555	88794	46.058	77168	43.265	90367	49.981
30	70685	36.588	88748	43.491	68155	34.083	87310	41.798	75135	39.367	89297	45.549
35	68023	32.921	87343	39.149	65113	30.558	85707	37.532	72890	35.501	88072	41.147
40	65141	29.265	85733	34.836	61861	27.031	83892	33.288	70411	31.661	86663	36.774
45	61861	25.681	83784	30.587	58138	23.598	81672	29.123	67600	27.872	84991	32.448
50	58204	22.134	81450	26.389	53908	20.248	78947	25.038	64538	24.073	83074	28.137
55	53696	18.775	78317	22.340	48739	17.123	75283	21.129	60708	20.428	80526	23.944
60	48354	15.564	74191	18.435	42810	14.138	70549	17.371	55958	16.941	77116	19.886
65	41603	12.669	68232	14.814	35625	11.472	63881	13.909	49617	13.771	72076	16.090
70	33437	10.137	59668	11.560	27431	9.139	54671	10.809	41371	10.999	64552	12.655
75	24281	8.008	47821	8.776	18816	7.182	42460	8.171	31447	8.665	53712	9.678
80	15332	6.246	33250	6.503	10976	5.580	28133	6.044	21030	6.722	39644	7.195
85	7904	4.881	18339	4.790	5078	4.351	14475	4.455	11609	5.216	23866	5.298
90	3150	3.845	7299	3.565	1757	3.429	5248	3.328	5003	4.075	10705	3.921
95	916	3.070	1903	2.707	428	2.740	1219	2.538	1583	3.226	3239	2.955
100	185	2.484	300	2.090	70	2.213	168	1.922	348	2.592	607	2.272

The life expectancy at birth for both sexes in Ethiopia had increased significantly from 49.259 years in 1990 to 66.236 years in 2019, representing an increase of 16.977 years. This is an overall 34.47% increase in life expectancy over the course of thirty years. While the life expectancy at birth for males had shown a 38.21% increase over the whole course of the three decades from 46.205 years in 1990 to 63.858 years in 2019, the percentage increase of females had been only 27% increase from 53.911 years in 1990 to 68.349 years in 2019. Though it apparently seems that the percentage increase of the life expectancy at birth of males had been better than that of the females, the reality is that the males are 4.463 years lagging behind as the females are lagging behind by 4.651 years from the current global average, i.e., 73 years. Generally, there had been improvements in life expectancy across all age groups showing a positive trend in mortality reduction.

Table 18: Life Expectancy at Birth of Ethiopia and its Regional States, 1990 and 2019 by sex



Life Expectancy at Birth of Ethiopia and its Regional States, 1990 and 2019 by sex

	Both Sexes combined		Males		Females	
	1990	2019	1990	2019	1990	2019
Ethiopia and its Regional States	e_0	e_0	e_0	e_0	e_0	e_0
Ethiopia	49.259	66.236	46.205	63.858	53.911	68.349
Tigray	51.359	67.539	49.139	65.064	54.591	67.081
Afar	51.658	66.851	49.455	64.282	54.907	66.935
Amhara	48.262	65.677	46.317	63.023	51.796	66.296
Oromia	49.514	66.044	47.355	63.407	52.887	66.364
Somali	56.189	65.220	53.802	62.574	59.021	66.148
Benshangul-Gumuz	44.920	64.185	42.964	61.520	48.660	65.391
SNNPR*	47.429	65.892	45.357	64.587	50.973	66.760
Gambella	47.875	67.106	45.770	63.277	51.338	66.328
Harari	49.993	66.121	47.795	63.542	53.083	66.180
Diredawa	49.771	66.201	47.589	63.600	52.945	66.206
Addis Ababa	61.947	69.483	59.598	67.278	64.233	68.300

Addis Ababa, Tigray, and Gambella were generally the three top regional states according to their life expectancies in 2019, while Benshangul - Gumuz, Somali, and Amhara were the lowest three.

The following figures help us visualize and understand the improvements in survival and the disparities among regions as well as between the sexes.

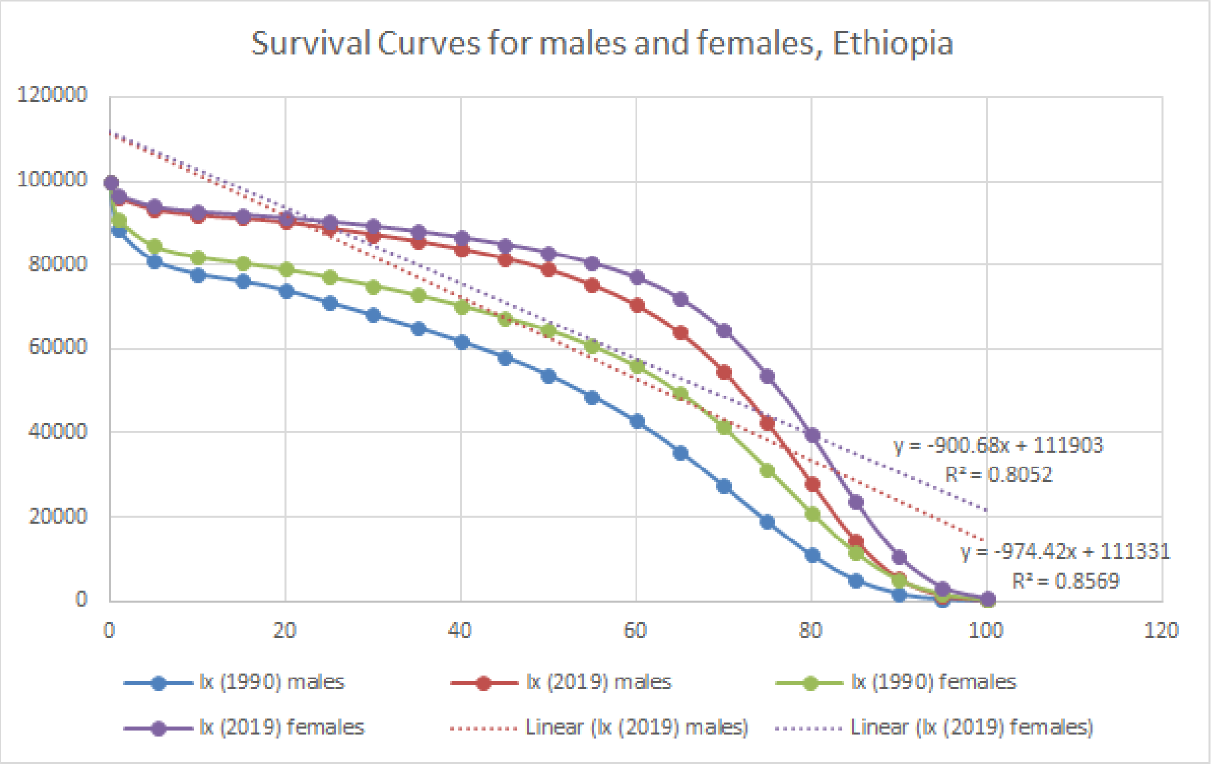


Figure 17: Age Vs Survivor by sex of Ethiopia, 1990 and 2019

The trend line slope for the male survivors of 2019 is -974.42, meaning that it is steeper than the female survivors' slope of -900.68. This indicates that the proportion of male survivors decreased more quickly than that of female survivors. From the R^2 values of the 2019 male and female survival curves, it is understood that more than 80% of the variations in the data were explained and showed a reasonably good fit.

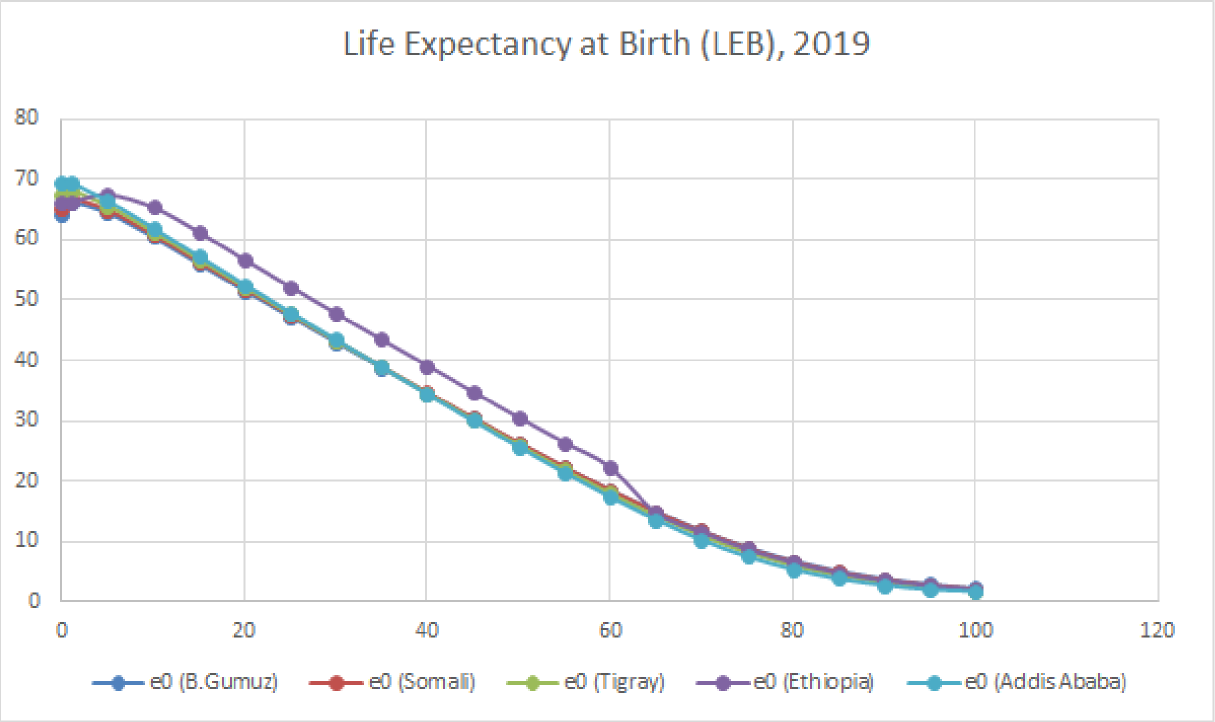


Figure 18: Age Vs LEB of Ethiopia and four of its regions with extreme values, 2019

The LEB curves show that Addis Ababa and Tigray had achieved relatively the highest life expectancy of under - five. However, from 5 to 65 years of age, the national life expectancy (that of Ethiopia) had been better than that of all the four regional states sampled out here. Between 60 and 65 years of age, the life expectancy of the nation sharply dropped from 22.34 years to 14.814 years with a difference of 33.689%.

4.4 Decomposing and measuring the change in life expectancies of Ethiopia and its regional states age - wise: 1990 - 2019

When analyzing changes in life expectancy at birth or studying differences in life expectancy between two populations, it is useful to estimate what mortality differences in a specific age group contribute to the total difference in life expectancy. The Arriaga method is a popular technique for decomposing life expectancy into direct and other effects by making use of the life table functions. This study aims to decompose the life expectancies of Ethiopia and its regional states into direct and other effects age - wise and assess the contributions of age groups, regions, and types of effect. The life expectancies of Ethiopia and its regional states were decomposed age - wise into direct and other effects using Arriaga method over 1990 - 2019. Results showed the life expectancy in Ethiopia increased from 49.3 years in 1990 to 66.2 in 2019. Of the types of effect, the other effect and of the age groups, infants and under five children were the main positive contributors to this increase. Regionally, no significant contribution differences were observed but Addis Ababa exhibited a negative other effect contribution in the old ages. Direct effect contribution was negligible in the age group of 0 - 4 years warns that improvements in life expectancy are due to indirect and interaction effects and thus further intervention is required to achieve direct effect improvements.

An age - wise breakdown of life expectancies of Ethiopia and a few selected regional states was conducted for the period 1990 to 2019. Life expectancies were broken down into components for Ethiopia and all of its states, but for the purpose of ease of analysis, only Ethiopia and four of its regional states: Addis Ababa, Tigray, Somali, and Benshangul Gumuz were included in the main body of analysis while the others were given in the Appendices section for further reference. 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.

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.

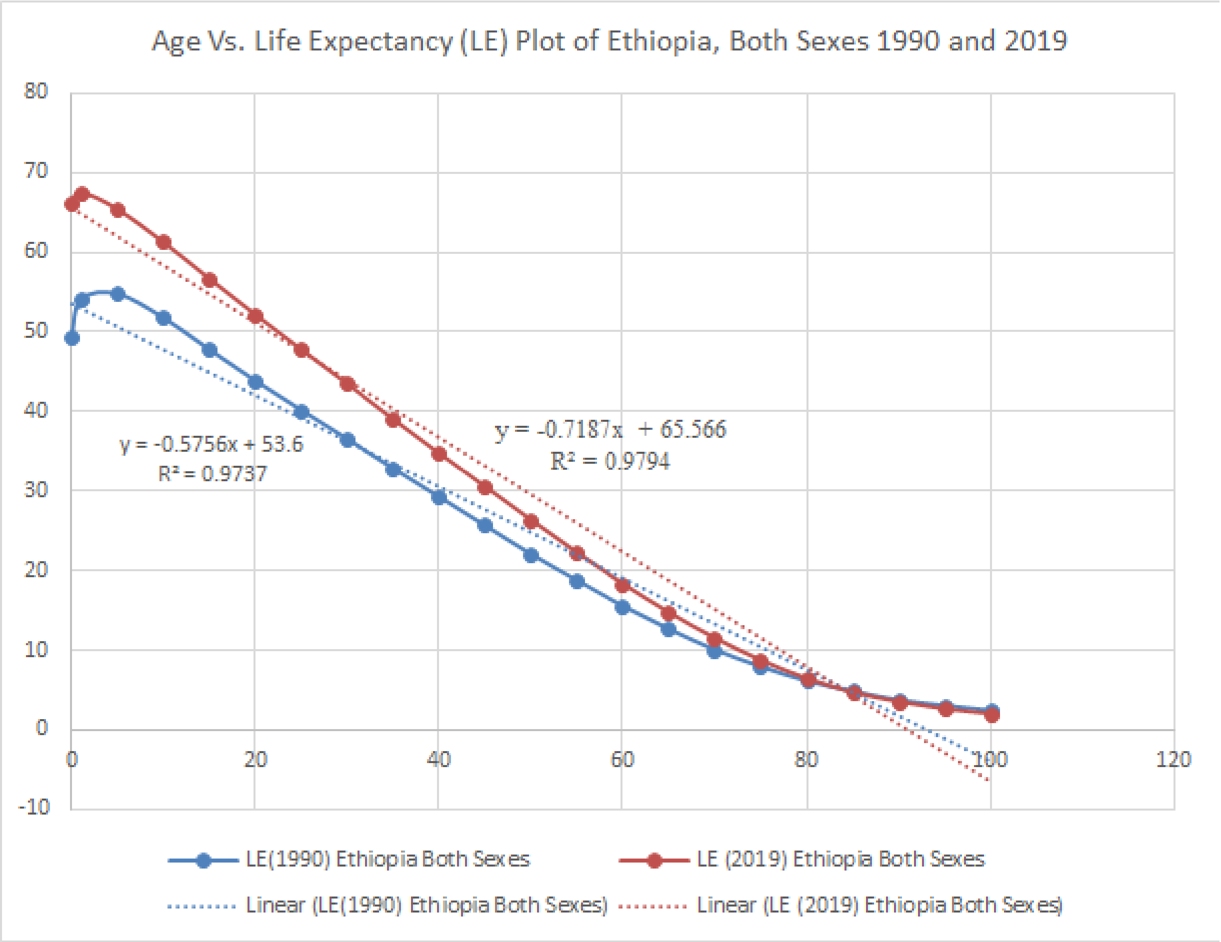


Figure 19: Age Vs Life Expectancy Plot of Ethiopia, Both Sexes 1990 - 2019

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.

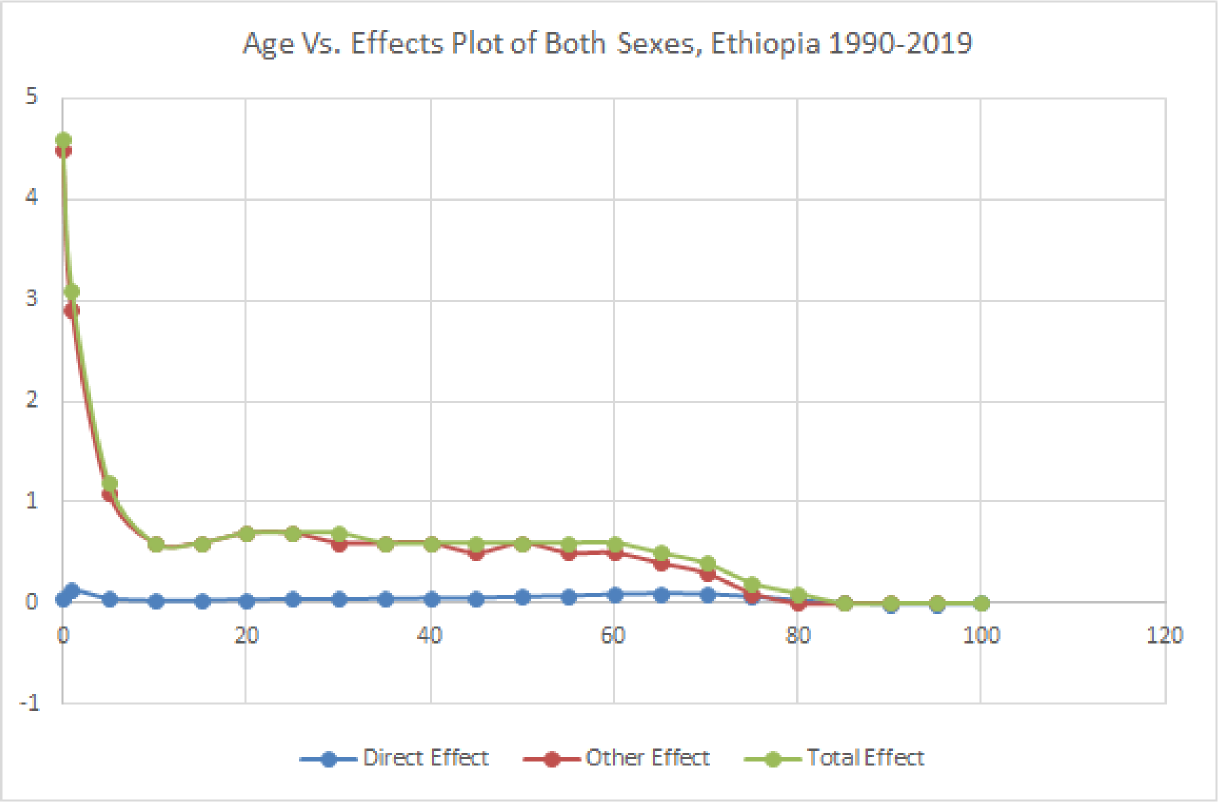


Figure 20: Age Vs Effect Type of Ethiopia, Both sexes, 1990 - 2019

The contribution of the direct effect to the total effect in life expectancy was relatively low as can be seen from the sketch. As a result, the other effect almost equaled 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. The direct effect contributions showed relatively higher values with age. From the start until about the age of 80, they kept getting bigger and bigger. At the age of 85, the other effect had disappeared, leaving only the direct effect. The other effect curve nearly matched the total effect curve across the plane, with the exception of a few age intervals, suggesting that the direct effect's contribution was usually insignificant.

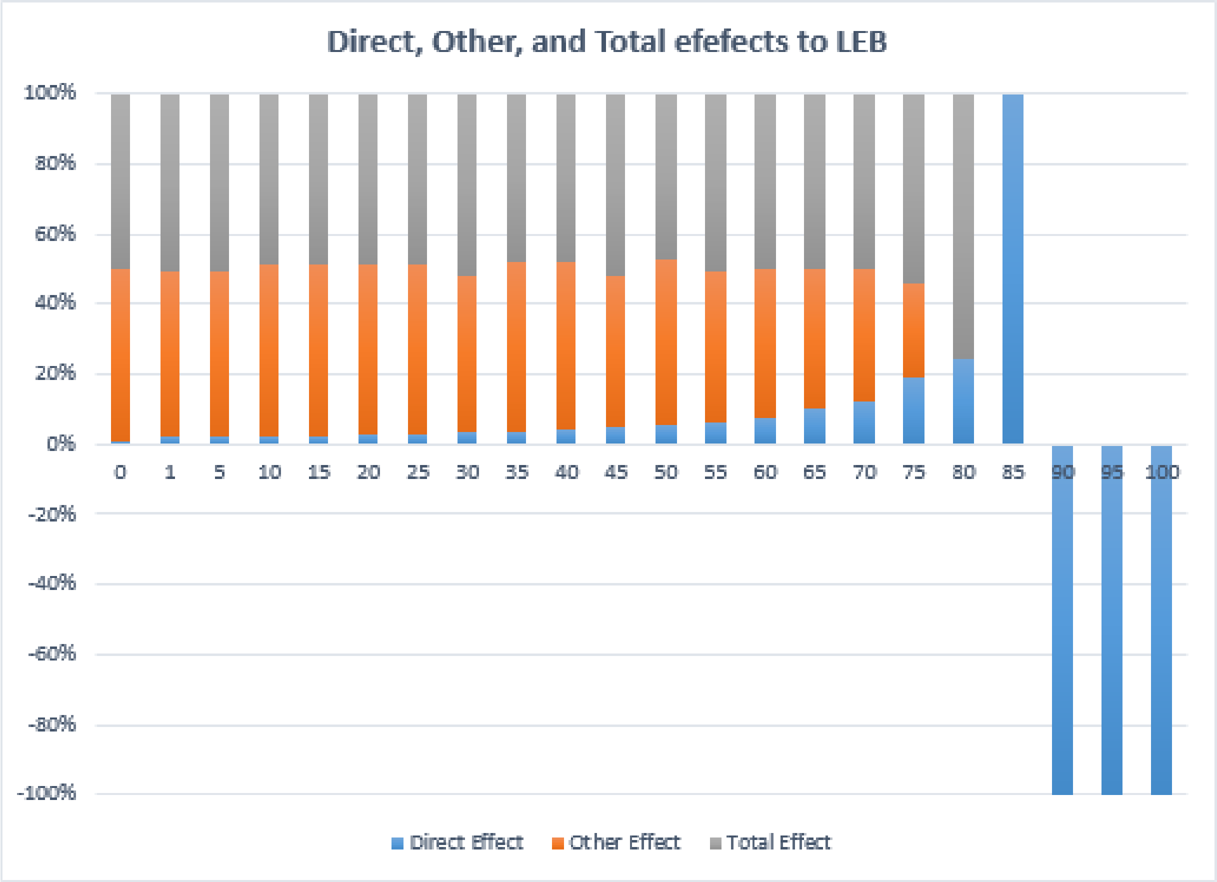


Figure 21: Age Vs Effect decomposition of LEB for Ethiopia: 1990 - 2019

The direct effect curve exhibits a J - shaped pattern, resembling the increasing death probability with increasing age. Both the other effect and the direct effect were found to be ineffective at very old ages, and at the worst, the direct effect had a negative contribution to the overall change in life expectancy at birth.

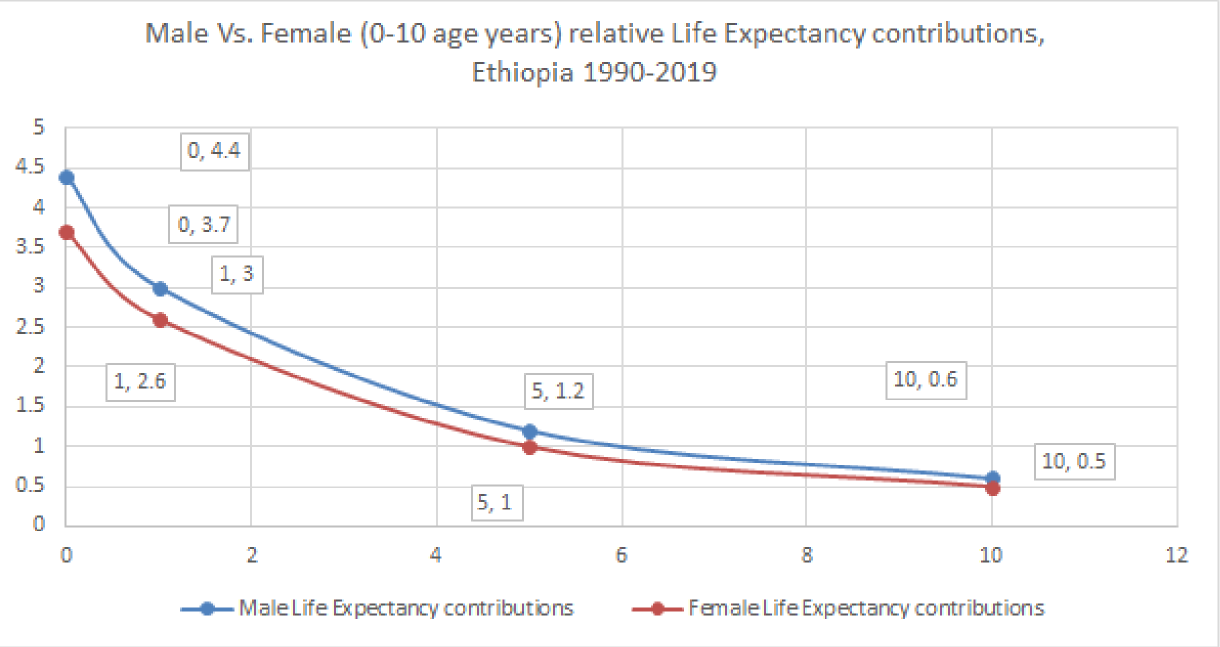
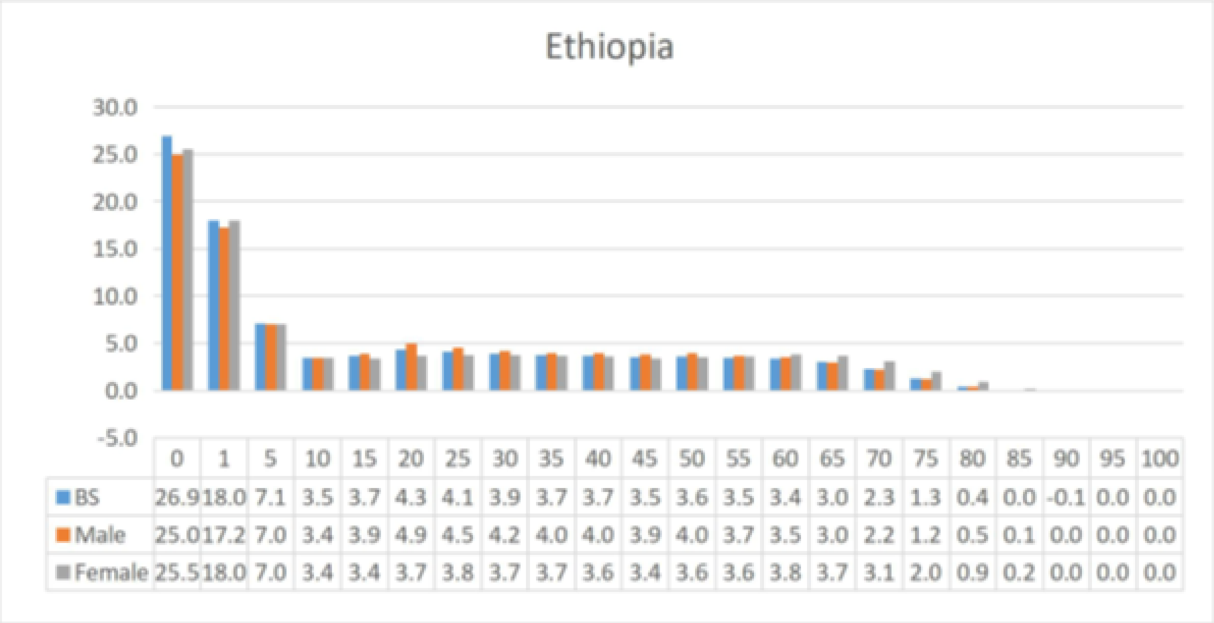


Figure 22: Age Vs Relative Total Effect Life Expectancy contributions by sex

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 (at age 0) as cohorts would respectively live 4.4 years and 3.7 years longer on average.



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	26.9	18.0	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.7	3.5	3.6	3.5	3.4	3.0	2.3	1.3	0.4	0.0	-0.1	0.0	0.0
■ Male	25.0	17.2	7.0	3.4	3.9	4.9	4.5	4.2	4.0	4.0	3.9	4.0	3.7	3.5	3.0	2.2	1.2	0.5	0.1	0.0	0.0	0.0
■ Female	25.5	18.0	7.0	3.4	3.4	3.7	3.8	3.7	3.7	3.6	3.4	3.6	3.6	3.8	3.7	3.1	2.0	0.9	0.2	0.0	0.0	0.0

Figure 23: Age Vs 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.

5 Discussion

Ethiopia, a nation with a growing population and an unstable political system, does currently have far too few reliable death statistics available. Recognizing this dearth of mortality statistics, the Brass' logit method has been employed as an innovative approach to constructing life tables for Ethiopia and its regional states. The choice of this method has been the fact that it leverages any incomplete or inaccurate data to create a more accurate picture of mortality patterns.

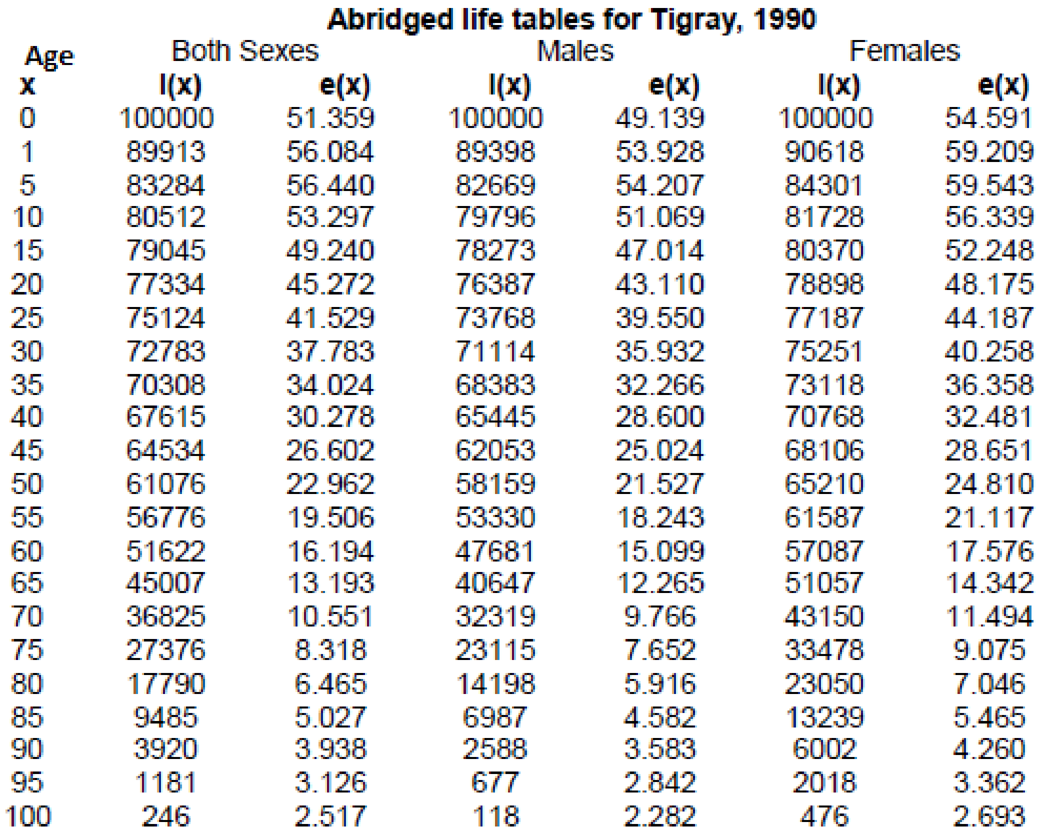
Therefore, this study sought to build a system of Brass' logit model life tables, estimate national and regional abridged life tables, and decompose life expectancies to measure the relative contribution of each age group to the overall change in mortality experiences that the country has undergone over the course of thirty years from 1990 to 2019.

5.1 Estimating model based abridged life tables for Ethiopia and its regional states

In order to estimate national and regional abridged life tables, this study first developed a system of Brass' logit model life tables. Then, changes from 1990 to 2019 were taken into consideration regarding sex disparities, infant mortality rates, under - five mortality rates, survival probabilities, and general mortality in Ethiopia and the regional states.

5.1.1 Abridged life tables for Tigray

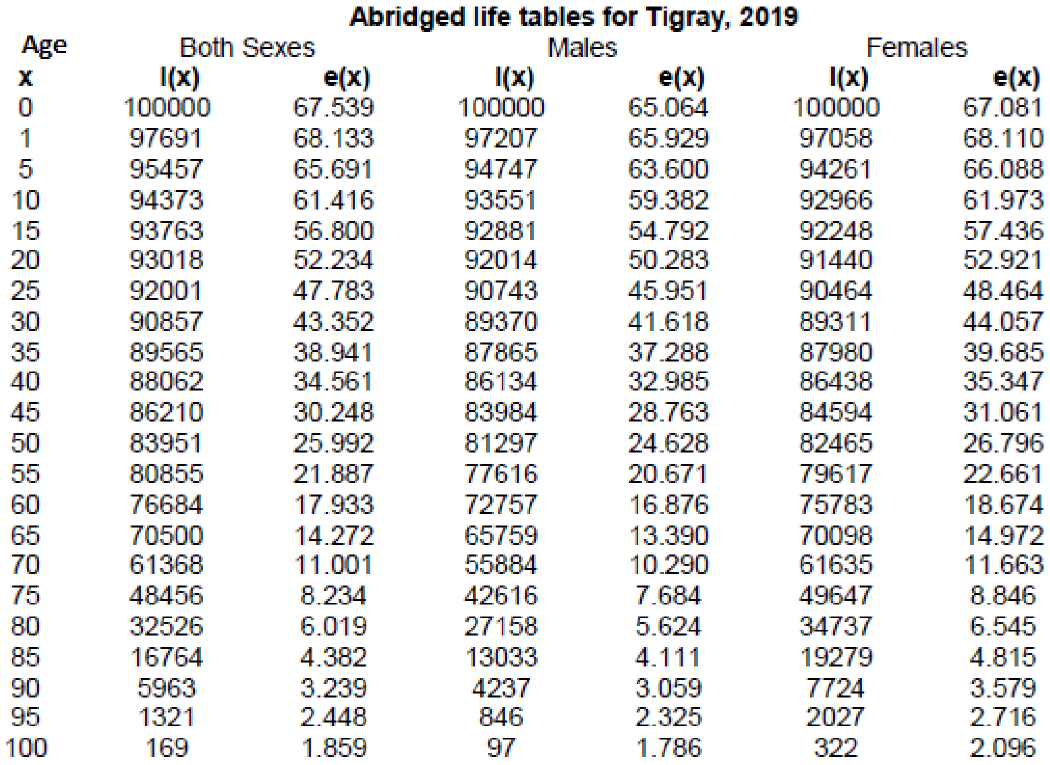
Table 19: Abridged life tables for Tigray, 1990



Abridged life tables for Tigray, 1990

Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	51.359	100000	49.139	100000	54.591
1	89913	56.084	89398	53.928	90618	59.209
5	83284	56.440	82669	54.207	84301	59.543
10	80512	53.297	79796	51.069	81728	56.339
15	79045	49.240	78273	47.014	80370	52.248
20	77334	45.272	76387	43.110	78898	48.175
25	75124	41.529	73768	39.550	77187	44.187
30	72783	37.783	71114	35.932	75251	40.258
35	70308	34.024	68383	32.266	73118	36.358
40	67615	30.278	65445	28.600	70768	32.481
45	64534	26.602	62053	25.024	68106	28.651
50	61076	22.962	58159	21.527	65210	24.810
55	56776	19.506	53330	18.243	61587	21.117
60	51622	16.194	47681	15.099	57087	17.576
65	45007	13.193	40647	12.265	51057	14.342
70	36825	10.551	32319	9.766	43150	11.494
75	27376	8.318	23115	7.652	33478	9.075
80	17790	6.465	14198	5.916	23050	7.046
85	9485	5.027	6987	4.582	13239	5.465
90	3920	3.938	2588	3.583	6002	4.260
95	1181	3.126	677	2.842	2018	3.362
100	246	2.517	118	2.282	476	2.693

Table 20: Abridged life tables for Tigray, 2019



Abridged life tables for Tigray, 2019

Age	Both Sexes		Males		Females	
x	l(x)	e(x)	l(x)	e(x)	l(x)	e(x)
0	100000	67.539	100000	65.064	100000	67.081
1	97691	68.133	97207	65.929	97058	68.110
5	95457	65.691	94747	63.600	94261	66.088
10	94373	61.416	93551	59.382	92966	61.973
15	93763	56.800	92881	54.792	92248	57.436
20	93018	52.234	92014	50.283	91440	52.921
25	92001	47.783	90743	45.951	90464	48.464
30	90857	43.352	89370	41.618	89311	44.057
35	89565	38.941	87865	37.288	87980	39.685
40	88062	34.561	86134	32.985	86438	35.347
45	86210	30.248	83984	28.763	84594	31.061
50	83951	25.992	81297	24.628	82465	26.796
55	80855	21.887	77616	20.671	79617	22.661
60	76684	17.933	72757	16.876	75783	18.674
65	70500	14.272	65759	13.390	70098	14.972
70	61368	11.001	55884	10.290	61635	11.663
75	48456	8.234	42616	7.684	49647	8.846
80	32526	6.019	27158	5.624	34737	6.545
85	16764	4.382	13033	4.111	19279	4.815
90	5963	3.239	4237	3.059	7724	3.579
95	1321	2.448	846	2.325	2027	2.716
100	169	1.859	97	1.786	322	2.096

The information provided in the life tables shows notable increases in the average lifespans of men and women as well as for both sexes combined. This is an encouraging development that suggests improvements possibly in healthcare, living standards, and overall well - being in in the country. When the analysis is broken down into components:

Overall increment

Life expectancy of the overall population of the regional state of Tigray has increased by 16.18 years from 51.359 years in 1990 to 67.539 years in 2019. This represents a 31.5% increase over the course of three decades.

Males

Life expectancy for males increased by 15.925 years from 49.139 years in 1990 to 65.064 years in 2019. This represents a 32.4% increase, slighty higher than the overall increase of the region.

Females

Life expectancy for females increased by 12.49 years from 54.591 years to 67.081 years and this represents a 22.9% increase which is lower than the percentage increments of the overall and the male populations.

Disparity

While the overall increase in life expectancy is encouraging, the gap between males and females remains significant. Further efforts are needed to address this disparity.

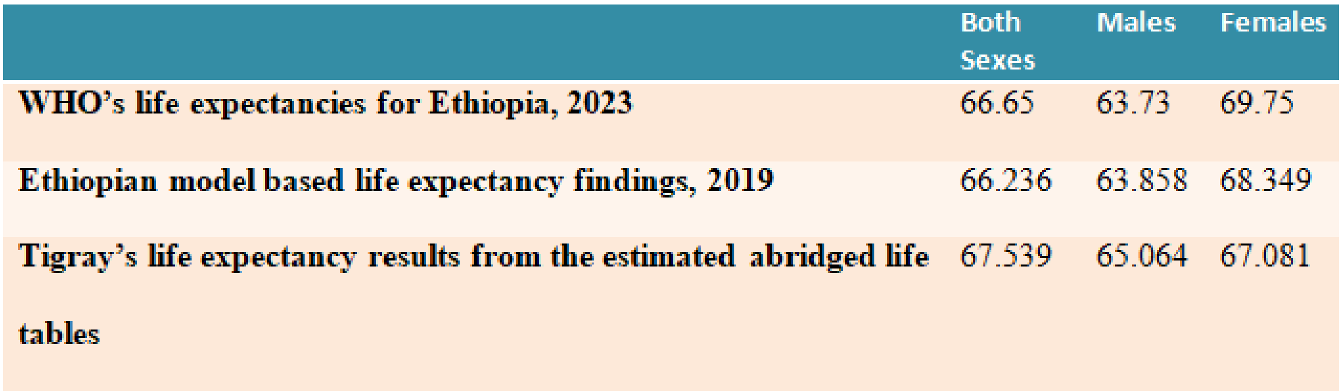
To increase life expectancy in Tigray by one year, it has taken an average of 1.854 years. This shows that for every 1.854 years that have elapsed since 1990, the expectation of living has increased by one year on average.

Over the course of three decades, the difference in life expectancy between males and females in Tigray has been $16.18 - 12.49 = 3.69$ years. This indicates that, on average, Tigrayan females will need to gain $3.69 * 1.854 = 6.84$ extra years of experience to catch up to their male counterparts. However, unless some extraordinary measures are taken to close the gap and enable the females to at least approach the males, this will remain impossible.

Comparisons with national and global results

According to the findings, Tigray had made relatively better progress than the country as a whole, with life expectancies for both sexes combined and for males in Tigray being higher than those in Ethiopia up until 2019. Although additional research may be necessary to determine whether Tigray has really outperformed the nation using additional data, the results presented here closely align with those reported by the World Health Organization. But it is important to note that Tigray has made less progress toward increasing the life expectancy of females, as noted in the World Health Organization's reports and the Brass' logit model life tables.

Table 21: Life expectancy comparisons from the model and from WHO



	Both Sexes	Males	Females
WHO's life expectancies for Ethiopia, 2023	66.65	63.73	69.75
Ethiopian model based life expectancy findings, 2019	66.236	63.858	68.349
Tigray's life expectancy results from the estimated abridged life tables	67.539	65.064	67.081

Analysis of infant, under - five, and child mortality indicators

According to the model, Tigray's infant, under - five, and child mortality rates were 0.10087, 0.16716, and 0.0737, respectively in 1990. This indicates that the rates of infant, under - five, and child mortality were 100.87, 167.16, and 73.7 per 1000 live births. Over a thirty - year period, Tigray's infant, under - five, and child mortality rates decreased from 100.87 to 23.09, 167.16 to 45.43, and 73.7 to 22.8 respectively.

Upon comparing these findings with Ethiopia's mortality rates as determined by the Brass' logit model and with the country's WHO results, it was discovered that Tigray's infant and under - five mortality rates had been 23.09 and 45.43 per 1000 live births respectively while The World Health Organization's report for Ethiopia was 29.9 and 41.2 per 1000 live births. Under - five mortality rate in Ethiopia was seen to be higher in the Brass' logit model than in the report of The World Health Organization.

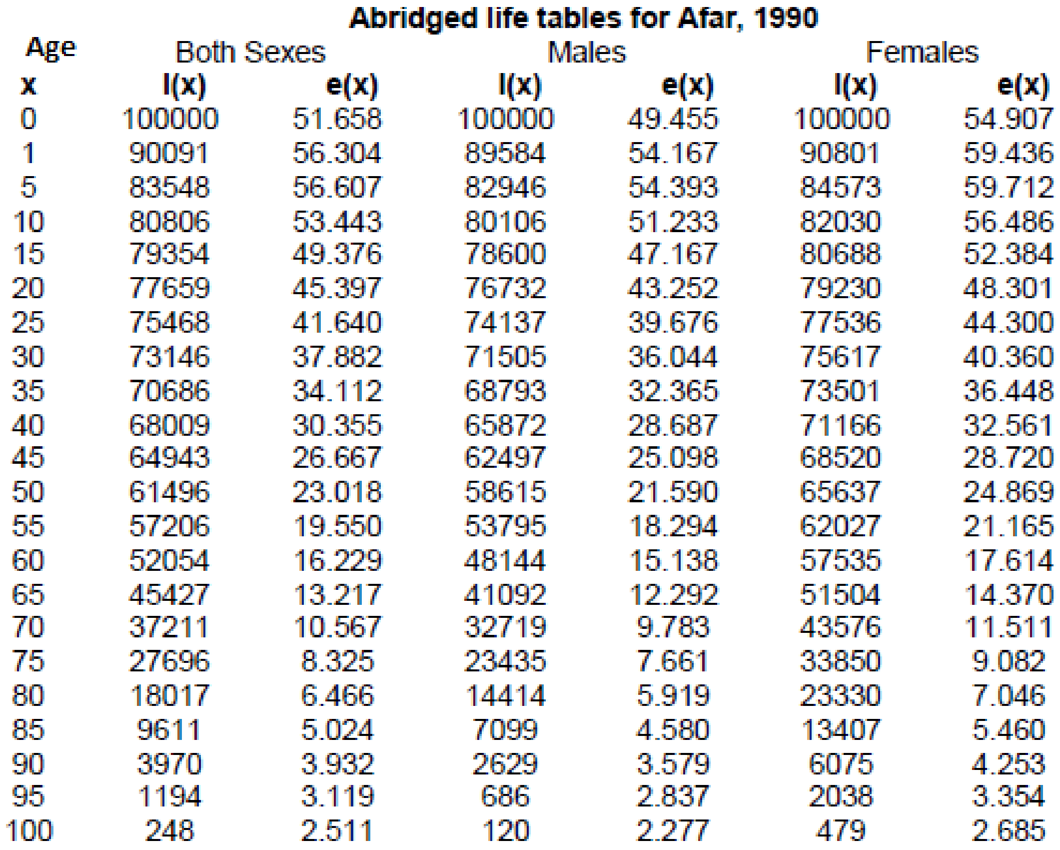
The United Nations World Population Prospects "infant mortality rate 1950 - 2024" (UN, 2024) report states that the average infant mortality rate worldwide in 2019 was 28.615 deaths per 1000 people. It appears that Tigray had surpassed the global average by a small amount.

This is not something the area should be proud of, though, as the average infant mortality rate worldwide is also so high that it must be decreased and needs to be addressed.

Generally, the regional state of Tigray had experienced a significant increase in life expectancy at birth of 31.50% from 1990 to 2019 indicating improvements in overall health and living conditions. There had been amazingly a 77.11% reduction in infant mortality rates from 100.87 deaths per 1000 live births in 1990 to 23.09 deaths per 1000 live births in 2019. But what seems strange is that it had a slightly higher life expectancy compared to the national average suggesting further studies be done to check disparities, if there were, in access to healthcare and socioeconomic factors.

5.1.2 Abridged life tables for Afar

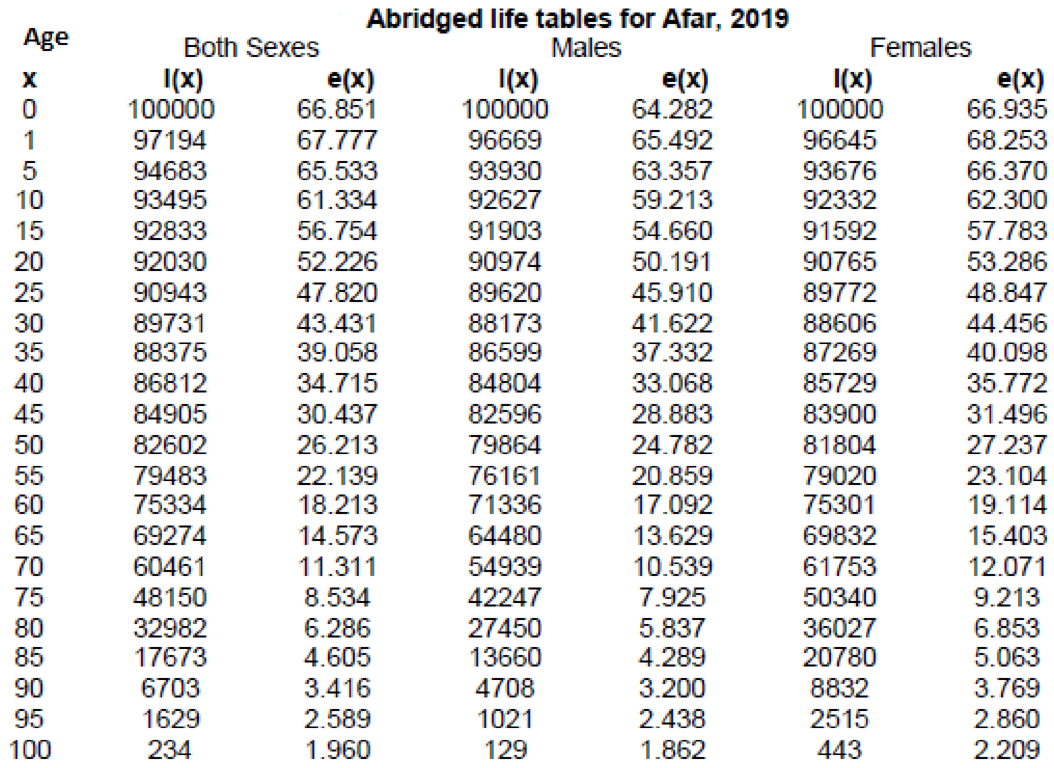
Table 22: Abridged life tables for Afar, 1990



Abridged life tables for Afar, 1990

Age	Both Sexes		Males		Females	
x	l(x)	e(x)	l(x)	e(x)	l(x)	e(x)
0	100000	51.658	100000	49.455	100000	54.907
1	90091	56.304	89584	54.167	90801	59.436
5	83548	56.607	82946	54.393	84573	59.712
10	80806	53.443	80106	51.233	82030	56.486
15	79354	49.376	78600	47.167	80688	52.384
20	77659	45.397	76732	43.252	79230	48.301
25	75468	41.640	74137	39.676	77536	44.300
30	73146	37.882	71505	36.044	75617	40.360
35	70686	34.112	68793	32.365	73501	36.448
40	68009	30.355	65872	28.687	71166	32.561
45	64943	26.667	62497	25.098	68520	28.720
50	61496	23.018	58615	21.590	65637	24.869
55	57206	19.550	53795	18.294	62027	21.165
60	52054	16.229	48144	15.138	57535	17.614
65	45427	13.217	41092	12.292	51504	14.370
70	37211	10.567	32719	9.783	43576	11.511
75	27696	8.325	23435	7.661	33850	9.082
80	18017	6.466	14414	5.919	23330	7.046
85	9611	5.024	7099	4.580	13407	5.460
90	3970	3.932	2629	3.579	6075	4.253
95	1194	3.119	686	2.837	2038	3.354
100	248	2.511	120	2.277	479	2.685

Table 23: Abridged life tables for Afar, 2019



Abridged life tables for Afar, 2019

Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.851	100000	64.282	100000	66.935
1	97194	67.777	96669	65.492	96645	68.253
5	94683	65.533	93930	63.357	93676	66.370
10	93495	61.334	92627	59.213	92332	62.300
15	92833	56.754	91903	54.660	91592	57.783
20	92030	52.226	90974	50.191	90765	53.286
25	90943	47.820	89620	45.910	89772	48.847
30	89731	43.431	88173	41.622	88606	44.456
35	88375	39.058	86599	37.332	87269	40.098
40	86812	34.715	84804	33.068	85729	35.772
45	84905	30.437	82596	28.883	83900	31.496
50	82602	26.213	79864	24.782	81804	27.237
55	79483	22.139	76161	20.859	79020	23.104
60	75334	18.213	71336	17.092	75301	19.114
65	69274	14.573	64480	13.629	69832	15.403
70	60461	11.311	54939	10.539	61753	12.071
75	48150	8.534	42247	7.925	50340	9.213
80	32982	6.286	27450	5.837	36027	6.853
85	17673	4.605	13660	4.289	20780	5.063
90	6703	3.416	4708	3.200	8832	3.769
95	1629	2.589	1021	2.438	2515	2.860
100	234	1.960	129	1.862	443	2.209

According to the estimated abridged life tables for Afar's readings, mortality trends have been improving, as has been the case both nationally and in the state of Tigray. Between 1990 and 2019, the region's life expectancy increased by 15.193 years, from 51.658 years to 66.851 years. This translates into a significant improvement in life expectancy of 29.4%.

Sex specific changes

Male life expectancy increased by 14.827 years, from 49.455 years to 64.282 years. This is a marginally higher increase than the overall increase, at 30%.The average life expectancy for females also rose by 12.028 years, from 54.907 to 66.935 years. This is an increase of 21.9%, less than both the general increase and the increase for males.

Over the course of thirty years, there was an average increase in life expectancy of one year in this region every nearly two years. Therefore, the gap observed between male and female life expectancies would amount to $(14.827 - 12.028) * 2 = 5.598$ years of difference.

Analysis of infant, and under - five mortality indicators

As has been the case nationwide, Afar's infant, under - five, and child mortality rates had significantly decreased over the period of the study. First of all, in 1990, there were 99.09 deaths per 1000 live births in Afar among infants. However, that rate dropped to 28.06

deaths per 1000 in 2019 - that is, after 30 years. Under - five mortality rate also dropped from 164.52 deaths to 53.17 deaths per 1000. The infant and under - five mortality rates decreased by 71.68% and 67.68% respectively, indicating significant progress in preventing mortality when viewed in the context of the region.

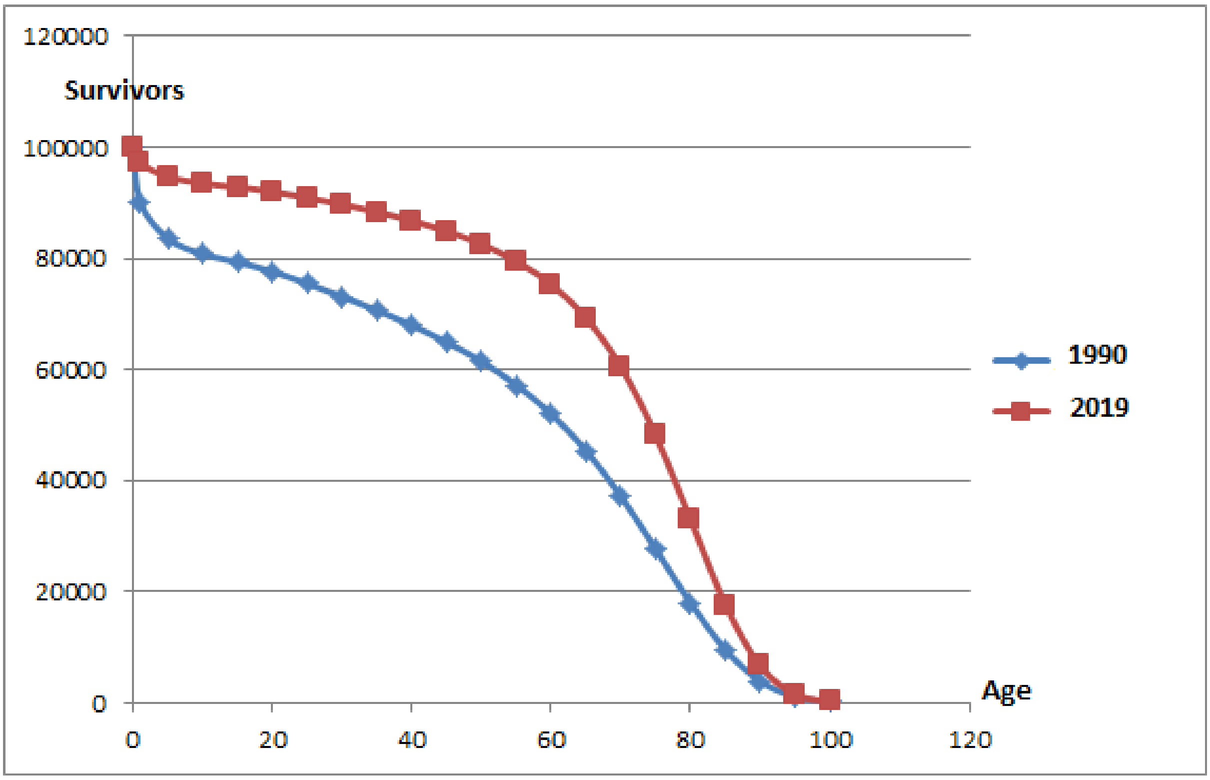


Figure 24: Graphic presentation of l_x column for both sexes together of Afar, 1990 - 2019

The difference between the two survival curves indicates the rise in life expectancy during the specified study period. The 1990 curve was almost completely downward from the start, indicating that death rates were high across all age groups. However, the 2019 curve continued to be concave downward, indicating improvements in the number of middle - aged survivors.

With regard to the e_x graph, it is evident that life expectancy is greater at age 1 than it is at age 0, suggesting that mortality is typically higher in the first year of life at age 0 than it is at age 1 and beyond. This is explained by the fact that e_0 represents the population as a whole and includes low age at death for infant deaths, whereas e_1 represents the population as a whole and does not include very low survival for the majority of survivors.

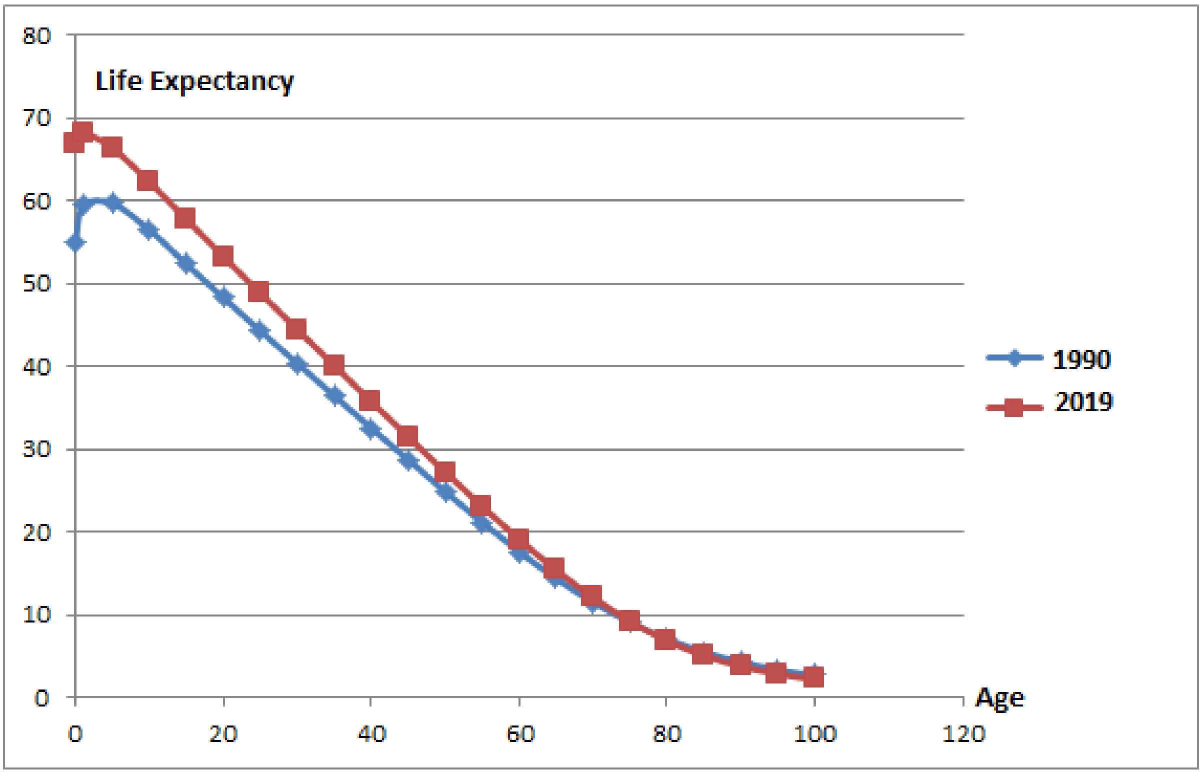
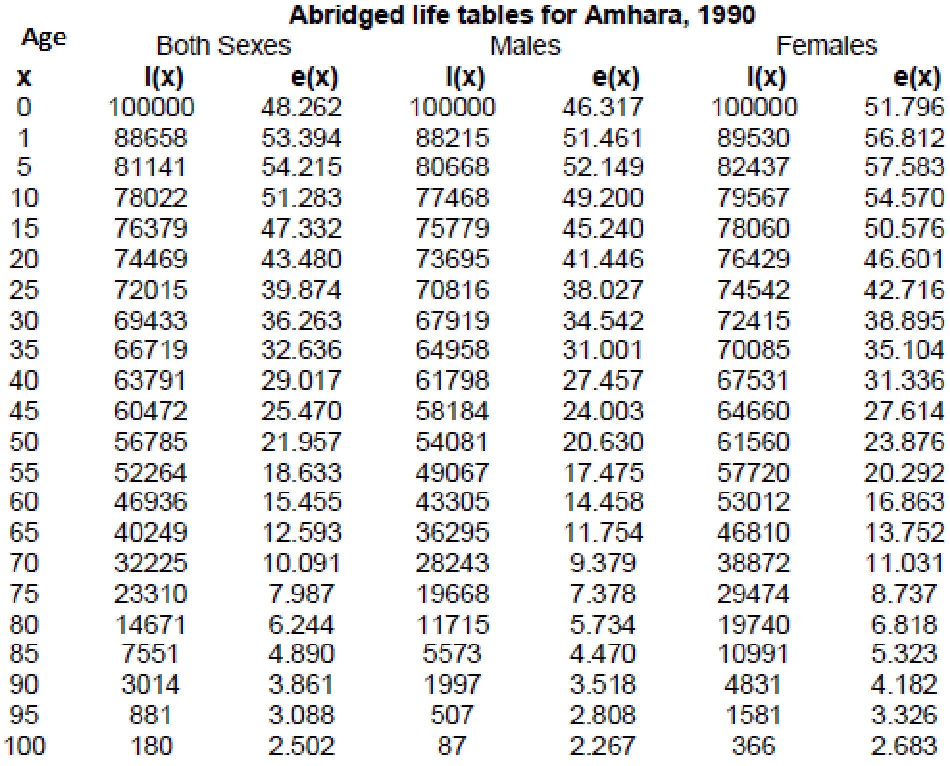


Figure 25: Graphic presentation of e_x column for females of Afar, 1990 - 2019

5.1.3 Abridged life tables for Amhara

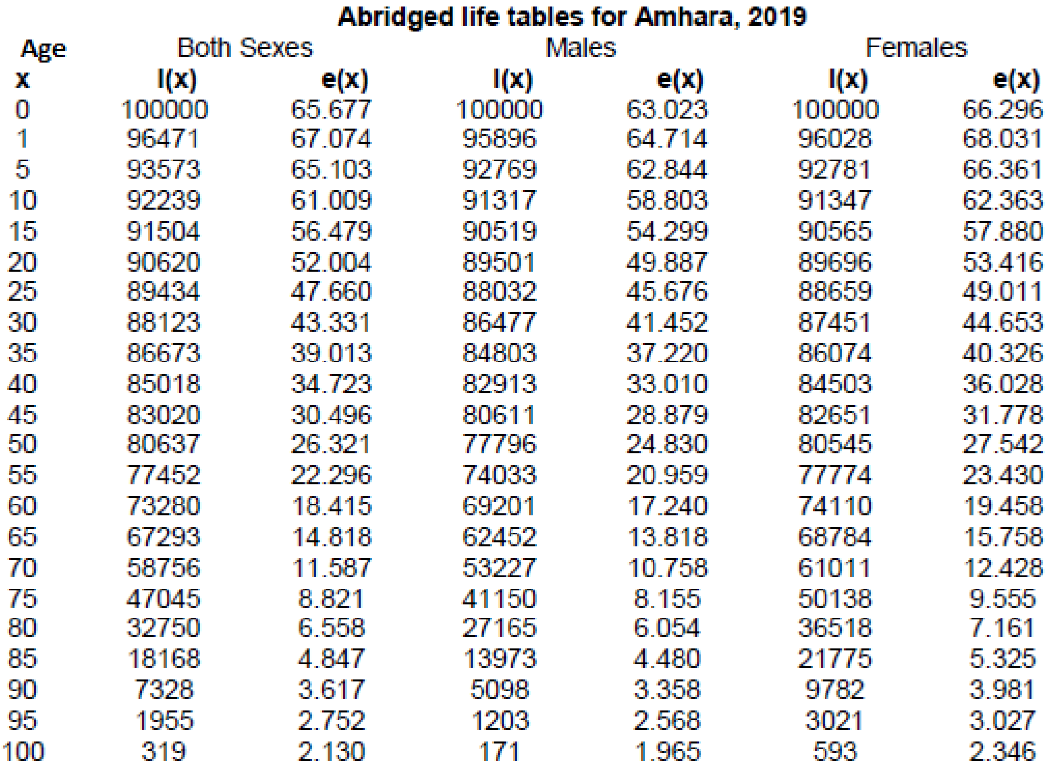
Table 24: Abridfed life tables for Amhara, 1990



Abridged life tables for Amhara, 1990

Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	48.262	100000	46.317	100000	51.796
1	88658	53.394	88215	51.461	89530	56.812
5	81141	54.215	80668	52.149	82437	57.583
10	78022	51.283	77468	49.200	79567	54.570
15	76379	47.332	75779	45.240	78060	50.576
20	74469	43.480	73695	41.446	76429	46.601
25	72015	39.874	70816	38.027	74542	42.716
30	69433	36.263	67919	34.542	72415	38.895
35	66719	32.636	64958	31.001	70085	35.104
40	63791	29.017	61798	27.457	67531	31.336
45	60472	25.470	58184	24.003	64660	27.614
50	56785	21.957	54081	20.630	61560	23.876
55	52264	18.633	49067	17.475	57720	20.292
60	46936	15.455	43305	14.458	53012	16.863
65	40249	12.593	36295	11.754	46810	13.752
70	32225	10.091	28243	9.379	38872	11.031
75	23310	7.987	19668	7.378	29474	8.737
80	14671	6.244	11715	5.734	19740	6.818
85	7551	4.890	5573	4.470	10991	5.323
90	3014	3.861	1997	3.518	4831	4.182
95	881	3.088	507	2.808	1581	3.326
100	180	2.502	87	2.267	366	2.683

Table 25: Abridfed life tables for Amhara, 2019



Abridged life tables for Amhara, 2019

Age	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	65.677	100000	63.023	100000	66.296
1	96471	67.074	95896	64.714	96028	68.031
5	93573	65.103	92769	62.844	92781	66.361
10	92239	61.009	91317	58.803	91347	62.363
15	91504	56.479	90519	54.299	90565	57.880
20	90620	52.004	89501	49.887	89696	53.416
25	89434	47.660	88032	45.676	88659	49.011
30	88123	43.331	86477	41.452	87451	44.653
35	86673	39.013	84803	37.220	86074	40.326
40	85018	34.723	82913	33.010	84503	36.028
45	83020	30.496	80611	28.879	82651	31.778
50	80637	26.321	77796	24.830	80545	27.542
55	77452	22.296	74033	20.959	77774	23.430
60	73280	18.415	69201	17.240	74110	19.458
65	67293	14.818	62452	13.818	68784	15.758
70	58756	11.587	53227	10.758	61011	12.428
75	47045	8.821	41150	8.155	50138	9.555
80	32750	6.558	27165	6.054	36518	7.161
85	18168	4.847	13973	4.480	21775	5.325
90	7328	3.617	5098	3.358	9782	3.981
95	1955	2.752	1203	2.568	3021	3.027
100	319	2.130	171	1.965	593	2.346

The Amhara regional state saw an increase in life expectancy between 1990 and 2019 of 17.415 years for the general population, 16.706 years for males, and 14.50 years for females. These changes reflect increments of 36%, 36%, and 27.99% years respectively.

The female population achieved much less of an increase in percentage terms, while males saw an increase comparable to the overall population.

The female population has been leading in overall life expectancy over the years, despite a 2.206 year difference in life expectancy between the sexes that represents nearly 3 years of survival in the rate of increase over the study period.

Over the previous three decades, Amhara had also successfully reduced infant, under - five, and child mortality rates, as had been the case throughout the nation and in the other regions. Compared to Ethiopia, where there were 32.68 infant, 60.15 under - five, and 28.3 child deaths per 1000 live births, it had 35.29 infant deaths, 64.27 under - five deaths, and 62.96 child deaths. There was a significant disparity in child mortality rates between Ethiopia and Amhara, with Ethiopia having 28.3 deaths per 1000, and Amhara having 62.96 deaths per 1000. However, the reductions in infant and under - five deaths had been nearly equal.

The mortality rates for infants and children under five were higher in Amhara than in Afar. Afar had rates of 28.06 and 53.17 per 1000 respectively, compared to 35.29 and 64.27 per 1000 in Amhara.

It is peculiar that the infant and under - five children mortality rates in Tigray were 23.09 and 45.43 per 1000, respectively, while Amhara's were 35.29 and 64.27 per 1000. This indicates that Tigray was performing better than its neighbor, Amhara. To determine whether these differences were caused by erroneous data reports or actual differences on the ground, more research is required.

Given below is a figure that was extracted from the 2019 Ethiopian Demographic and Health Mini Survey solely for the purpose of visualizing and contrasting data from various sources with the output of the Brass' logit model used in this investigation.

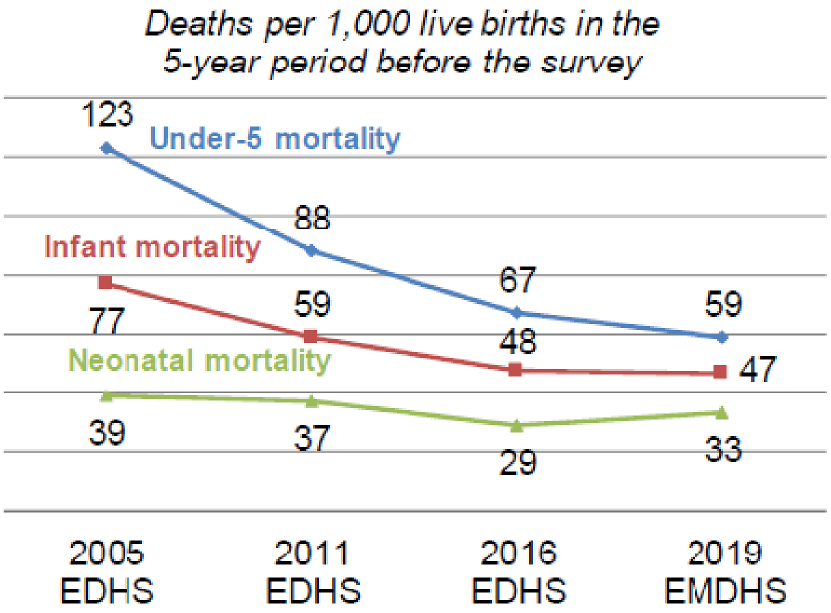


Figure 26: IMRs and U5MRs of Ethiopia based on the 2019 mini survey

Source: (Ephi, 2021)

5.2 Comparative analysis of mortality trends across the regional states and between the sexes of Ethiopia

While the life expectancy at birth for males had shown a 38.21% increase over the whole course of the three decades from 46.205 years in 1990 to 63.858 years in 2019, the percentage increase of females had been only 27% increase from 53.911 years in 1990 to 68.349 years in 2019.

Addis Ababa, Tigray, and Gambella with life expectancies of 69.483, 67.539, and 67.106 years respectively were generally the three top regional states in 2019, while Benshangul - Gumuz, Somali, and Amhara with life expectancies of 64.185, 65.220, and 65.677 years respectively were the lowest three.

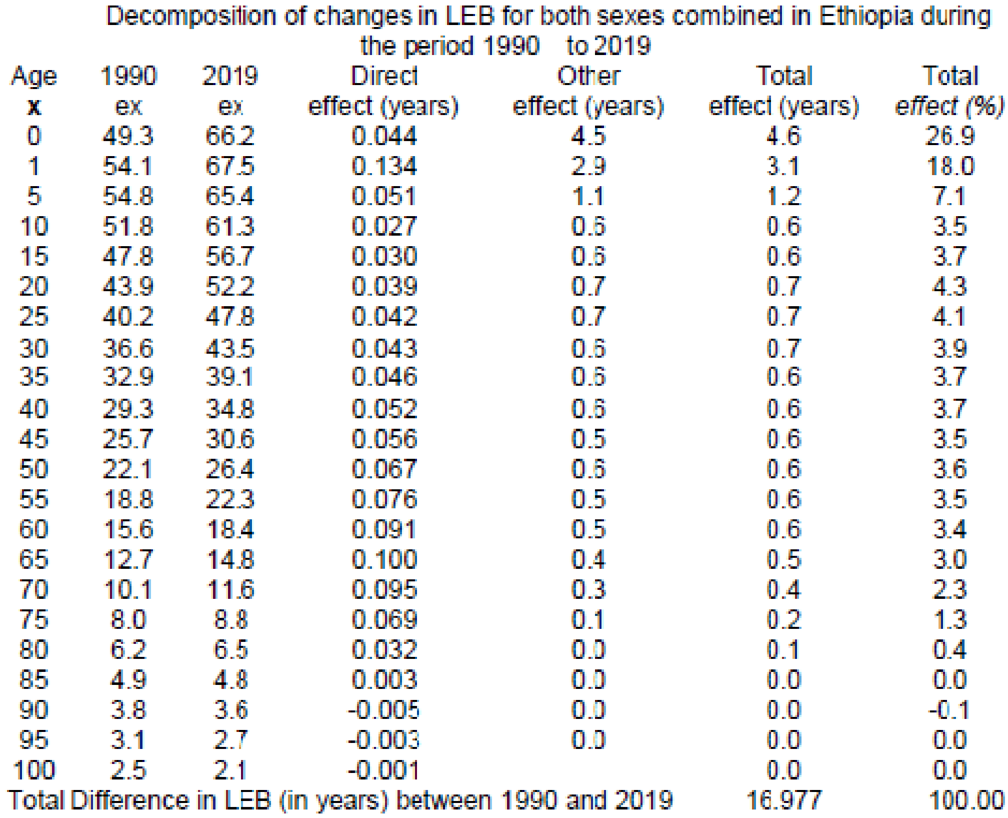
5.3 Decomposing and measuring the change in life expectancies of Ethiopia and its regional states age - wise: 1990 - 2019

Through an analysis of the age - wise distribution of life expectancies in Ethiopia and its regional states between 1990 and 2019, the Arriaga method was used to measure the relative contribution of each age group to the overall change in life expectancy at birth of the country and its regions.

The results show that between 1990 and 2019, life expectancy rose in Ethiopia and all of its regional states. Decreases in infant, child, and adult mortality rates were all contributing factors to this. The age - specific contributions to life expectancy indicated that the reductions in infant mortality were responsible for the largest contributions.

5.3.1 Decomposition of changes in Life Expectancy at Birth of Ethiopia

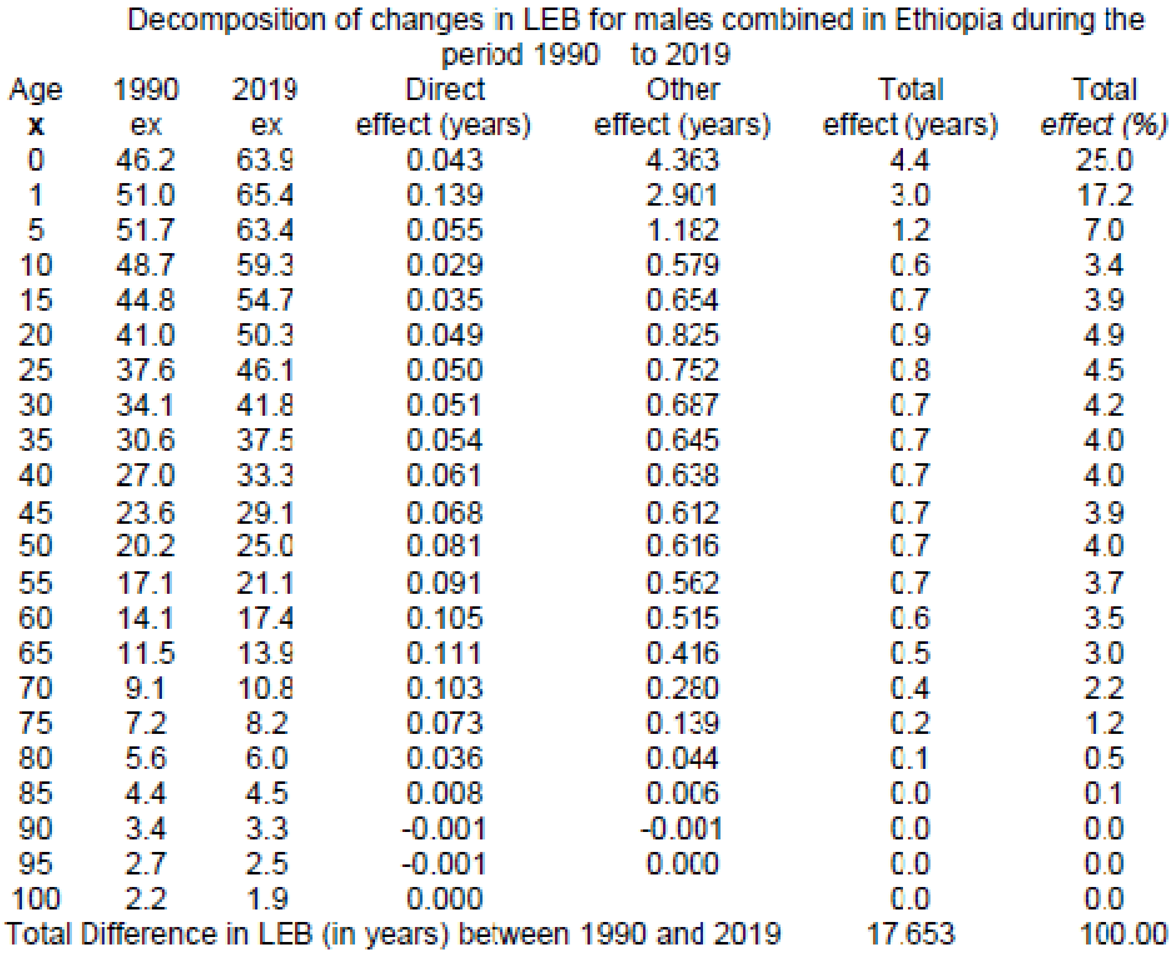
Table 26: LEB decomposition of Ethiopia for both sexes: 1990 - 2019



Decomposition of changes in LEB for both sexes combined in Ethiopia during the period 1990 to 2019

Age **x**	1990 ex	2019 ex	Direct effect (years)	Other effect (years)	Total effect (years)	Total *effect (%)*
0	49.3	66.2	0.044	4.5	4.6	26.9
1	54.1	67.5	0.134	2.9	3.1	18.0
5	54.8	65.4	0.051	1.1	1.2	7.1
10	51.8	61.3	0.027	0.6	0.6	3.5
15	47.8	56.7	0.030	0.6	0.6	3.7
20	43.9	52.2	0.039	0.7	0.7	4.3
25	40.2	47.8	0.042	0.7	0.7	4.1
30	36.6	43.5	0.043	0.6	0.7	3.9
35	32.9	39.1	0.046	0.6	0.6	3.7
40	29.3	34.8	0.052	0.6	0.6	3.7
45	25.7	30.6	0.056	0.5	0.6	3.5
50	22.1	26.4	0.067	0.6	0.6	3.6
55	18.8	22.3	0.076	0.5	0.6	3.5
60	15.6	18.4	0.091	0.5	0.6	3.4
65	12.7	14.8	0.100	0.4	0.5	3.0
70	10.1	11.6	0.095	0.3	0.4	2.3
75	8.0	8.8	0.069	0.1	0.2	1.3
80	6.2	6.5	0.032	0.0	0.1	0.4
85	4.9	4.8	0.003	0.0	0.0	0.0
90	3.8	3.6	-0.005	0.0	0.0	-0.1
95	3.1	2.7	-0.003	0.0	0.0	0.0
100	2.5	2.1	-0.001		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					16.977	100.00

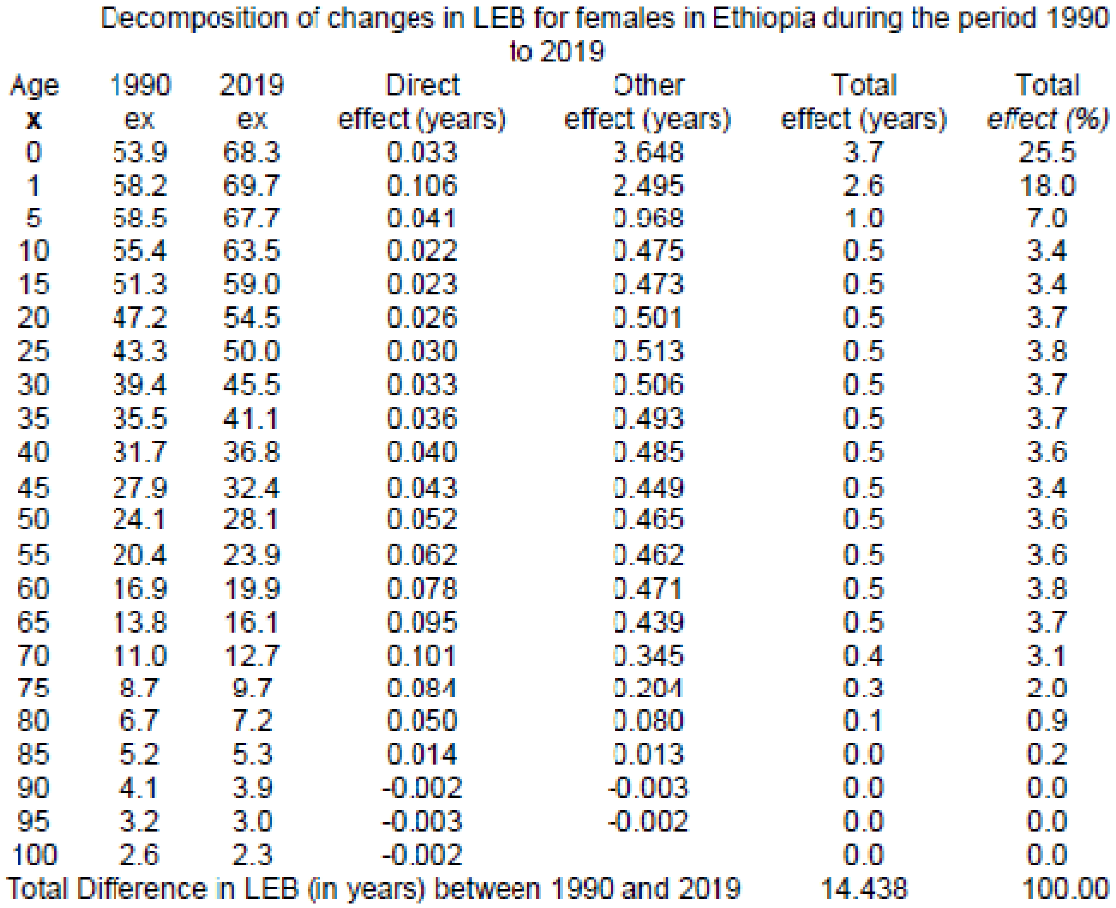
Table 27: LEB decomposition of Ethiopia for males: 1990 - 2019



Decomposition of changes in LEB for males combined in Ethiopia during the period 1990 to 2019

Age x	1990 ex	2019 ex	Direct effect (years)	Other effect (years)	Total effect (years)	Total *effect (%)*
0	46.2	63.9	0.043	4.363	4.4	25.0
1	51.0	65.4	0.139	2.901	3.0	17.2
5	51.7	63.4	0.055	1.162	1.2	7.0
10	48.7	59.3	0.029	0.579	0.6	3.4
15	44.8	54.7	0.035	0.654	0.7	3.9
20	41.0	50.3	0.049	0.825	0.9	4.9
25	37.6	46.1	0.050	0.752	0.8	4.5
30	34.1	41.8	0.051	0.687	0.7	4.2
35	30.6	37.5	0.054	0.645	0.7	4.0
40	27.0	33.3	0.061	0.638	0.7	4.0
45	23.6	29.1	0.068	0.612	0.7	3.9
50	20.2	25.0	0.081	0.616	0.7	4.0
55	17.1	21.1	0.091	0.562	0.7	3.7
60	14.1	17.4	0.105	0.515	0.6	3.5
65	11.5	13.9	0.111	0.416	0.5	3.0
70	9.1	10.8	0.103	0.280	0.4	2.2
75	7.2	8.2	0.073	0.139	0.2	1.2
80	5.6	6.0	0.036	0.044	0.1	0.5
85	4.4	4.5	0.008	0.006	0.0	0.1
90	3.4	3.3	-0.001	-0.001	0.0	0.0
95	2.7	2.5	-0.001	0.000	0.0	0.0
100	2.2	1.9	0.000		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					17.653	100.00

Table 28: LEB decomposition of Ethiopia for females: 1990 - 2019



Decomposition of changes in LEB for females in Ethiopia during the period 1990 to 2019

Age x	1990 ex	2019 ex	Direct effect (years)	Other effect (years)	Total effect (years)	Total *effect (%)*
0	53.9	68.3	0.033	3.648	3.7	25.5
1	58.2	69.7	0.106	2.495	2.6	18.0
5	58.5	67.7	0.041	0.968	1.0	7.0
10	55.4	63.5	0.022	0.475	0.5	3.4
15	51.3	59.0	0.023	0.473	0.5	3.4
20	47.2	54.5	0.026	0.501	0.5	3.7
25	43.3	50.0	0.030	0.513	0.5	3.8
30	39.4	45.5	0.033	0.506	0.5	3.7
35	35.5	41.1	0.036	0.493	0.5	3.7
40	31.7	36.8	0.040	0.485	0.5	3.6
45	27.9	32.4	0.043	0.449	0.5	3.4
50	24.1	28.1	0.052	0.465	0.5	3.6
55	20.4	23.9	0.062	0.462	0.5	3.6
60	16.9	19.9	0.078	0.471	0.5	3.8
65	13.8	16.1	0.095	0.439	0.5	3.7
70	11.0	12.7	0.101	0.345	0.4	3.1
75	8.7	9.7	0.084	0.204	0.3	2.0
80	6.7	7.2	0.050	0.080	0.1	0.9
85	5.2	5.3	0.014	0.013	0.0	0.2
90	4.1	3.9	-0.002	-0.003	0.0	0.0
95	3.2	3.0	-0.003	-0.002	0.0	0.0
100	2.6	2.3	-0.002		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					14.438	100.00

Identifying specific age groups driving changes in Life Expectancy at Birth

After breaking down the life expectancy at birth of Ethiopia by age and sex from 1990 to 2019, it was feasible to identify the age groups experiencing the biggest increases and decreases. Consequently, infants accounted for a quarter of all life expectancy at birth gains in the overall population as well as in the male and female populations.

Typically, children under five years old accounted for over half, or 52%, of Ethiopia's overall increase in life expectancy over the previous thirty years. This may imply, albeit not definitively, that infants were successfully treated with medical interventions.

Decomposition of life expectancy, however, also reveals indicators that, while seemingly appropriate, are discovered entangled with other indicators.

Revealing the life expectancy contributions by effect of each age group

It was discovered that infants contributed 26.9% of the 16.977 years of life expectancy gained for the Ethiopian population overall between 1990 and 2019; however, of this 26.9% contribution, 26.5% resulted from the "other effect" and only 2.3% from direct effect.

Thus, rather than the direct intervention effect on infants, certain associated effects with healthy conditions favoring infants played a more substantial role in improving the health outcomes of the infants, thereby enabling the highest gain in life expectancy.

Interpreting the increased “other effect” obtained in the breakdown of the 1990 to 2019 Ethiopian life expectancy

In every age group and for both sexes, it was discovered that the other effects had been greater than the direct effects. This emphasizes how significant broad - based behavioral, environmental, and social determinants are to health. This could imply that concentrating only on direct health interventions might not be enough to optimize increases in life expectancy. Investing in these broader facets of population health and well - being may yield even greater improvements in longevity and health.

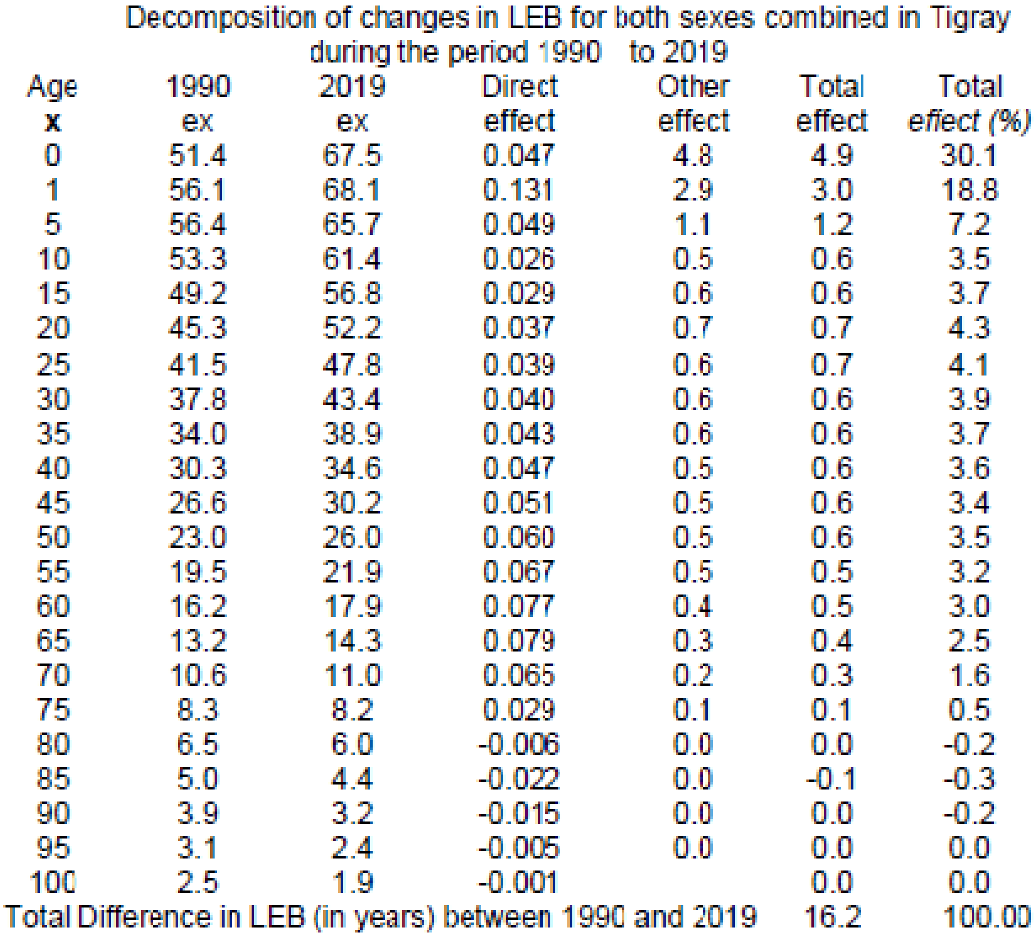
Important considerations to bear in mind with the “direct” and “other” effects

Even though the “other effects” accounted for the majority of the increases in life expectancy, they were not specifically named because the factors that contribute to them can change based on the analysis’s context and data. This study limited its content scope by only analyzing the age breakdown of the increases in Ethiopian life expectancy over a thirty - year period. This prevented it from identifying the key drivers contributing to improved health outcomes or analyzing the precise composition of the “other factors”.

Even though a higher value for “other effects” might indicate a positive impact, a more thorough investigation is required to determine the causal relationships and possible mediating factors.

5.3.2 Decomposition of changes in Life Expectancy at Birth of the regional state of Tigray

Table 29: LEB decomposition of Tigray for both sexes: 1990 - 2019



Decomposition of changes in LEB for both sexes combined in Tigray during the period 1990 to 2019

Age x	1990 ex	2019 ex	Direct effect	Other effect	Total effect	Total *effect (%)*
0	51.4	67.5	0.047	4.8	4.9	30.1
1	56.1	68.1	0.131	2.9	3.0	18.8
5	56.4	65.7	0.049	1.1	1.2	7.2
10	53.3	61.4	0.026	0.5	0.6	3.5
15	49.2	56.8	0.029	0.6	0.6	3.7
20	45.3	52.2	0.037	0.7	0.7	4.3
25	41.5	47.8	0.039	0.6	0.7	4.1
30	37.8	43.4	0.040	0.6	0.6	3.9
35	34.0	38.9	0.043	0.6	0.6	3.7
40	30.3	34.6	0.047	0.5	0.6	3.6
45	26.6	30.2	0.051	0.5	0.6	3.4
50	23.0	26.0	0.060	0.5	0.6	3.5
55	19.5	21.9	0.067	0.5	0.5	3.2
60	16.2	17.9	0.077	0.4	0.5	3.0
65	13.2	14.3	0.079	0.3	0.4	2.5
70	10.6	11.0	0.065	0.2	0.3	1.6
75	8.3	8.2	0.029	0.1	0.1	0.5
80	6.5	6.0	-0.006	0.0	0.0	-0.2
85	5.0	4.4	-0.022	0.0	-0.1	-0.3
90	3.9	3.2	-0.015	0.0	0.0	-0.2
95	3.1	2.4	-0.005	0.0	0.0	0.0
100	2.5	1.9	-0.001		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					16.2	100.00

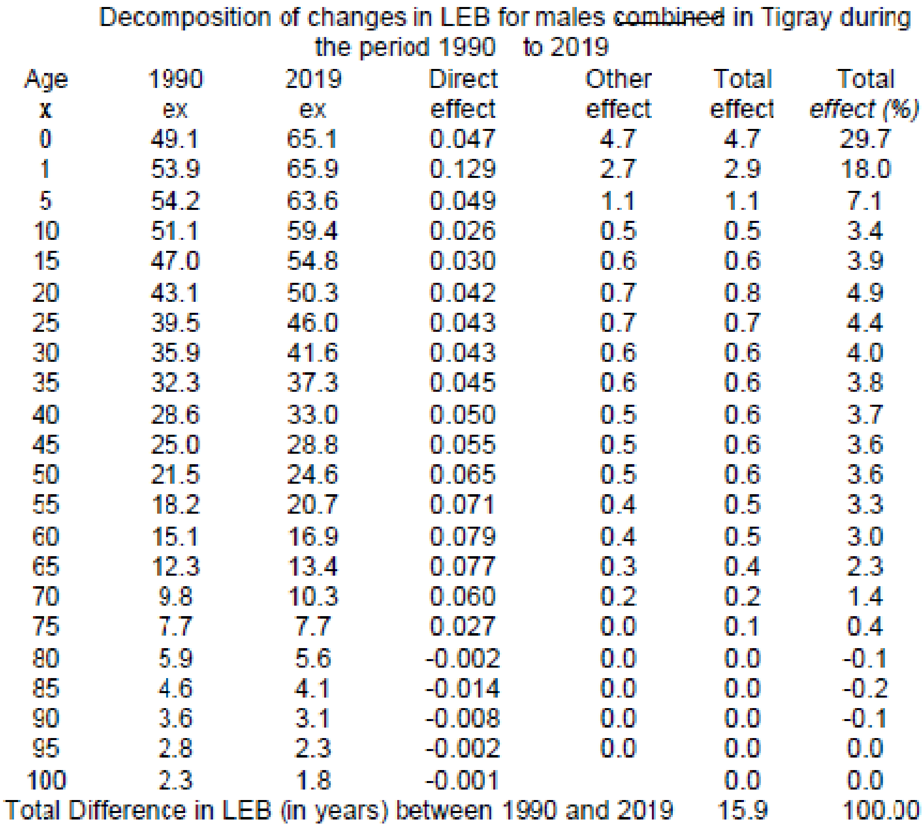
In Tigray, the average life expectancy for the general population has increased by 16.2 years over the last thirty years, with infants accounting for 4.9 of those extra years. Nonetheless, "other effects" were responsible for 98% of this increase in life expectancy.

Because age groups are influenced by the mortality experiences of their adjacent groups, working on indirect infant health determining factors is therefore very beneficial to society as a whole. Preserving newborns' lives also preserves children's lives, which in turn preserves the lives of the young, and so on, improving overall health and longevity.

The model's results demonstrate that improvements in life expectancy were made across all age groups, with infats making the largest contribution. However, the results of the "other effect" contradict the mortality perspective, which holds that "A generation carries its own mortality with it". Had that been the case, the high infant survival rates would have been noted in the other age groups as well, but as age increases, the survival curves slope downward. Once more, generations are not leaving their positive experiences with mortality from their early years behind; instead, they are taking their survivals with them to certain age groups and dropping them in others.

On the other hand, protecting infants also protects other age groups; however, infants were protected more through “other effect” than through direct effect; which means, other age groups were best suited to save infants. This implies that not saving infants is meant not saving other age groups.

Table 30: LEB decomposition of Tigray for males: 1990 - 2019

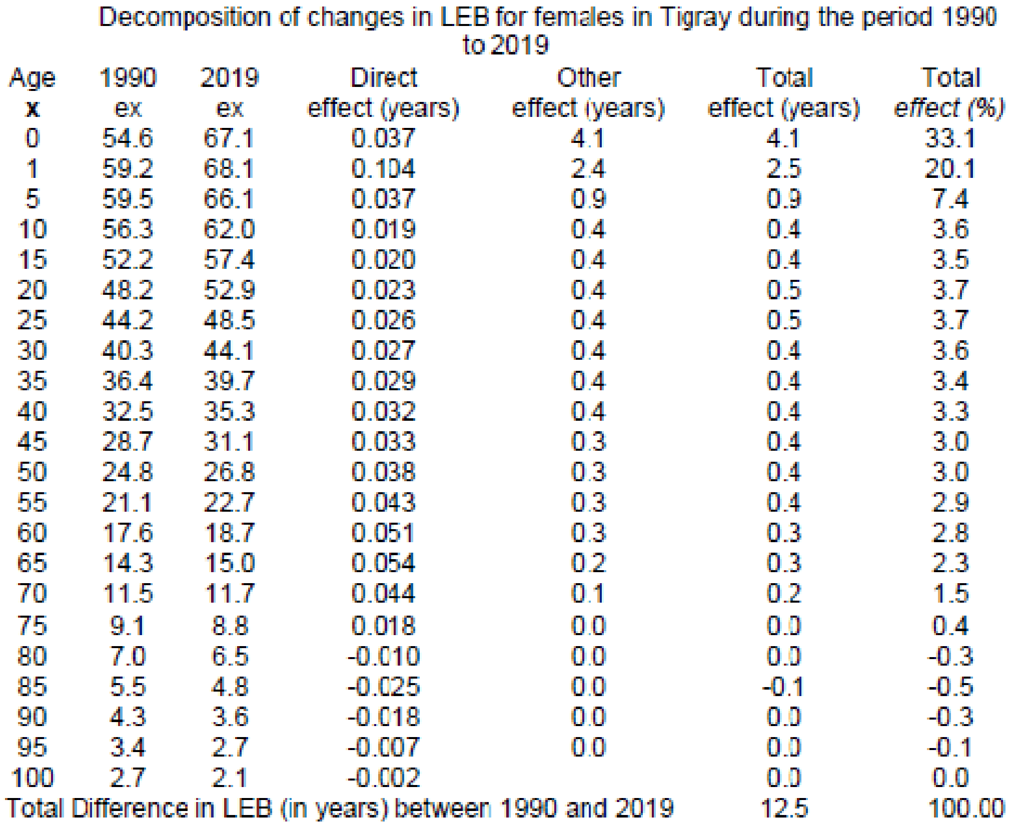


Decomposition of changes in LEB for males ~~combined~~ in Tigray during the period 1990 to 2019

Age x	1990 ex	2019 ex	Direct effect	Other effect	Total effect	Total *effect (%)*
0	49.1	65.1	0.047	4.7	4.7	29.7
1	53.9	65.9	0.129	2.7	2.9	18.0
5	54.2	63.6	0.049	1.1	1.1	7.1
10	51.1	59.4	0.026	0.5	0.5	3.4
15	47.0	54.8	0.030	0.6	0.6	3.9
20	43.1	50.3	0.042	0.7	0.8	4.9
25	39.5	46.0	0.043	0.7	0.7	4.4
30	35.9	41.6	0.043	0.6	0.6	4.0
35	32.3	37.3	0.045	0.6	0.6	3.8
40	28.6	33.0	0.050	0.5	0.6	3.7
45	25.0	28.8	0.055	0.5	0.6	3.6
50	21.5	24.6	0.065	0.5	0.6	3.6
55	18.2	20.7	0.071	0.4	0.5	3.3
60	15.1	16.9	0.079	0.4	0.5	3.0
65	12.3	13.4	0.077	0.3	0.4	2.3
70	9.8	10.3	0.060	0.2	0.2	1.4
75	7.7	7.7	0.027	0.0	0.1	0.4
80	5.9	5.6	-0.002	0.0	0.0	-0.1
85	4.6	4.1	-0.014	0.0	0.0	-0.2
90	3.6	3.1	-0.008	0.0	0.0	-0.1
95	2.8	2.3	-0.002	0.0	0.0	0.0
100	2.3	1.8	-0.001		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					15.9	100.00

The contributions of life expectancy to the overall changes over the last thirty years have been similar for both sexes and all regional states, with infants and children under - five making the largest contributions to the gains. According to these patterns, the infants in the Tigrayan male population contributed 4.7 years of the 15.9 years of total change, with nearly all of these contributions coming from “other effects.”

Table 31: LEB decomposition of Tigray for females: 1990 - 2019

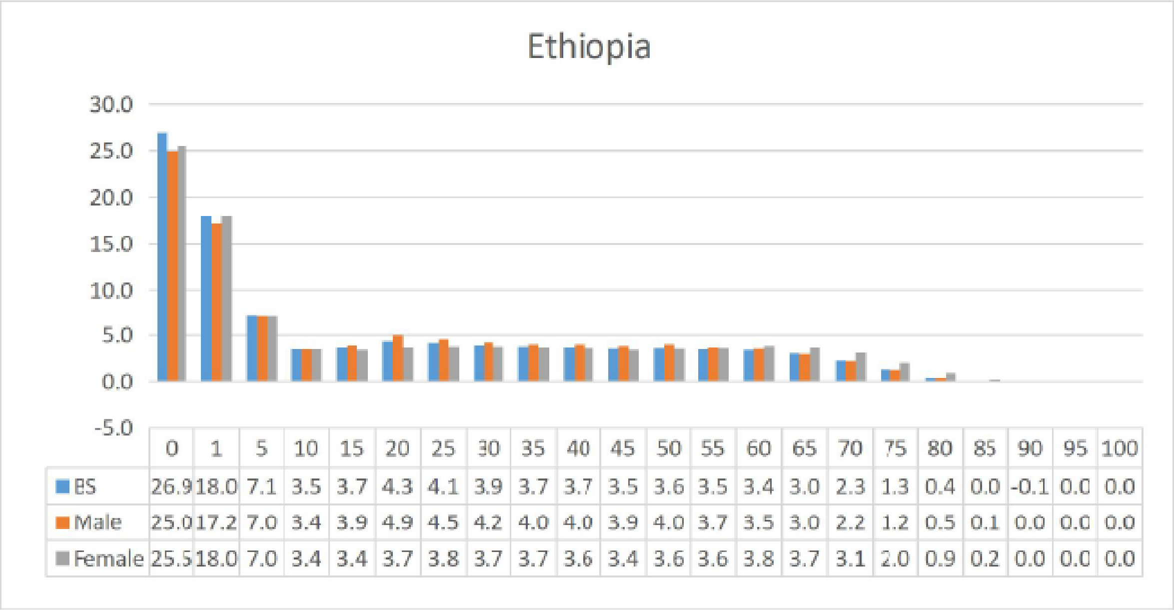


Decomposition of changes in LEB for females in Tigray during the period 1990 to 2019

Age x	1990 ex	2019 ex	Direct effect (years)	Other effect (years)	Total effect (years)	Total *effect (%)*
0	54.6	67.1	0.037	4.1	4.1	33.1
1	59.2	68.1	0.104	2.4	2.5	20.1
5	59.5	66.1	0.037	0.9	0.9	7.4
10	56.3	62.0	0.019	0.4	0.4	3.6
15	52.2	57.4	0.020	0.4	0.4	3.5
20	48.2	52.9	0.023	0.4	0.5	3.7
25	44.2	48.5	0.026	0.4	0.5	3.7
30	40.3	44.1	0.027	0.4	0.4	3.6
35	36.4	39.7	0.029	0.4	0.4	3.4
40	32.5	35.3	0.032	0.4	0.4	3.3
45	28.7	31.1	0.033	0.3	0.4	3.0
50	24.8	26.8	0.038	0.3	0.4	3.0
55	21.1	22.7	0.043	0.3	0.4	2.9
60	17.6	18.7	0.051	0.3	0.3	2.8
65	14.3	15.0	0.054	0.2	0.3	2.3
70	11.5	11.7	0.044	0.1	0.2	1.5
75	9.1	8.8	0.018	0.0	0.0	0.4
80	7.0	6.5	-0.010	0.0	0.0	-0.3
85	5.5	4.8	-0.025	0.0	-0.1	-0.5
90	4.3	3.6	-0.018	0.0	0.0	-0.3
95	3.4	2.7	-0.007	0.0	0.0	-0.1
100	2.7	2.1	-0.002		0.0	0.0
Total Difference in LEB (in years) between 1990 and 2019					12.5	100.00

With 53% of the total age contribution gained from under five children, females in Tigray added 12.5 years to the overall increase in life expectancy. The adult age group contributed nearly uniformly to the "other effect", according to the life expectancy at birth decomposition results, while the older age group contributed negatively to the direct effect and no age to the "other effect".

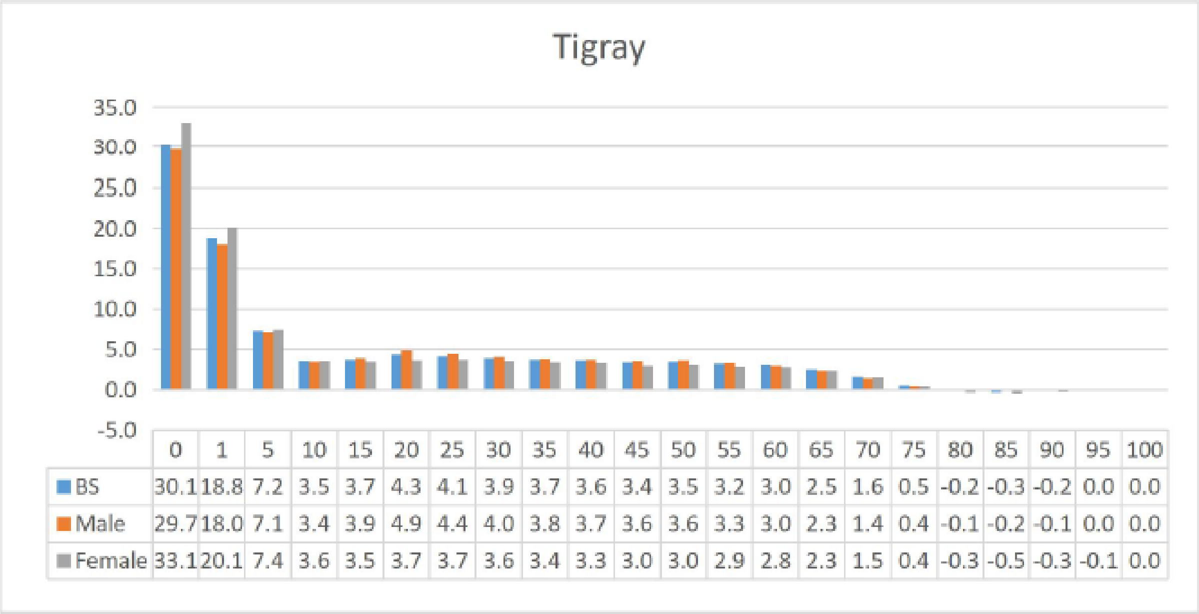
5.4 Comparison of results of decomposition of changes in LEB of Ethiopia and its regional states: 1990 - 2019



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	26.9	18.0	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.7	3.5	3.6	3.5	3.4	3.0	2.3	1.3	0.4	0.0	-0.1	0.0	0.0
🟧 Male	25.0	17.2	7.0	3.4	3.9	4.9	4.5	4.2	4.0	4.0	3.9	4.0	3.7	3.5	3.0	2.2	1.2	0.5	0.1	0.0	0.0	0.0
⬜ Female	25.5	18.0	7.0	3.4	3.4	3.7	3.8	3.7	3.7	3.6	3.4	3.6	3.6	3.8	3.7	3.1	2.0	0.9	0.2	0.0	0.0	0.0

Figure 27: Age Vs Ethiopia's relative age group contributions to LEB: 1990 - 2019

Over 25% and 50%, respectively, of the variations in Ethiopia's life expectancy by age group were ascribed to newborns and children under - five in the general population. In the age range of 5 to 60 years, the combined contributions of males, females, and both sexes were almost equal, although the combined contributions of infants of both sexes were slightly higher than those of males and females.



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	30.1	18.8	7.2	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.5	3.2	3.0	2.5	1.6	0.5	-0.2	-0.3	-0.2	0.0	0.0
🟧 Male	29.7	18.0	7.1	3.4	3.9	4.9	4.4	4.0	3.8	3.7	3.6	3.6	3.3	3.0	2.3	1.4	0.4	-0.1	-0.2	-0.1	0.0	0.0
▨ Female	33.1	20.1	7.4	3.6	3.5	3.7	3.7	3.6	3.4	3.3	3.0	3.0	2.9	2.8	2.3	1.5	0.4	-0.3	-0.5	-0.3	-0.1	0.0

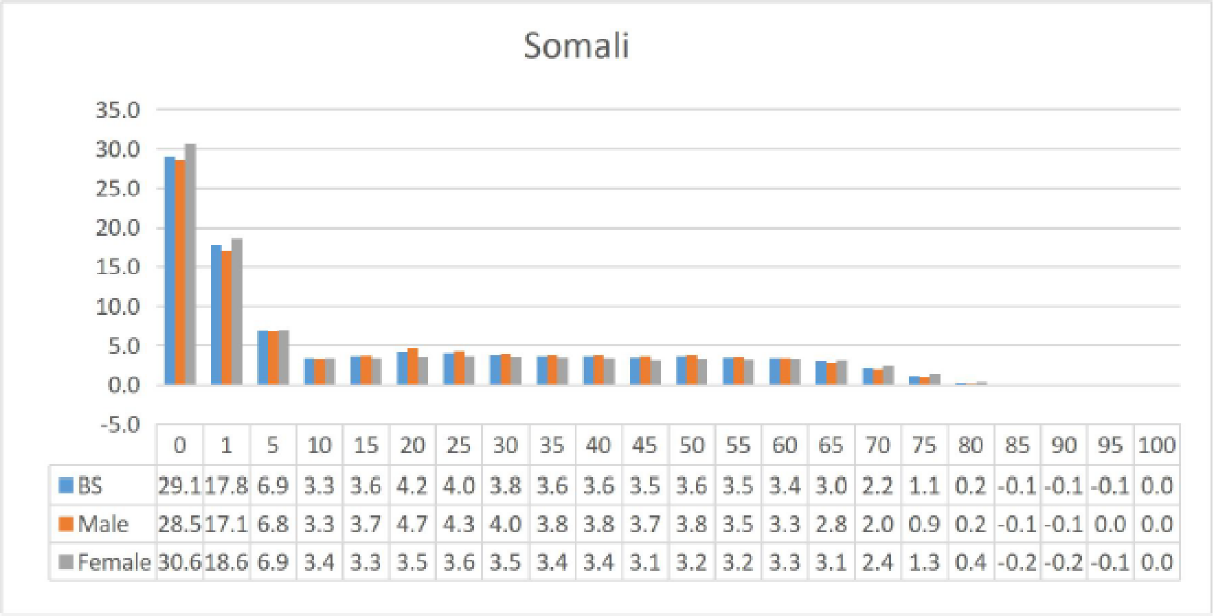
Figure 28: Age Vs Tigray's relative age group contributions to LEB: 1990 - 2019

In Tigray, female infants outperformed both the general infant population and male infants in terms of contribution, in contrast to the pattern seen in the early stages of the Ethiopian population, when the combined population of both sexes contributed the most.

Dividing the population into three age groups $0-14$, $15-60$, and $60+$ for relative comparison purposes, it is clear that the first age group, which includes those in the $0-14$ age range, was the largest contributor to the overall increase. This implies a significant improvement in relative child survival as well as a significant relative drop in infant mortality.

While not as well as the first group, the second group, which consists of adults in the working age range, nevertheless made a significant number of years' worth of contributions to the overall change. This suggests that there have been some progress made in lowering the death rate among adults in their working years.

The $60+$ age group showed no contributions, or at worst, negative contributions. This highlights how little attention has been paid to treating medical conditions and raising the chances of survival for older adults in the regional state of Tigray.



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	29.1	17.8	6.9	3.3	3.6	4.2	4.0	3.8	3.6	3.6	3.5	3.6	3.5	3.4	3.0	2.2	1.1	0.2	-0.1	-0.1	-0.1	0.0
🟧 Male	28.5	17.1	6.8	3.3	3.7	4.7	4.3	4.0	3.8	3.8	3.7	3.8	3.5	3.3	2.8	2.0	0.9	0.2	-0.1	-0.1	0.0	0.0
⬜ Female	30.6	18.6	6.9	3.4	3.3	3.5	3.6	3.5	3.4	3.4	3.1	3.2	3.2	3.3	3.1	2.4	1.3	0.4	-0.2	-0.2	-0.1	0.0

Figure 29: Age Vs Somali's relative age group contributions to LEB: 1990 - 2019

A few departures from the national and other regional states' behaviors have been identified by the relative age group life expectancy contribution of Somalia to the overall gains in life expectancy at birth over the course of thirty years.

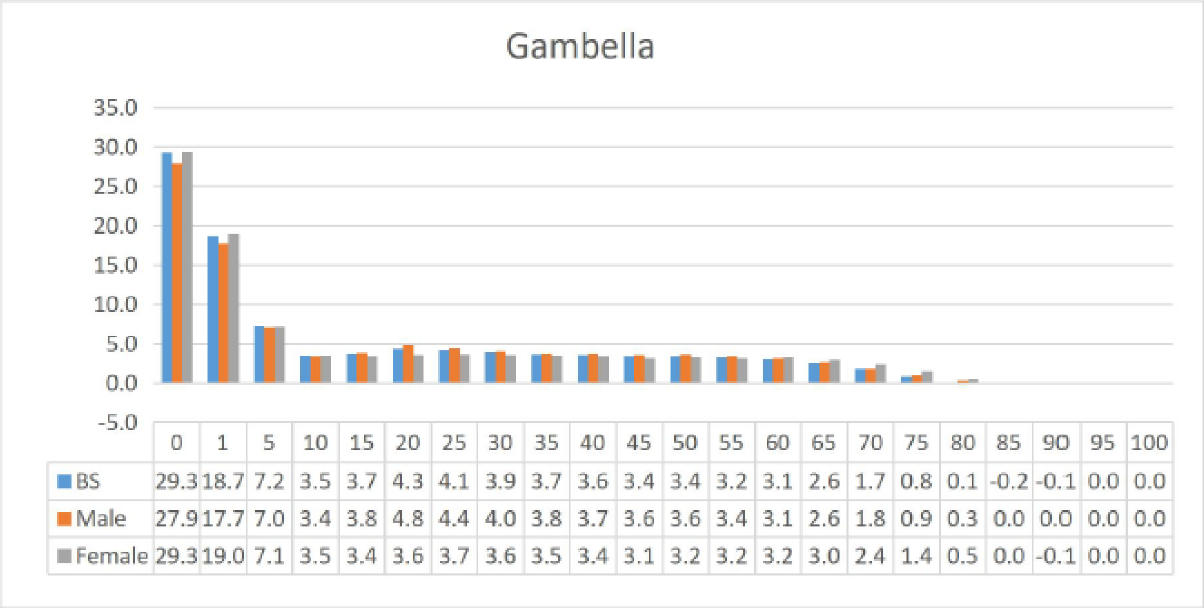
During the study period, life expectancy at birth increased by at least 15 years in the country and all its regional states except Addis Ababa; however, this region only saw increases of 9 years, 8.8 years, and 7.1 years for the general, male, and female populations, respectively.

With its average life expectancy at birth, Somali was superior to the entire nation and all other regions prior to the last thirty years, with the exception of Addis Ababa. Its life expectancy was 56.189 years, compared to 49.259 years for the entire nation.

Therefore, one obvious explanation for this delay is that, initially, this region had a higher life expectancy at birth than the country and all other regions - apart from Addis Ababa - and it may have been challenging to achieve further improvements.

The trend over the past thirty years in the country has been 1.77 years of survival for each year of improvement in life expectancy on average. Given its 6.93 - year life expectancy at birth advantage over the nation, Somali had 12.3 years of survival ahead of it in the beginning, assuming approximately that was the trend prior to 1990 as well.

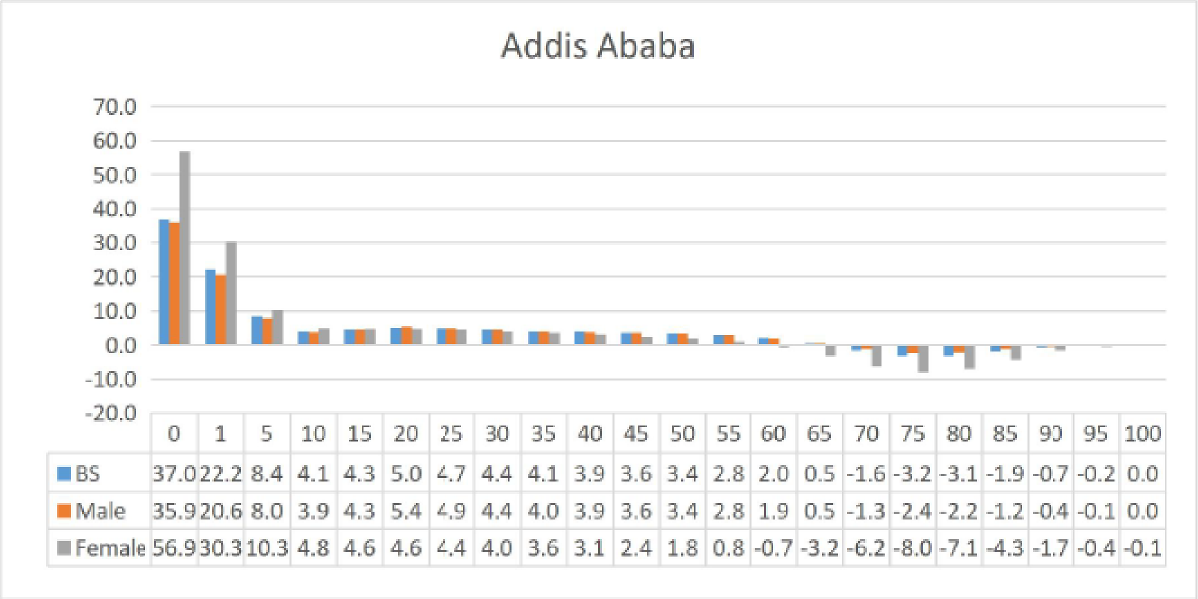
The country's life expectancy at birth is currently one year higher than Somali's, indicating that the latter had stagnated until being surpassed by $12.3 + 1.77 = 14$ years.



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	29.3	18.7	7.2	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.4	3.2	3.1	2.6	1.7	0.8	0.1	-0.2	-0.1	0.0	0.0
■ Male	27.9	17.7	7.0	3.4	3.8	4.8	4.4	4.0	3.8	3.7	3.6	3.6	3.4	3.1	2.6	1.8	0.9	0.3	0.0	0.0	0.0	0.0
■ Female	29.3	19.0	7.1	3.5	3.4	3.6	3.7	3.6	3.5	3.4	3.1	3.2	3.2	3.2	3.0	2.4	1.4	0.5	0.0	-0.1	0.0	0.0

Figure 30: Age Vs Gambella's relative age group contributions to LEB: 1990 - 2019

Gambella had equal general population and female population relative life expectacy contributions to the overall increase of life expectancy at birth over the past three decades almost in the entire age groups. This sets the area apart from other regions where females have been the primary drivers of the overall change in life expectancy at birth, especially in the under - five and infant age groups.



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	37.0	22.2	8.4	4.1	4.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	2.8	2.0	0.5	-1.6	-3.2	-3.1	-1.9	-0.7	-0.2	0.0
■ Male	35.9	20.6	8.0	3.9	4.3	5.4	4.9	4.4	4.0	3.9	3.6	3.4	2.8	1.9	0.5	-1.3	-2.4	-2.2	-1.2	-0.4	-0.1	0.0
■ Female	56.9	30.3	10.3	4.8	4.6	4.6	4.4	4.0	3.6	3.1	2.4	1.8	0.8	-0.7	-3.2	-6.2	-8.0	-7.1	-4.3	-1.7	-0.4	-0.1

Figure 31: Age Vs Addis Ababa's relative age group contributions to LEB: 1990 - 2019

The relative age group life expectancy contribution of Addis Ababa to the overall gains in life expectancy over the course of thirty years has revealed some deviations from the national and other regional states' behaviors, but Somali.

Firstly, the total gain in life expectancy at birth for the overall population in the period 1990 to 2019 was only 7.5 years while that of the other regional states varied from 15.2 years in Afar to 19.3 years in Benshangul - Gumuz and while the national average has been 16.977 years.

Secondly, the under - five children alone contributed 5.1 years of the total 7.5 years, or 68% of the total gain.

Thirdly, the 60+ age group completely had a negative contribution to the total change in life expectancy at birth.

Possible explanations for these anomalous findings include the following: either Addis Abeba was accustomed to disclosing population mortality data without manipulation, so the findings are accurate, or the city was fortunate from the start and found it difficult to attain better results than it did. The second argument, nevertheless, seems plausible given that Addis Ababa has been leading the country in terms of overall population life expectancy of 69.483 years, while the national average has been determined to be 66.236 years. However, the results indicate that there have been serious issues with treating the elderly population healthily and lowering the associated mortality.

6 Ensuring Validity and Generalizabilty of the model developed

6.1 Assessing truthfulness of the results of the model

6.1.1 Goodness of fit

The goodness of fit of a mortality model is generally used to check if the model accurately reflects the underlying mortality patterns and if the estimated life tables are dependable. The Brass logit model's advantage over the other existing model life tables, as well explained in the monograph's body, is that it has two flexible parameters α and β that enable one check the goodness of fit of the model when some observed incomplete or fragmentary data are used in the construction.

In this instance, the absence of observed mortality data in Ethiopia makes it difficult to evaluate the model's goodness of fit directly, which is why the model had to be created. However, to ensure the reliability of this model the following indirect techniques were carried out:

(1) A significant amount of the data variation was explained by the trend lines and R^2 measures created in the analysis section, which showed a good fit of the data points in straight lines.

(2) The judgment of experts, or the subject matter expertise of the study's leaders, was taken into account as external proof that the model's results were accurate.

6.1.2 Comparisons with World data

When the outcomes of this model were compared to those of the World Health Organization and the United Nations, two of the most respectable organizations in the world, they showed a fair amount of agreement.

The WHO's 2023 life expectancy results for Ethiopia were 66.236 for both sexes, 63.858 for males, and 68.349 for females (https://www.worldometers.info/demographics/life expectancy/, 2023).

Whereas the model's 2019 results had been 66.65 years for both sexes, 63.73 years for males, and 69.75 years for females.

6.2 Bias and Confounding

It is possible that a number of factors added bias and confounding to the Brass' logit model that was created for Ethiopia.

Data quality: The caliber of the underlying data has a major impact on the model's accuracy. In Ethiopia, the contentious issue has not been the caliber of the data but rather its very existence. It makes sense to admit, then, that this component might have had a significant impact on the model's quality.

Model assumptions: The survival probability functions' linearity is one of the assumptions made by the Brass' logit model, which is not always true. As a result, the assumptions' limitations have also been the limitations of this work.

Selection bias: This model may not reflect specific subpopulations such as migrants and internally displaced persons.

Confounding factors: Death rates are influenced by a variety of factors, including socioeconomic status, access to healthcare, place of residence, political stability, and many more. These factors can be challenging to include in the model, which reduces its inclusivity.

Therefore, it is crucial to see the life table as a tool for comprehending mortality patterns rather than as a final depiction of reality for this reason.

6.3 Possibility of inferring finding to the other settings

The possibility of inferring the results of the model life tables to other settings depends on several factors such as similarities between settings, data availability, and model adaptation.

6.3.1 Similarities between settings

When the target setting and the original setting where the model was developed have similar characteristics, the results' transferability increases. This includes:

Mortality levels: There is a greater chance that the model will work in environments with comparable death rates.

Age patterns of mortality: There is a greater chance that the model will work in environments with comparable death rates.

Socioeconomic and demographic factors: When the social, economic, and demographic characteristics of the populations are similar, the accuracy of the model increases.

6.3.2 Data availability

For the model to be applied and modified, data in the target setting must be available. This includes:

Poppulation size and age distribution data: Age specific population data is needed to construct the model based life tables.

Mortality data: age - specific death data are required to estimate the model parameters.

Covariates : Additional information on pertinent variables such as education, income, or health improves the accuracy of the model.

6.3.3 Model adaptation

It might be necessary to modify Brass' logit model to fit the particulars of the target setting on the basis of:

Adjusting model parameters : The characteristics of the target population may require adjusting the model's parameters, including the scaling factor and reference life table.

Incorporating additional information: The model's accuracy can be increased by adding more data, such as statistics on the causes of deaths or details on particular risk factors.

6.3.4 Validation

Using the available data, it is crucial to validate the model's performance in the target setting. This entails evaluating the model's goodness of fit by contrasting the life tables produced by the model with observed mortality trends.

6.4 Implications of the study

Policy: inform resource allocation, monitor progress towards development, evaluate the impact of interventions, and so on.
Public health: identify high risk populations, develop targetted interventions, monitor disease trends.
Academia: improve understanding of mortality patterns, develop and refine demographic models, stimulate further research.
Practice: guide actuarial calculations, inform pension planning, support infrastructure and development scheme planning.

6.5 Validity

6.5.1 Data quality

The quality of the input data has a major impact on the model's developed accuracy as well as the estimated demographic indicators. One method to make sure the data is valid is to use high - quality sources. Thus, this study made use of data from the Global Burden of Disease Study and the United Nations, which are thought to be among the best data sources available.

6.5.2 Model selection

With the understanding that it also best fits the mortality pattern seen in Ethiopia, a variation of Brass' logit model that fits the population of Sub - Saharan Africa was chosen. Before the model was constructed, an Ethiopian standard base data set was obtained in order to avoid relying solely on that of Sub - Saharan Africa. These processes then served as evidence that the comparatively superior model was selected.

6.5.3 Internal consistency

The estimated life table functions were analyzed across different age groups, different regions, different time periods, and across the sexes. Accordingly, the following results were observed:

(1) Survival probabilities (l_x) typically decline with age, reflecting expected patterns of mortality.

(2) Age - related increases in death probabilities (q_x) are consistent with the model's findings of higher mortality rates at older ages.

(3) According to the model, Ethiopia's 2019 life expectancy at birth is 66.236 years, which is quite similar to the country's actual life expectancy of 66.6 years, as reported by the United Nations (Leong et al., 2018).

(4) Life expectancies at different ages (e_x) decrease with age but the rate of decrease is not constant, reflecting changes in mortality patterns across different age groups.

The life table functions derived from the estimated model demonstrate internal consistency and have reasonable values for various age groups. This implies that the Brass' logit model, which was created for this study, successfully captures the underlying patterns of mortality in the data and offers a trustworthy foundation for estimating abridged life tables.

6.5.4 Comparing results with standard global estimates

The model's outputs could be compared and contrasted with estimates from reliable international organizations to externally validate them, despite the fact that it was not feasible to directly observe mortality trends in the Ethiopian context and draw conclusions from them. Therefore, the following comparisons were made and the outputs of the model showed close proximities with the global results collected from the United Nations Inter - Agency Group for Child Mortality Estimation (IGME, 2024).

U5MR comparisons

In 2019, Ethiopia's global U5MR results were 42.72, 52.06, and 63.48, respectively, for the lower, median, and upper categories. The model produced an output of 60.15. The close relationship between the model's output and the upper global result suggests that the model's results are conclusive at their best.

IMR comparisons

The lower, median, and upper global IMR values for Ethiopia in 2019 were estimated to be 31.83, 37.31, and 43.85 respectively. The model's output, 32.68, again showed a good indication that the results were acceptable, coming very close to the lower global estimate.

6.6 Generalizability

6.6.1 Spatial variation

The results of the development of region - specific model - based abridged life tables and the use of geographically categorized data have demonstrated comparatively consistent mortality patterns, as has the aggregated national data.

6.6.2 Model intercomparison

Similar patterns emerged when the national model - based abridged life tables and the model - based abridged life tables of the regional states were compared. Consequently, this is a positive sign for the model's generalizability.

6.6.3 Sociodemographic characterstics

Examining differences in death trends between age and sex sociodemographic characters allowed for the inclusion of group behavior in the model and, consequently, improved generalizability by exhibiting similar trends in mortality patterns and in life expectancy variations.

7 Strengths and limitations

7.0.1 Methodological strengths

Flexibility: Many different types of data sources, including erroneous or incomplete data, can be used with Brass' logit model. For Ethiopia, which lacks a vital registration system, this is especially pertinent.

Goodness of fit for developing countries: Since the Brass' logit model was developed specifically for these kinds of high mortality populations, Ethiopian populations make an excellent fit for it.

Detailed age patterns: With the help of the model, which generates condensed life tables containing comprehensive data on age - specific mortality trends, interventions can be more precisely targeted and vulnerable populations can be identified.

Widely used and accepted: The Brass' logit model is a popular and recognized technique for creating life tables and facilitates cross - national comparison of study outcomes.

7.0.2 Methodological challenges

Data quality: The quality of the underlying data determines how accurate life tables are. There are no functioning vital registration systems in Ethiopia, and census data are also unreliable. Despite the smoothing and adjustment techniques made to them, the data used in this study were susceptible to all the drawbacks of secondary data.

Model assumptions: A number of population assumptions, including the absence of migration and long - term stable mortality patterns, are made by this model. However, these presumptions might not be applicable in every situation.

Sensitivity to parameter selection: The model's results can be sensitive to the choice of parameters, such as the reference life table and the number of age groups used.

8 Conclusions

Using data from the Global Burden of Disease Study 2019 and the United Nations World Population Prospects 2022, a system of Brass' logit model life tables was created for Ethiopia. The development and analysis of the model allowed for the accomplishment of several important goals, such as:

Infant, Under - 5, and Child mortality Rates

The model results showed that Ethiopia's healthcare system made notable strides in general between 1990 and 2019. With a 7.7% increase in the likelihood of survival at birth, life expectancy increased by 16.977 years, from 49.259 to 66.236 years. Between 1990 and 2019, the rate of infant mortality decreased by 69.5%, from 107.19 per thousand live births to 32.68. Ethiopia has achieved a noteworthy decrease in under - five mortality rate over the past few decades, going from 179.33 per 1000 live births in 1990 to 60.15 in 2019. This represents a remarkable 66% decline in 30 years.

Male and female child mortality rates were 30.48 and 28.65, respectively. The child mortality rate (CMR) reveals a sex disparity of 1.83 deaths per 1000 live births, with males continuing to have a higher mortality rate. Comparisons of IMRs, U5MRs, and CMRs have shown a small to moderate sex disparity in mortality rates, with males having a 16% to 6% higher risk of dying than females.

Comparative analysis of mortality trends

Over the previous thirty years, infant mortality rates have improved significantly, with an average percentage change of -72.96% across all regions. The difference in life expectancy at birth based on sex decreased significantly from 7.706 years in 1990 to 4.491 years in 2019. In 1990, the average under - five death rate for all regions was 175.05, but in 2019 it was 57.69, representing a reduction of over 67%. Over the past thirty years the average change in U5MR of the regions has been 117.36. Addis Ababa and Benshangul - Gumuz have been operating at rates significantly lower than this average value, while Tigray, Amhara, Harari, and Diredawa were operating at rates that were almost identical to it.

IMRs ranged from 12.88 deaths per 1000 live births in Addis Ababa to 43.94 in Benshangul - Gumuz. U5MRs also exhibited sizeable variations among the regional states with the lowest in Addis Ababa (28.16 deaths per 1000 live births) and the highest rates in Benshangul - Gumuz (77.32 deaths per 1000 live births).

Life Expectancy Decompositions

All regional states made significant contributions to the overall transformation in life expectancy of the nation, 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.

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.

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 also.

Overall, this dissertation work provides insightful information about how mortality is changing in various populations and geographical areas. Policy makers and public health officials need this information in their efforts to improve health outcomes and lower mortality. The development of the model offers a reliable tool for mortality analysis, the estimation of abridged life tables fortifies the country's mortality database, and the study of childhood mortality rates yields vital information.

This dissertation work has faced several challenges, including a lack of trustworthy related data and the fact that different sources have given different details of the same issue. Hence, this result acknowledges potential limitations even though every effort has been made to ensure it is free of unjustified errors.

9 Recommendations

In order to estimate regional abridged life tables, this dissertation work had created a new mortality analysis tool for Ethiopia. It then broke down life expectancies by age and came to some conclusions. However, because these findings only address specific areas of concern, their scope has been limited. Then, in order to inform stakeholders and help them complement this work, implement the findings, and extend it further, some recommendations were sent.

Operational recommendations

This dissertation work suggests that enhancing partnerships, ensuring culturally relevant and appropriate interventions for community engagement, and improving healthcare service delivery be put to the best use to reduce mortality rates further and translate them into life expectancy gains. Training and capacity building for researchers and policy makers along with Expanding and Localizing the model are also important.

Policy recommendations

It is advisable to implement universal health coverage programs that guarantee everyone has access to high - quality, affordable health care services, irrespective of their financial situation or social standing. This will improve health outcomes and lower mortality rates for all age groups, thereby improving life expectancy and well being in life. To lessen socioeconomic disparities in health and mortality, it is also advisable to prioritize public health interventions and strengthen social safety nets to offer monetary and social support to the underprivileged populations. It is also worthwhile that Health and Demographic Surveillance (HDSS) and functional vital registration Systems be established nation wide with proper representative branches in the regional states to facilitate comprehensive data collection for further analysis of population issues. Policy makers are also advised that they use Model Life Table results along with that of censuses and surveys. Besides, Integrating the model into Health planning and Collaborating with stakeholders to ensure the model integrates into health systems and research frameworks are also advisable.

Scientific recommendations

It is recommended that age - specific interventions take center stage. In order to ensure accurate and trustworthy data on mortality trends with the establishment of database centers, it is also advisable to strengthen data collection systems and invest in robust statistical analysis. Updating the model with new data and validating it against other models, and Methodological improvements - such as Exploring modifications and Calibrations are also necessary points that this study suggest be carried out.

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Appendices

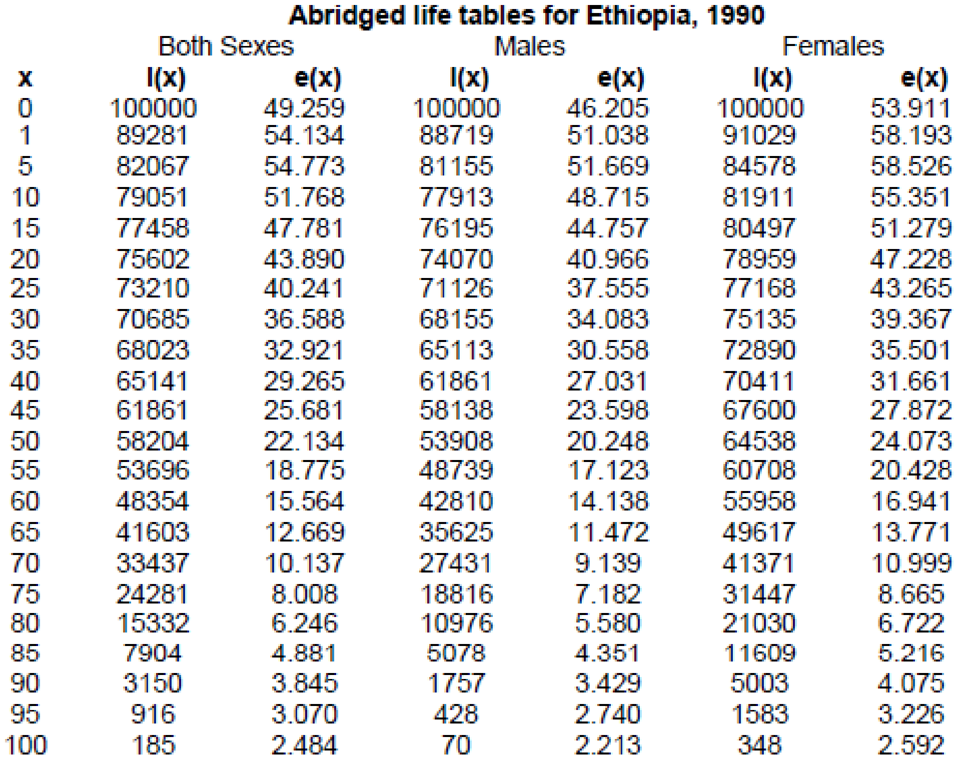
Main and Supplementary data sources

$POP/DB/WPP/Revenue.2022/MORT/F07-1.$

$https://journals.plos.org/globalpublichealth/article?id=10.1371/journal.pgph.0001471.$

Estimated abridged life tables for Ethiopia and its regional states

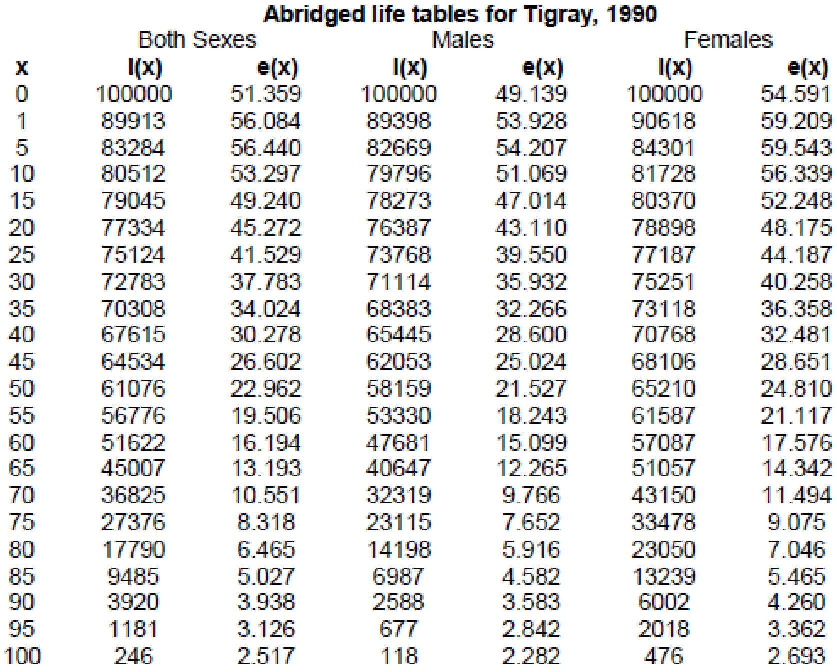
Table 32: Abridged life tables for Ethiopia, 1990



Abridged life tables for Ethiopia, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	49.259	100000	46.205	100000	53.911
1	89281	54.134	88719	51.038	91029	58.193
5	82067	54.773	81155	51.669	84578	58.526
10	79051	51.768	77913	48.715	81911	55.351
15	77458	47.781	76195	44.757	80497	51.279
20	75602	43.890	74070	40.966	78959	47.228
25	73210	40.241	71126	37.555	77168	43.265
30	70685	36.588	68155	34.083	75135	39.367
35	68023	32.921	65113	30.558	72890	35.501
40	65141	29.265	61861	27.031	70411	31.661
45	61861	25.681	58138	23.598	67600	27.872
50	58204	22.134	53908	20.248	64538	24.073
55	53696	18.775	48739	17.123	60708	20.428
60	48354	15.564	42810	14.138	55958	16.941
65	41603	12.669	35625	11.472	49617	13.771
70	33437	10.137	27431	9.139	41371	10.999
75	24281	8.008	18816	7.182	31447	8.665
80	15332	6.246	10976	5.580	21030	6.722
85	7904	4.881	5078	4.351	11609	5.216
90	3150	3.845	1757	3.429	5003	4.075
95	916	3.070	428	2.740	1583	3.226
100	185	2.484	70	2.213	348	2.592

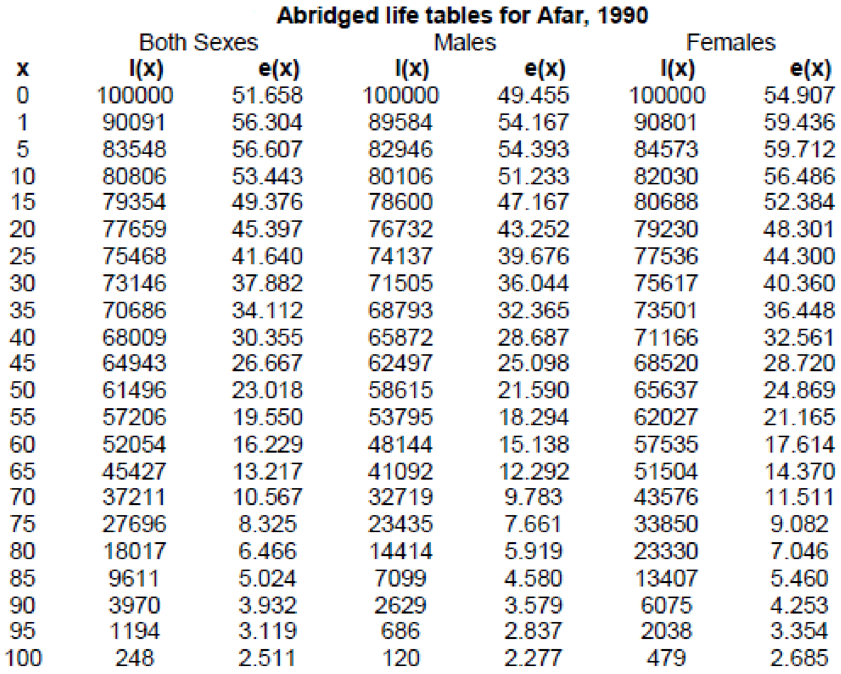
Table 33: Abridged life tables for Tigray, 1990



Abridged life tables for Tigray, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	51.359	100000	49.139	100000	54.591
1	89913	56.084	89398	53.928	90618	59.209
5	83284	56.440	82669	54.207	84301	59.543
10	80512	53.297	79796	51.069	81728	56.339
15	79045	49.240	78273	47.014	80370	52.248
20	77334	45.272	76387	43.110	78898	48.175
25	75124	41.529	73768	39.550	77187	44.187
30	72783	37.783	71114	35.932	75251	40.258
35	70308	34.024	68383	32.266	73118	36.358
40	67615	30.278	65445	28.600	70768	32.481
45	64534	26.602	62053	25.024	68106	28.651
50	61076	22.962	58159	21.527	65210	24.810
55	56776	19.506	53330	18.243	61587	21.117
60	51622	16.194	47681	15.099	57087	17.576
65	45007	13.193	40647	12.265	51057	14.342
70	36825	10.551	32319	9.766	43150	11.494
75	27376	8.318	23115	7.652	33478	9.075
80	17790	6.465	14198	5.916	23050	7.046
85	9485	5.027	6987	4.582	13239	5.465
90	3920	3.938	2588	3.583	6002	4.260
95	1181	3.126	677	2.842	2018	3.362
100	246	2.517	118	2.282	476	2.693

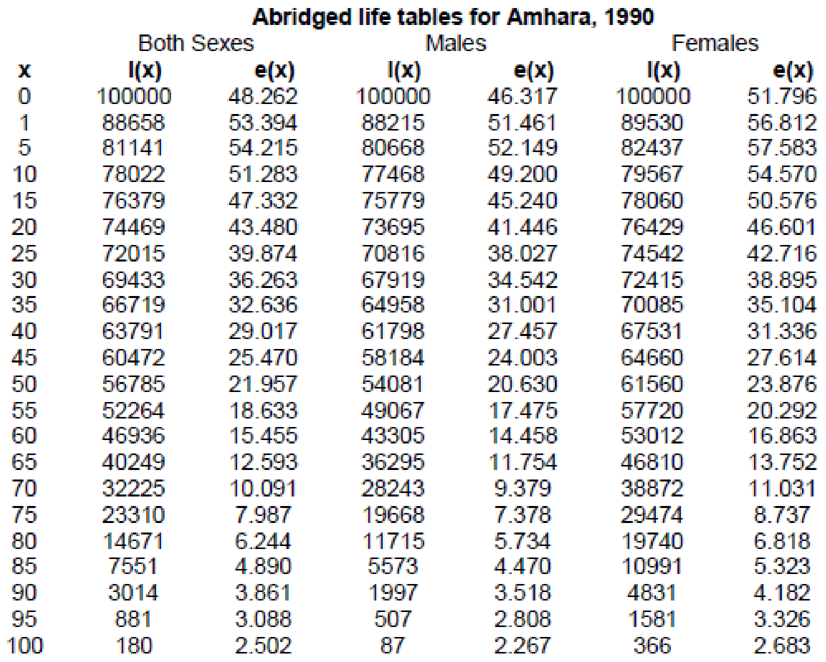
Table 34: Abridged life tables for Afar, 1990



Abridged life tables for Afar, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	51.658	100000	49.455	100000	54.907
1	90091	56.304	89584	54.167	90801	59.436
5	83548	56.607	82946	54.393	84573	59.712
10	80806	53.443	80106	51.233	82030	56.486
15	79354	49.376	78600	47.167	80688	52.384
20	77659	45.397	76732	43.252	79230	48.301
25	75468	41.640	74137	39.676	77536	44.300
30	73146	37.882	71505	36.044	75617	40.360
35	70686	34.112	68793	32.365	73501	36.448
40	68009	30.355	65872	28.687	71166	32.561
45	64943	26.667	62497	25.098	68520	28.720
50	61496	23.018	58615	21.590	65637	24.869
55	57206	19.550	53795	18.294	62027	21.165
60	52054	16.229	48144	15.138	57535	17.614
65	45427	13.217	41092	12.292	51504	14.370
70	37211	10.567	32719	9.783	43576	11.511
75	27696	8.325	23435	7.661	33850	9.082
80	18017	6.466	14414	5.919	23330	7.046
85	9611	5.024	7099	4.580	13407	5.460
90	3970	3.932	2629	3.579	6075	4.253
95	1194	3.119	686	2.837	2038	3.354
100	248	2.511	120	2.277	479	2.685

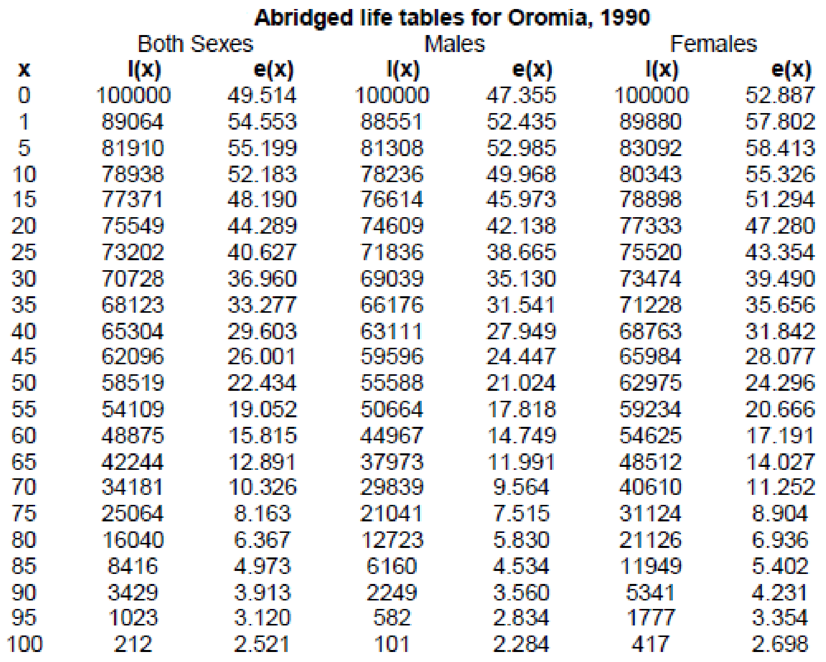
Table 35: Abridged life tables for Amhara, 1990



Abridged life tables for Amhara, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	48.262	100000	46.317	100000	51.796
1	88658	53.394	88215	51.461	89530	56.812
5	81141	54.215	80668	52.149	82437	57.583
10	78022	51.283	77468	49.200	79567	54.570
15	76379	47.332	75779	45.240	78060	50.576
20	74469	43.480	73695	41.446	76429	46.601
25	72015	39.874	70816	38.027	74542	42.716
30	69433	36.263	67919	34.542	72415	38.895
35	66719	32.636	64958	31.001	70085	35.104
40	63791	29.017	61798	27.457	67531	31.336
45	60472	25.470	58184	24.003	64660	27.614
50	56785	21.957	54081	20.630	61560	23.876
55	52264	18.633	49067	17.475	57720	20.292
60	46936	15.455	43305	14.458	53012	16.863
65	40249	12.593	36295	11.754	46810	13.752
70	32225	10.091	28243	9.379	38872	11.031
75	23310	7.987	19668	7.378	29474	8.737
80	14671	6.244	11715	5.734	19740	6.818
85	7551	4.890	5573	4.470	10991	5.323
90	3014	3.861	1997	3.518	4831	4.182
95	881	3.088	507	2.808	1581	3.326
100	180	2.502	87	2.267	366	2.683

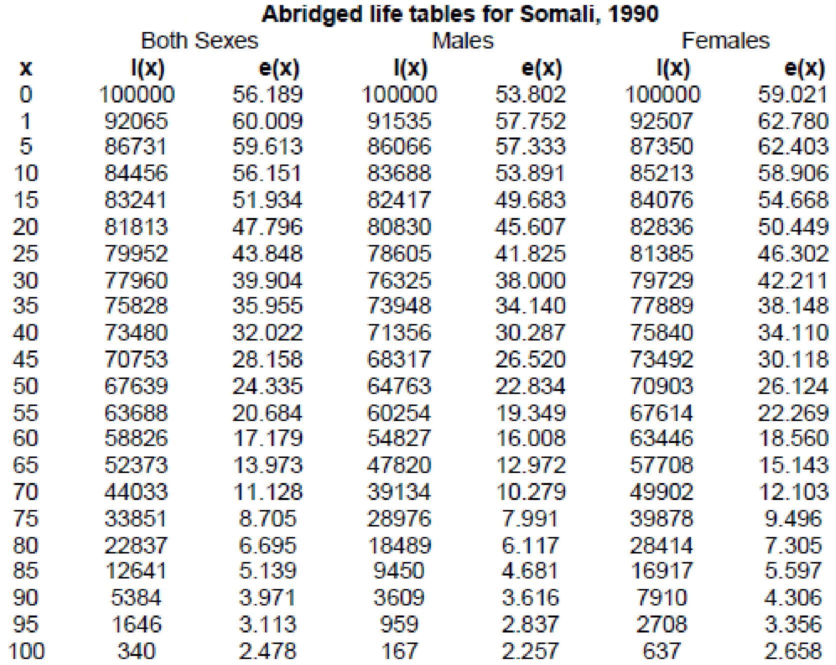
Table 36: Abridged life tables for Oromia, 1990



Abridged life tables for Oromia, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	49.514	100000	47.355	100000	52.887
1	89064	54.553	88551	52.435	89880	57.802
5	81910	55.199	81308	52.985	83092	58.413
10	78938	52.183	78236	49.968	80343	55.326
15	77371	48.190	76614	45.973	78898	51.294
20	75549	44.289	74609	42.138	77333	47.280
25	73202	40.627	71836	38.665	75520	43.354
30	70728	36.960	69039	35.130	73474	39.490
35	68123	33.277	66176	31.541	71228	35.656
40	65304	29.603	63111	27.949	68763	31.842
45	62096	26.001	59596	24.447	65984	28.077
50	58519	22.434	55588	21.024	62975	24.296
55	54109	19.052	50664	17.818	59234	20.666
60	48875	15.815	44967	14.749	54625	17.191
65	42244	12.891	37973	11.991	48512	14.027
70	34181	10.326	29839	9.564	40610	11.252
75	25064	8.163	21041	7.515	31124	8.904
80	16040	6.367	12723	5.830	21126	6.936
85	8416	4.973	6160	4.534	11949	5.402
90	3429	3.913	2249	3.560	5341	4.231
95	1023	3.120	582	2.834	1777	3.354
100	212	2.521	101	2.284	417	2.698

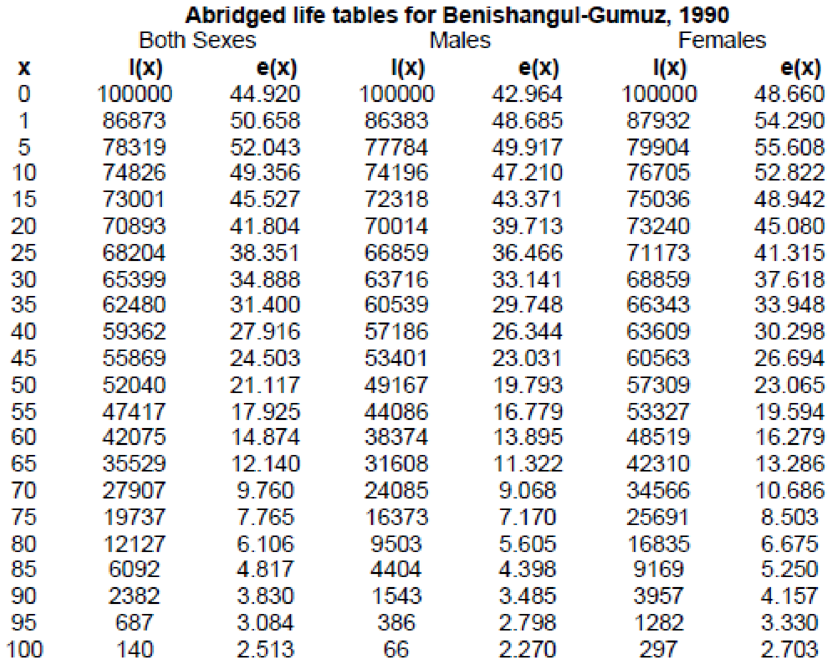
Table 37: Abridged life tables for Somali, 1990



Abridged life tables for Somali, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	56.189	100000	53.802	100000	59.021
1	92065	60.009	91535	57.752	92507	62.780
5	86731	59.613	86066	57.333	87350	62.403
10	84456	56.151	83688	53.891	85213	58.906
15	83241	51.934	82417	49.683	84076	54.668
20	81813	47.796	80830	45.607	82836	50.449
25	79952	43.848	78605	41.825	81385	46.302
30	77960	39.904	76325	38.000	79729	42.211
35	75828	35.955	73948	34.140	77889	38.148
40	73480	32.022	71356	30.287	75840	34.110
45	70753	28.158	68317	26.520	73492	30.118
50	67639	24.335	64763	22.834	70903	26.124
55	63688	20.684	60254	19.349	67614	22.269
60	58826	17.179	54827	16.008	63446	18.560
65	52373	13.973	47820	12.972	57708	15.143
70	44033	11.128	39134	10.279	49902	12.103
75	33851	8.705	28976	7.991	39878	9.496
80	22837	6.695	18489	6.117	28414	7.305
85	12641	5.139	9450	4.681	16917	5.597
90	5384	3.971	3609	3.616	7910	4.306
95	1646	3.113	959	2.837	2708	3.356
100	340	2.478	167	2.257	637	2.658

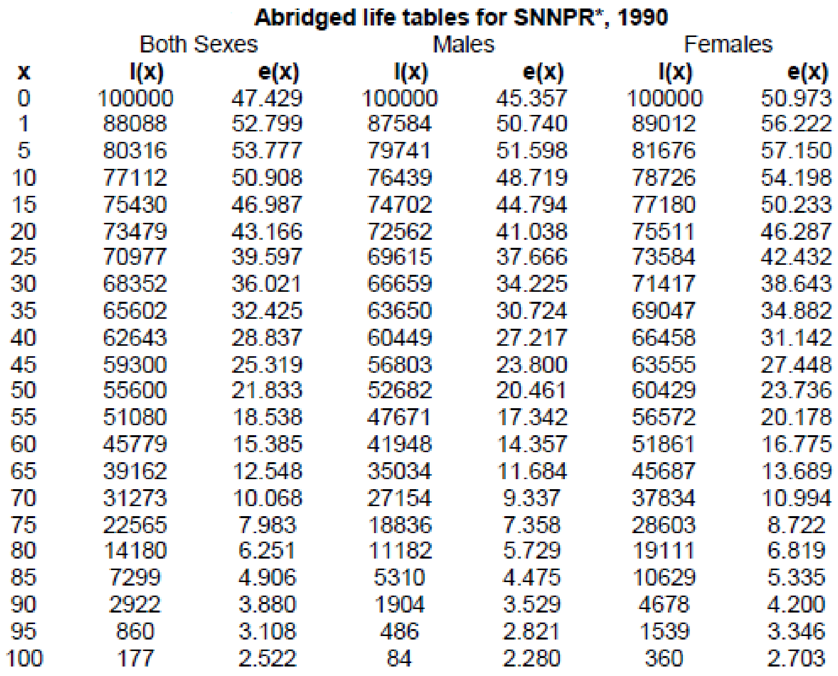
Table 38: Abridged life tables for Benshangul - Gumuz, 1990



Abridged life tables for Benishangul-Gumuz, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	44.920	100000	42.964	100000	48.660
1	86873	50.658	86383	48.685	87932	54.290
5	78319	52.043	77784	49.917	79904	55.608
10	74826	49.356	74196	47.210	76705	52.822
15	73001	45.527	72318	43.371	75036	48.942
20	70893	41.804	70014	39.713	73240	45.080
25	68204	38.351	66859	36.466	71173	41.315
30	65399	34.888	63716	33.141	68859	37.618
35	62480	31.400	60539	29.748	66343	33.948
40	59362	27.916	57186	26.344	63609	30.298
45	55869	24.503	53401	23.031	60563	26.694
50	52040	21.117	49167	19.793	57309	23.065
55	47417	17.925	44086	16.779	53327	19.594
60	42075	14.874	38374	13.895	48519	16.279
65	35529	12.140	31608	11.322	42310	13.286
70	27907	9.760	24085	9.068	34566	10.686
75	19737	7.765	16373	7.170	25691	8.503
80	12127	6.106	9503	5.605	16835	6.675
85	6092	4.817	4404	4.398	9169	5.250
90	2382	3.830	1543	3.485	3957	4.157
95	687	3.084	386	2.798	1282	3.330
100	140	2.513	66	2.270	297	2.703

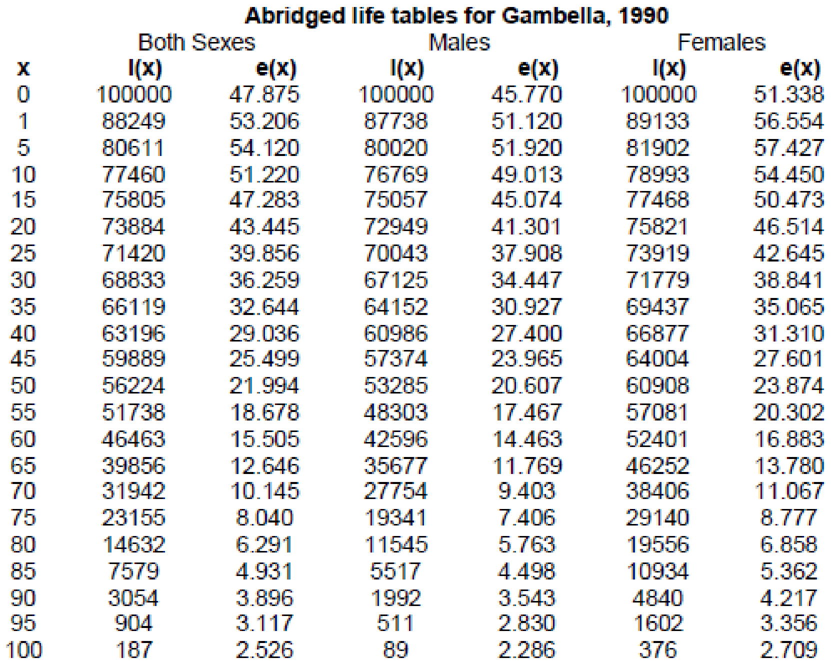
Table 39: Abridged life tables for SNNRP*, 1990



Abridged life tables for SNNPR*, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	47.429	100000	45.357	100000	50.973
1	88088	52.799	87584	50.740	89012	56.222
5	80316	53.777	79741	51.598	81676	57.150
10	77112	50.908	76439	48.719	78726	54.198
15	75430	46.987	74702	44.794	77180	50.233
20	73479	43.166	72562	41.038	75511	46.287
25	70977	39.597	69615	37.666	73584	42.432
30	68352	36.021	66659	34.225	71417	38.643
35	65602	32.425	63650	30.724	69047	34.882
40	62643	28.837	60449	27.217	66458	31.142
45	59300	25.319	56803	23.800	63555	27.448
50	55600	21.833	52682	20.461	60429	23.736
55	51080	18.538	47671	17.342	56572	20.178
60	45779	15.385	41948	14.357	51861	16.775
65	39162	12.548	35034	11.684	45687	13.689
70	31273	10.068	27154	9.337	37834	10.994
75	22565	7.983	18836	7.358	28603	8.722
80	14180	6.251	11182	5.729	19111	6.819
85	7299	4.906	5310	4.475	10629	5.335
90	2922	3.880	1904	3.529	4678	4.200
95	860	3.108	486	2.821	1539	3.346
100	177	2.522	84	2.280	360	2.703

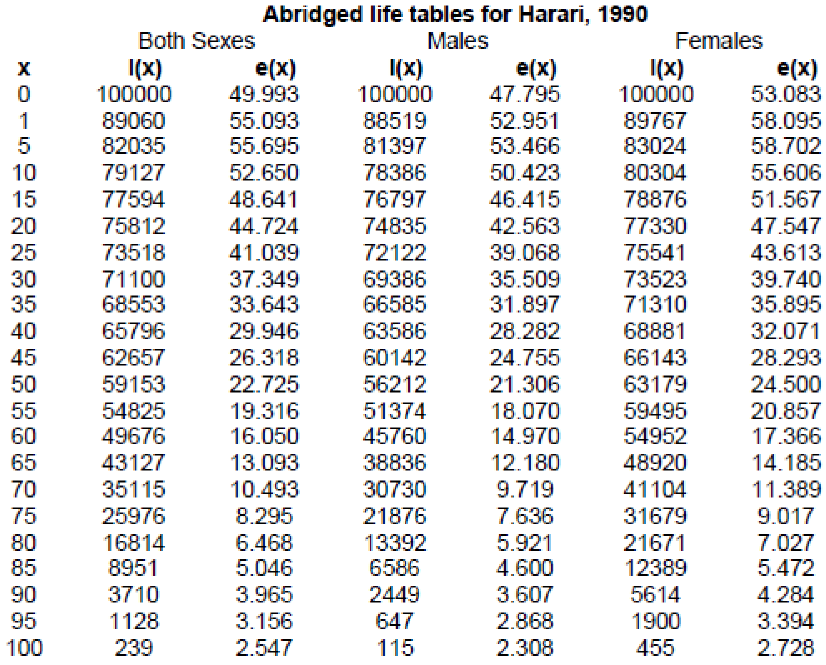
Table 40: Abridged life tables for Gambella, 1990



Abridged life tables for Gambella, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	47.875	100000	45.770	100000	51.338
1	88249	53.206	87738	51.120	89133	56.554
5	80611	54.120	80020	51.920	81902	57.427
10	77460	51.220	76769	49.013	78993	54.450
15	75805	47.283	75057	45.074	77468	50.473
20	73884	43.445	72949	41.301	75821	46.514
25	71420	39.856	70043	37.908	73919	42.645
30	68833	36.259	67125	34.447	71779	38.841
35	66119	32.644	64152	30.927	69437	35.065
40	63196	29.036	60986	27.400	66877	31.310
45	59889	25.499	57374	23.965	64004	27.601
50	56224	21.994	53285	20.607	60908	23.874
55	51738	18.678	48303	17.467	57081	20.302
60	46463	15.505	42596	14.463	52401	16.883
65	39856	12.646	35677	11.769	46252	13.780
70	31942	10.145	27754	9.403	38406	11.067
75	23155	8.040	19341	7.406	29140	8.777
80	14632	6.291	11545	5.763	19556	6.858
85	7579	4.931	5517	4.498	10934	5.362
90	3054	3.896	1992	3.543	4840	4.217
95	904	3.117	511	2.830	1602	3.356
100	187	2.526	89	2.286	376	2.709

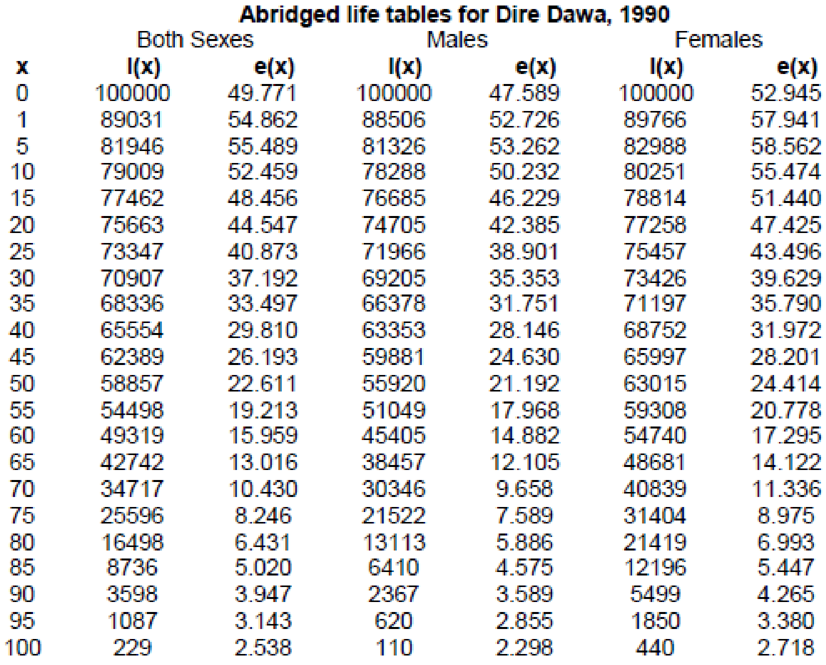
Table 41: Abridged life tables for Harari, 1990



Abridged life tables for Harari, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	49.993	100000	47.795	100000	53.083
1	89060	55.093	88519	52.951	89767	58.095
5	82035	55.695	81397	53.466	83024	58.702
10	79127	52.650	78386	50.423	80304	55.606
15	77594	48.641	76797	46.415	78876	51.567
20	75812	44.724	74835	42.563	77330	47.547
25	73518	41.039	72122	39.068	75541	43.613
30	71100	37.349	69386	35.509	73523	39.740
35	68553	33.643	66585	31.897	71310	35.895
40	65796	29.946	63586	28.282	68881	32.071
45	62657	26.318	60142	24.755	66143	28.293
50	59153	22.725	56212	21.306	63179	24.500
55	54825	19.316	51374	18.070	59495	20.857
60	49676	16.050	45760	14.970	54952	17.366
65	43127	13.093	38836	12.180	48920	14.185
70	35115	10.493	30730	9.719	41104	11.389
75	25976	8.295	21876	7.636	31679	9.017
80	16814	6.468	13392	5.921	21671	7.027
85	8951	5.046	6586	4.600	12389	5.472
90	3710	3.965	2449	3.607	5614	4.284
95	1128	3.156	647	2.868	1900	3.394
100	239	2.547	115	2.308	455	2.728

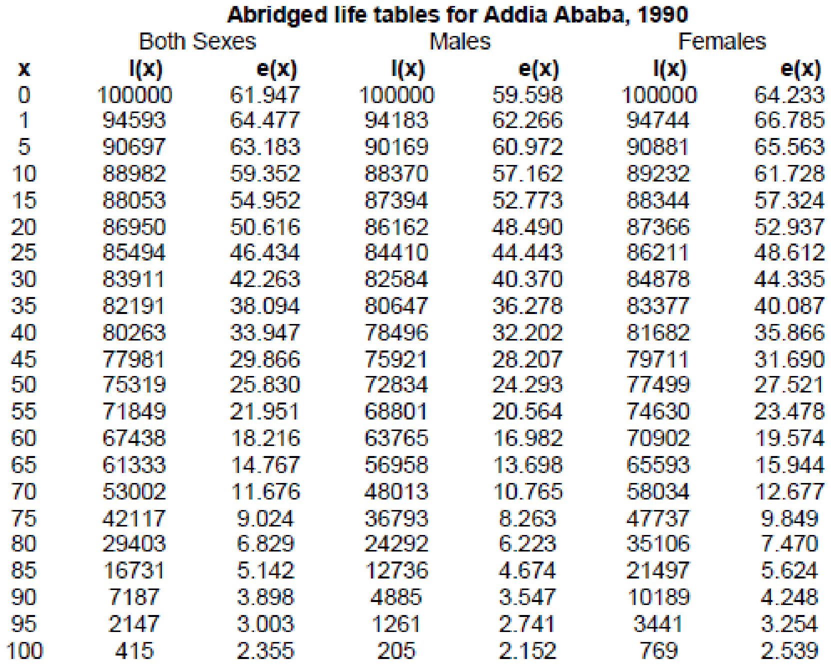
Table 42: Abridged life tables for Dire Dawa, 1990



Abridged life tables for Dire Dawa, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	49.771	100000	47.589	100000	52.945
1	89031	54.862	88506	52.726	89766	57.941
5	81946	55.489	81326	53.262	82988	58.562
10	79009	52.459	78288	50.232	80251	55.474
15	77462	48.456	76685	46.229	78814	51.440
20	75663	44.547	74705	42.385	77258	47.425
25	73347	40.873	71966	38.901	75457	43.496
30	70907	37.192	69205	35.353	73426	39.629
35	68336	33.497	66378	31.751	71197	35.790
40	65554	29.810	63353	28.146	68752	31.972
45	62389	26.193	59881	24.630	65997	28.201
50	58857	22.611	55920	21.192	63015	24.414
55	54498	19.213	51049	17.968	59308	20.778
60	49319	15.959	45405	14.882	54740	17.295
65	42742	13.016	38457	12.105	48681	14.122
70	34717	10.430	30346	9.658	40839	11.336
75	25596	8.246	21522	7.589	31404	8.975
80	16498	6.431	13113	5.886	21419	6.993
85	8736	5.020	6410	4.575	12196	5.447
90	3598	3.947	2367	3.589	5499	4.265
95	1087	3.143	620	2.855	1850	3.380
100	229	2.538	110	2.298	440	2.718

Table 43: Abridged life tables for Addis Ababa, 1990



Abridged life tables for Addia Ababa, 1990

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	61.947	100000	59.598	100000	64.233
1	94593	64.477	94183	62.266	94744	66.785
5	90697	63.183	90169	60.972	90881	65.563
10	88982	59.352	88370	57.162	89232	61.728
15	88053	54.952	87394	52.773	88344	57.324
20	86950	50.616	86162	48.490	87366	52.937
25	85494	46.434	84410	44.443	86211	48.612
30	83911	42.263	82584	40.370	84878	44.335
35	82191	38.094	80647	36.278	83377	40.087
40	80263	33.947	78496	32.202	81682	35.866
45	77981	29.866	75921	28.207	79711	31.690
50	75319	25.830	72834	24.293	77499	27.521
55	71849	21.951	68801	20.564	74630	23.478
60	67438	18.216	63765	16.982	70902	19.574
65	61333	14.767	56958	13.698	65593	15.944
70	53002	11.676	48013	10.765	58034	12.677
75	42117	9.024	36793	8.263	47737	9.849
80	29403	6.829	24292	6.223	35106	7.470
85	16731	5.142	12736	4.674	21497	5.624
90	7187	3.898	4885	3.547	10189	4.248
95	2147	3.003	1261	2.741	3441	3.254
100	415	2.355	205	2.152	769	2.539

Table 44: Abridged life tables for Ethiopia, 2019

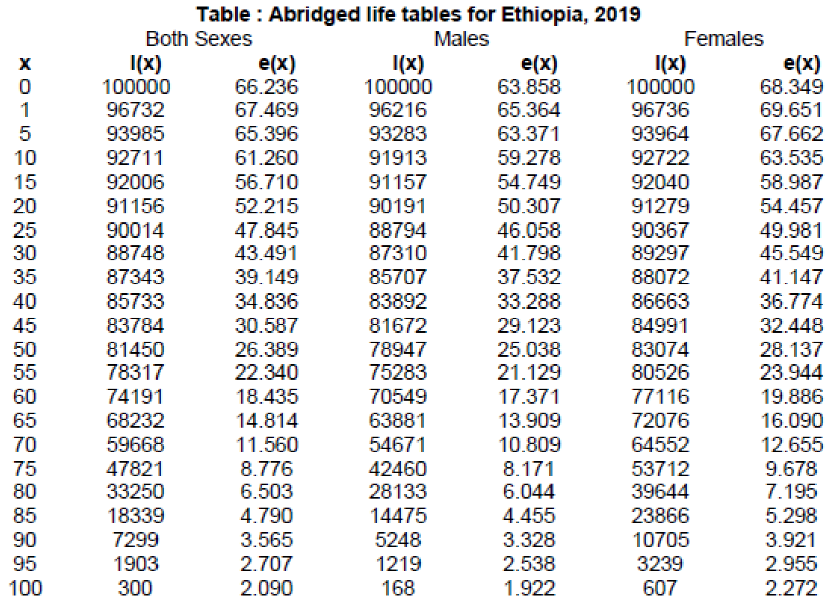


Table : Abridged life tables for Ethiopia, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.236	100000	63.858	100000	68.349
1	96732	67.469	96216	65.364	96736	69.651
5	93985	65.396	93283	63.371	93964	67.662
10	92711	61.260	91913	59.278	92722	63.535
15	92006	56.710	91157	54.749	92040	58.987
20	91156	52.215	90191	50.307	91279	54.457
25	90014	47.845	88794	46.058	90367	49.981
30	88748	43.491	87310	41.798	89297	45.549
35	87343	39.149	85707	37.532	88072	41.147
40	85733	34.836	83892	33.288	86663	36.774
45	83784	30.587	81672	29.123	84991	32.448
50	81450	26.389	78947	25.038	83074	28.137
55	78317	22.340	75283	21.129	80526	23.944
60	74191	18.435	70549	17.371	77116	19.886
65	68232	14.814	63881	13.909	72076	16.090
70	59668	11.560	54671	10.809	64552	12.655
75	47821	8.776	42460	8.171	53712	9.678
80	33250	6.503	28133	6.044	39644	7.195
85	18339	4.790	14475	4.455	23866	5.298
90	7299	3.565	5248	3.328	10705	3.921
95	1903	2.707	1219	2.538	3239	2.955
100	300	2.090	168	1.922	607	2.272

Table 45: Abridged life tables for Tigray, 2019

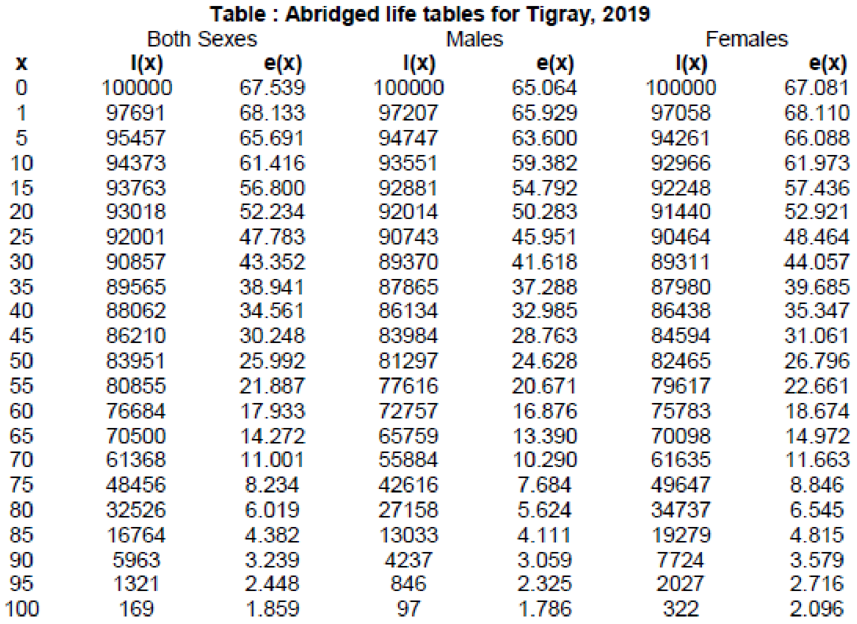


Table : Abridged life tables for Tigray, 2019

x	Both Sexes l(x)	Both Sexes e(x)	Males l(x)	Males e(x)	Females l(x)	Females e(x)
0	100000	67.539	100000	65.064	100000	67.081
1	97691	68.133	97207	65.929	97058	68.110
5	95457	65.691	94747	63.600	94261	66.088
10	94373	61.416	93551	59.382	92966	61.973
15	93763	56.800	92881	54.792	92248	57.436
20	93018	52.234	92014	50.283	91440	52.921
25	92001	47.783	90743	45.951	90464	48.464
30	90857	43.352	89370	41.618	89311	44.057
35	89565	38.941	87865	37.288	87980	39.685
40	88062	34.561	86134	32.985	86438	35.347
45	86210	30.248	83984	28.763	84594	31.061
50	83951	25.992	81297	24.628	82465	26.796
55	80855	21.887	77616	20.671	79617	22.661
60	76684	17.933	72757	16.876	75783	18.674
65	70500	14.272	65759	13.390	70098	14.972
70	61368	11.001	55884	10.290	61635	11.663
75	48456	8.234	42616	7.684	49647	8.846
80	32526	6.019	27158	5.624	34737	6.545
85	16764	4.382	13033	4.111	19279	4.815
90	5963	3.239	4237	3.059	7724	3.579
95	1321	2.448	846	2.325	2027	2.716
100	169	1.859	97	1.786	322	2.096

Table 46: Abridged life tables for Afar, 2019

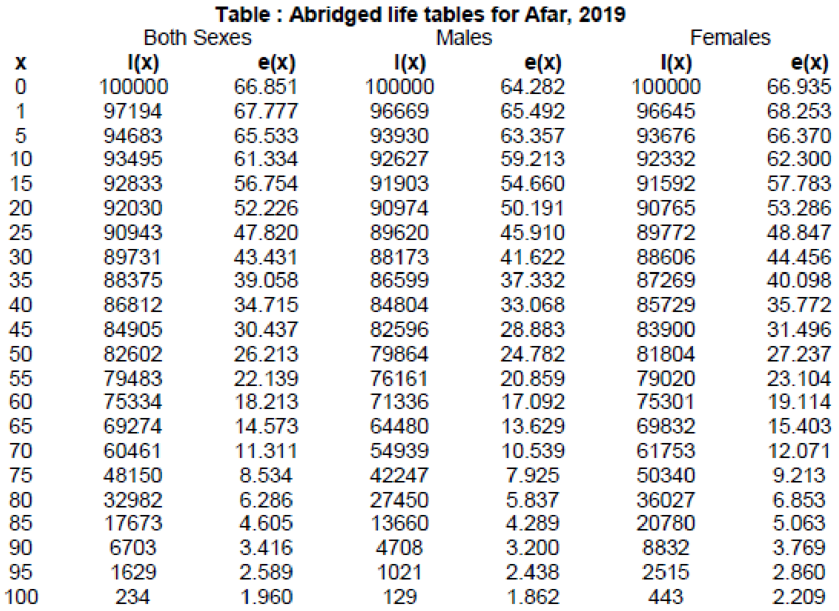


Table : Abridged life tables for Afar, 2019

x	Both Sexes l(x)	Both Sexes e(x)	Males l(x)	Males e(x)	Females l(x)	Females e(x)
0	100000	66.851	100000	64.282	100000	66.935
1	97194	67.777	96669	65.492	96645	68.253
5	94683	65.533	93930	63.357	93676	66.370
10	93495	61.334	92627	59.213	92332	62.300
15	92833	56.754	91903	54.660	91592	57.783
20	92030	52.226	90974	50.191	90765	53.286
25	90943	47.820	89620	45.910	89772	48.847
30	89731	43.431	88173	41.622	88606	44.456
35	88375	39.058	86599	37.332	87269	40.098
40	86812	34.715	84804	33.068	85729	35.772
45	84905	30.437	82596	28.883	83900	31.496
50	82602	26.213	79864	24.782	81804	27.237
55	79483	22.139	76161	20.859	79020	23.104
60	75334	18.213	71336	17.092	75301	19.114
65	69274	14.573	64480	13.629	69832	15.403
70	60461	11.311	54939	10.539	61753	12.071
75	48150	8.534	42247	7.925	50340	9.213
80	32982	6.286	27450	5.837	36027	6.853
85	17673	4.605	13660	4.289	20780	5.063
90	6703	3.416	4708	3.200	8832	3.769
95	1629	2.589	1021	2.438	2515	2.860
100	234	1.960	129	1.862	443	2.209

Table 47: Abridged life tables for Amhara, 2019

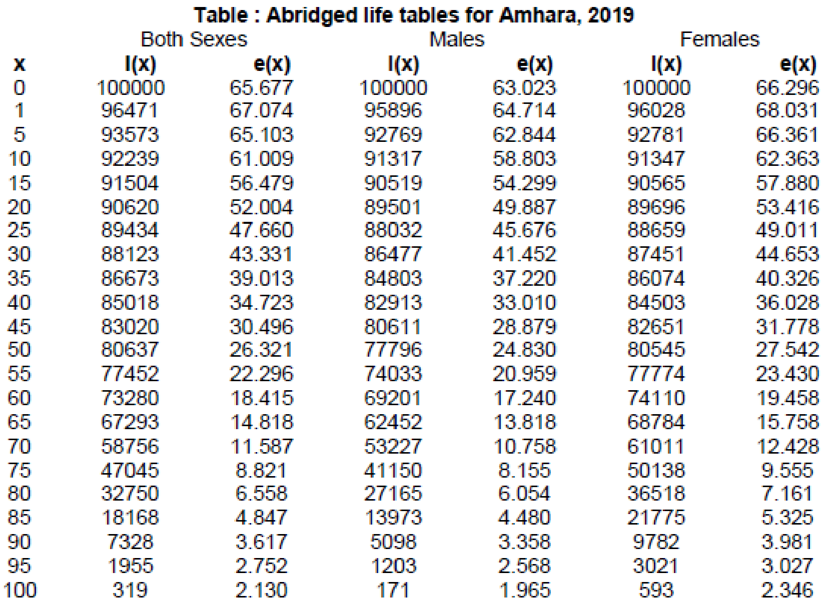


Table : Abridged life tables for Amhara, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	65.677	100000	63.023	100000	66.296
1	96471	67.074	95896	64.714	96028	68.031
5	93573	65.103	92769	62.844	92781	66.361
10	92239	61.009	91317	58.803	91347	62.363
15	91504	56.479	90519	54.299	90565	57.880
20	90620	52.004	89501	49.887	89696	53.416
25	89434	47.660	88032	45.676	88659	49.011
30	88123	43.331	86477	41.452	87451	44.653
35	86673	39.013	84803	37.220	86074	40.326
40	85018	34.723	82913	33.010	84503	36.028
45	83020	30.496	80611	28.879	82651	31.778
50	80637	26.321	77796	24.830	80545	27.542
55	77452	22.296	74033	20.959	77774	23.430
60	73280	18.415	69201	17.240	74110	19.458
65	67293	14.818	62452	13.818	68784	15.758
70	58756	11.587	53227	10.758	61011	12.428
75	47045	8.821	41150	8.155	50138	9.555
80	32750	6.558	27165	6.054	36518	7.161
85	18168	4.847	13973	4.480	21775	5.325
90	7328	3.617	5098	3.358	9782	3.981
95	1955	2.752	1203	2.568	3021	3.027
100	319	2.130	171	1.965	593	2.346

Table 48: Abridged life tables for Oromia, 2019

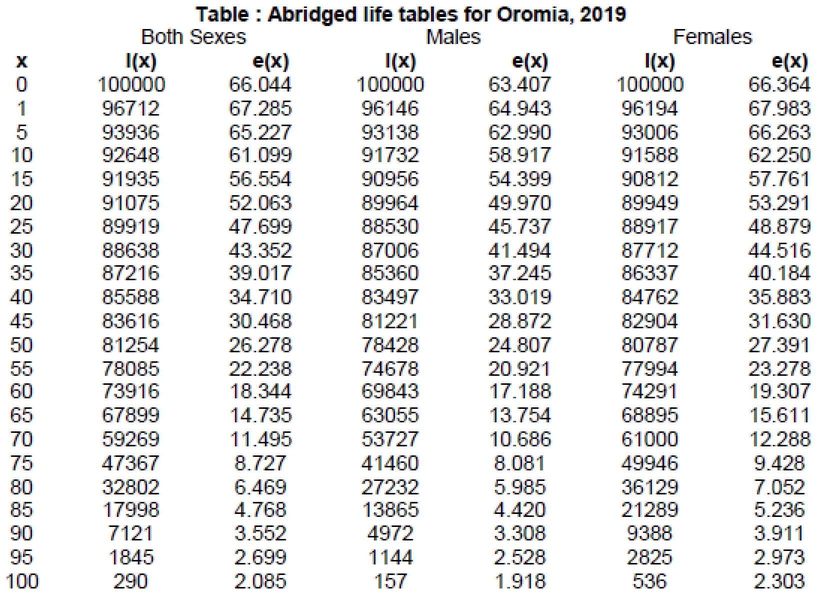


Table : Abridged life tables for Oromia, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.044	100000	63.407	100000	66.364
1	96712	67.285	96146	64.943	96194	67.983
5	93936	65.227	93138	62.990	93006	66.263
10	92648	61.099	91732	58.917	91588	62.250
15	91935	56.554	90956	54.399	90812	57.761
20	91075	52.063	89964	49.970	89949	53.291
25	89919	47.699	88530	45.737	88917	48.879
30	88638	43.352	87006	41.494	87712	44.516
35	87216	39.017	85360	37.245	86337	40.184
40	85588	34.710	83497	33.019	84762	35.883
45	83616	30.468	81221	28.872	82904	31.630
50	81254	26.278	78428	24.807	80787	27.391
55	78085	22.238	74678	20.921	77994	23.278
60	73916	18.344	69843	17.188	74291	19.307
65	67899	14.735	63055	13.754	68895	15.611
70	59269	11.495	53727	10.686	61000	12.288
75	47367	8.727	41460	8.081	49946	9.428
80	32802	6.469	27232	5.985	36129	7.052
85	17998	4.768	13865	4.420	21289	5.236
90	7121	3.552	4972	3.308	9388	3.911
95	1845	2.699	1144	2.528	2825	2.973
100	290	2.085	157	1.918	536	2.303

Table 49: Abridged life tables for Somali, 2019

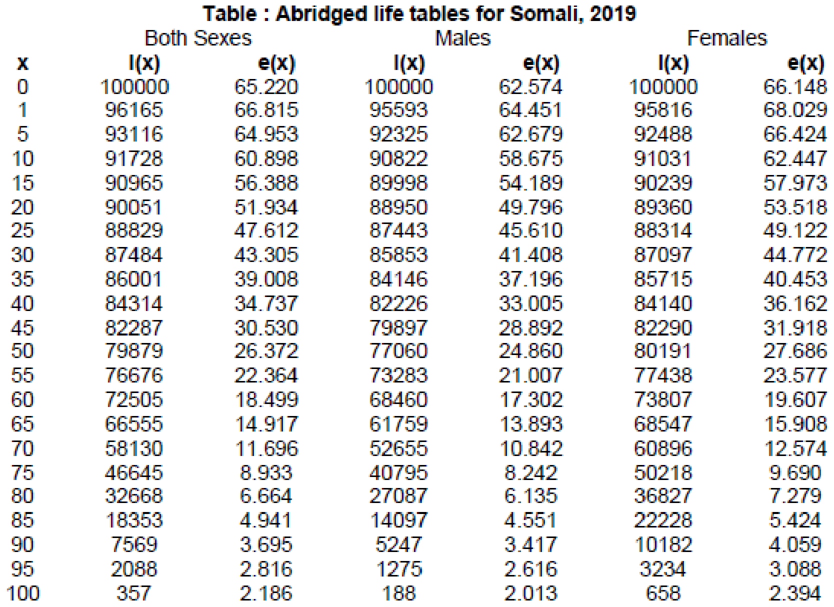


Table : Abridged life tables for Somali, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	65.220	100000	62.574	100000	66.148
1	96165	66.815	95593	64.451	95816	68.029
5	93116	64.953	92325	62.679	92488	66.424
10	91728	60.898	90822	58.675	91031	62.447
15	90965	56.388	89998	54.189	90239	57.973
20	90051	51.934	88950	49.796	89360	53.518
25	88829	47.612	87443	45.610	88314	49.122
30	87484	43.305	85853	41.408	87097	44.772
35	86001	39.008	84146	37.196	85715	40.453
40	84314	34.737	82226	33.005	84140	36.162
45	82287	30.530	79897	28.892	82290	31.918
50	79879	26.372	77060	24.860	80191	27.686
55	76676	22.364	73283	21.007	77438	23.577
60	72505	18.499	68460	17.302	73807	19.607
65	66555	14.917	61759	13.893	68547	15.908
70	58130	11.696	52655	10.842	60896	12.574
75	46645	8.933	40795	8.242	50218	9.690
80	32668	6.664	27087	6.135	36827	7.279
85	18353	4.941	14097	4.551	22228	5.424
90	7569	3.695	5247	3.417	10182	4.059
95	2088	2.816	1275	2.616	3234	3.088
100	357	2.186	188	2.013	658	2.394

Table 50: Abridged life tables for Benshangul - Gumuz, 2019

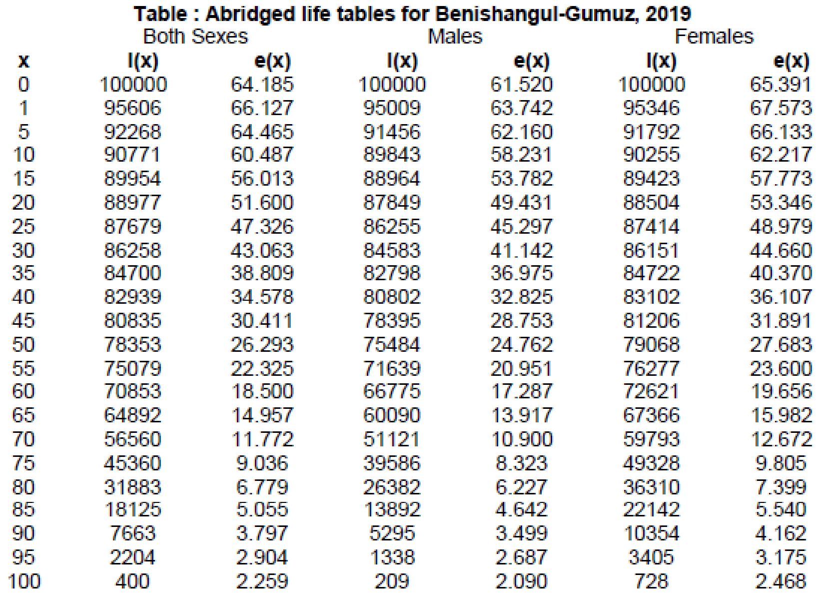


Table : Abridged life tables for Benishangul-Gumuz, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	64.185	100000	61.520	100000	65.391
1	95606	66.127	95009	63.742	95346	67.573
5	92268	64.465	91456	62.160	91792	66.133
10	90771	60.487	89843	58.231	90255	62.217
15	89954	56.013	88964	53.782	89423	57.773
20	88977	51.600	87849	49.431	88504	53.346
25	87679	47.326	86255	45.297	87414	48.979
30	86258	43.063	84583	41.142	86151	44.660
35	84700	38.809	82798	36.975	84722	40.370
40	82939	34.578	80802	32.825	83102	36.107
45	80835	30.411	78395	28.753	81206	31.891
50	78353	26.293	75484	24.762	79068	27.683
55	75079	22.325	71639	20.951	76277	23.600
60	70853	18.500	66775	17.287	72621	19.656
65	64892	14.957	60090	13.917	67366	15.982
70	56560	11.772	51121	10.900	59793	12.672
75	45360	9.036	39586	8.323	49328	9.805
80	31883	6.779	26382	6.227	36310	7.399
85	18125	5.055	13892	4.642	22142	5.540
90	7663	3.797	5295	3.499	10354	4.162
95	2204	2.904	1338	2.687	3405	3.175
100	400	2.259	209	2.090	728	2.468

Table 51: Abridged life tables for SNNRP*, 2019

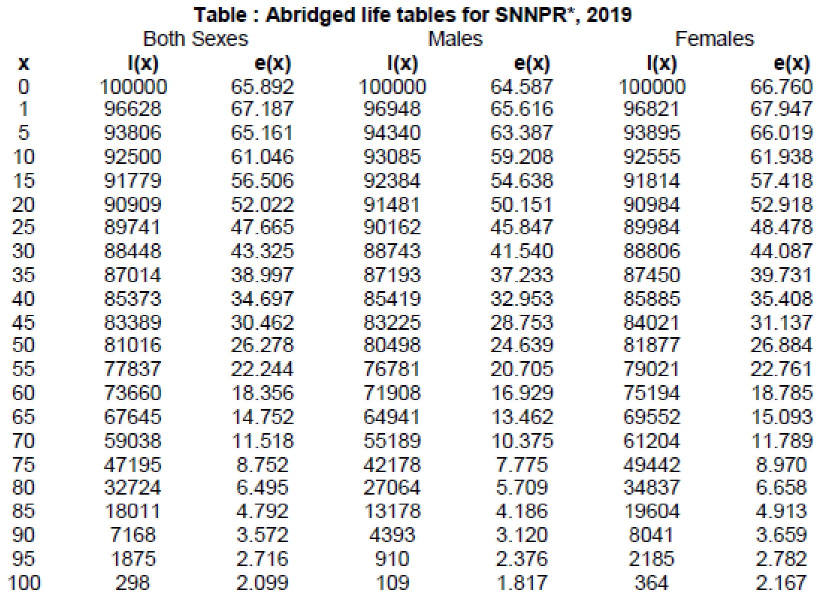


Table : Abridged life tables for SNNPR*, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	65.892	100000	64.587	100000	66.760
1	96628	67.187	96948	65.616	96821	67.947
5	93806	65.161	94340	63.387	93895	66.019
10	92500	61.046	93085	59.208	92555	61.938
15	91779	56.506	92384	54.638	91814	57.418
20	90909	52.022	91481	50.151	90984	52.918
25	89741	47.665	90162	45.847	89984	48.478
30	88448	43.325	88743	41.540	88806	44.087
35	87014	38.997	87193	37.233	87450	39.731
40	85373	34.697	85419	32.953	85885	35.408
45	83389	30.462	83225	28.753	84021	31.137
50	81016	26.278	80498	24.639	81877	26.884
55	77837	22.244	76781	20.705	79021	22.761
60	73660	18.356	71908	16.929	75194	18.785
65	67645	14.752	64941	13.462	69552	15.093
70	59038	11.518	55189	10.375	61204	11.789
75	47195	8.752	42178	7.775	49442	8.970
80	32724	6.495	27064	5.709	34837	6.658
85	18011	4.792	13178	4.186	19604	4.913
90	7168	3.572	4393	3.120	8041	3.659
95	1875	2.716	910	2.376	2185	2.782
100	298	2.099	109	1.817	364	2.167

Table 52: Abridged life tables for Gambella, 2019

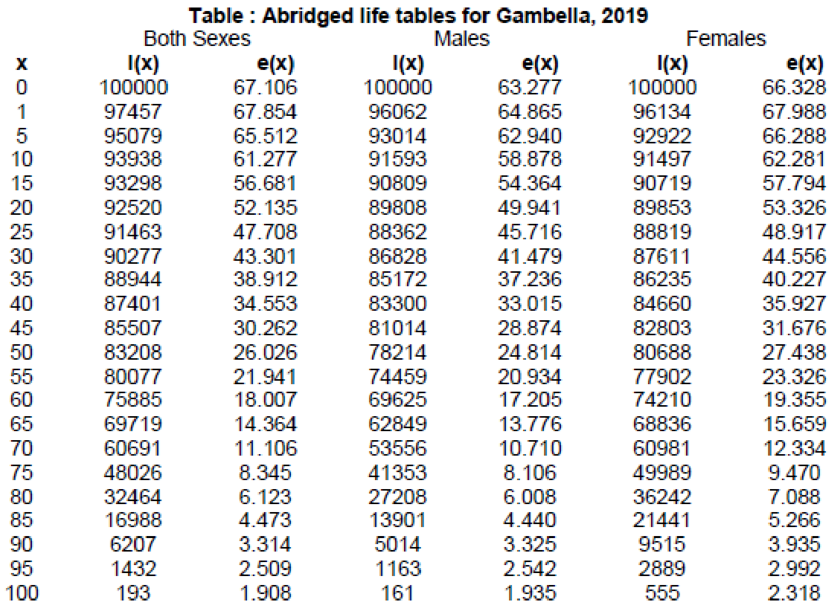


Table : Abridged life tables for Gambella, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	67.106	100000	63.277	100000	66.328
1	97457	67.854	96062	64.865	96134	67.988
5	95079	65.512	93014	62.940	92922	66.288
10	93938	61.277	91593	58.878	91497	62.281
15	93298	56.681	90809	54.364	90719	57.794
20	92520	52.135	89808	49.941	89853	53.326
25	91463	47.708	88362	45.716	88819	48.917
30	90277	43.301	86828	41.479	87611	44.556
35	88944	38.912	85172	37.236	86235	40.227
40	87401	34.553	83300	33.015	84660	35.927
45	85507	30.262	81014	28.874	82803	31.676
50	83208	26.026	78214	24.814	80688	27.438
55	80077	21.941	74459	20.934	77902	23.326
60	75885	18.007	69625	17.205	74210	19.355
65	69719	14.364	62849	13.776	68836	15.659
70	60691	11.106	53556	10.710	60981	12.334
75	48026	8.345	41353	8.106	49989	9.470
80	32464	6.123	27208	6.008	36242	7.088
85	16988	4.473	13901	4.440	21441	5.266
90	6207	3.314	5014	3.325	9515	3.935
95	1432	2.509	1163	2.542	2889	2.992
100	193	1.908	161	1.935	555	2.318

Table 53: Abridged life tables for Harari, 2019

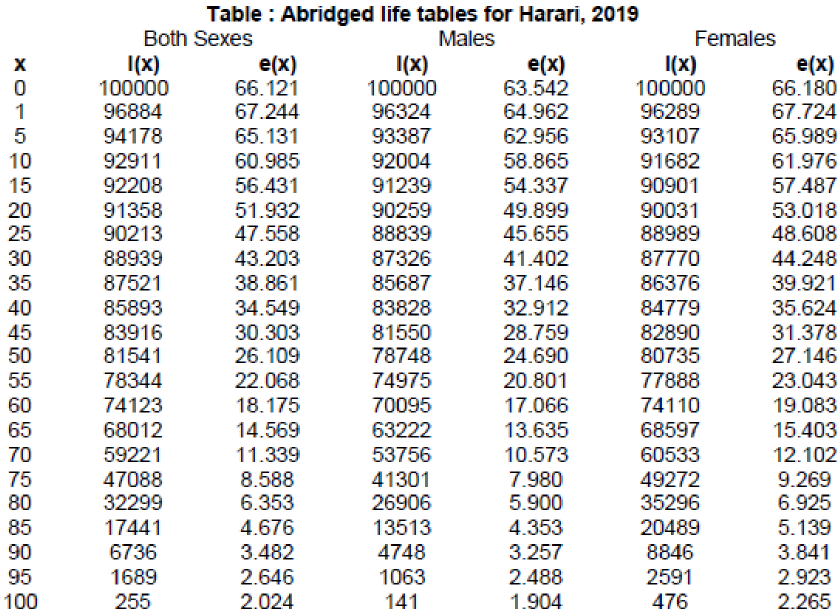


Table : Abridged life tables for Harari, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.121	100000	63.542	100000	66.180
1	96884	67.244	96324	64.962	96289	67.724
5	94178	65.131	93387	62.956	93107	65.989
10	92911	60.985	92004	58.865	91682	61.976
15	92208	56.431	91239	54.337	90901	57.487
20	91358	51.932	90259	49.899	90031	53.018
25	90213	47.558	88839	45.655	88989	48.608
30	88939	43.203	87326	41.402	87770	44.248
35	87521	38.861	85687	37.146	86376	39.921
40	85893	34.549	83828	32.912	84779	35.624
45	83916	30.303	81550	28.759	82890	31.378
50	81541	26.109	78748	24.690	80735	27.146
55	78344	22.068	74975	20.801	77888	23.043
60	74123	18.175	70095	17.066	74110	19.083
65	68012	14.569	63222	13.635	68597	15.403
70	59221	11.339	53756	10.573	60533	12.102
75	47088	8.588	41301	7.980	49272	9.269
80	32299	6.353	26906	5.900	35296	6.925
85	17441	4.676	13513	4.353	20489	5.139
90	6736	3.482	4748	3.257	8846	3.841
95	1689	2.646	1063	2.488	2591	2.923
100	255	2.024	141	1.904	476	2.265

Table 54: Abridged life tables for Dire Dawa, 2019

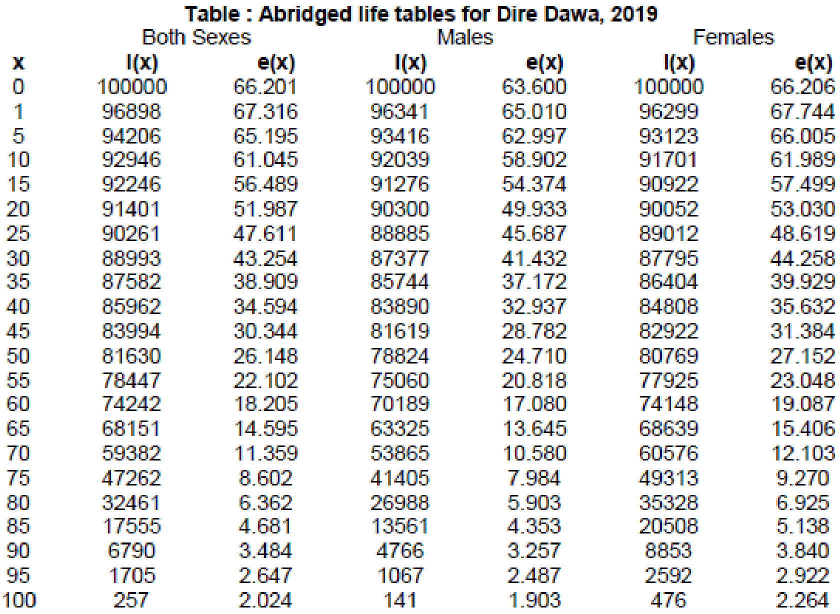


Table : Abridged life tables for Dire Dawa, 2019

	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	66.201	100000	63.600	100000	66.206
1	96898	67.316	96341	65.010	96299	67.744
5	94206	65.195	93416	62.997	93123	66.005
10	92946	61.045	92039	58.902	91701	61.989
15	92246	56.489	91276	54.374	90922	57.499
20	91401	51.987	90300	49.933	90052	53.030
25	90261	47.611	88885	45.687	89012	48.619
30	88993	43.254	87377	41.432	87795	44.258
35	87582	38.909	85744	37.172	86404	39.929
40	85962	34.594	83890	32.937	84808	35.632
45	83994	30.344	81619	28.782	82922	31.384
50	81630	26.148	78824	24.710	80769	27.152
55	78447	22.102	75060	20.818	77925	23.048
60	74242	18.205	70189	17.080	74148	19.087
65	68151	14.595	63325	13.645	68639	15.406
70	59382	11.359	53865	10.580	60576	12.103
75	47262	8.602	41405	7.984	49313	9.270
80	32461	6.362	26988	5.903	35328	6.925
85	17555	4.681	13561	4.353	20508	5.138
90	6790	3.484	4766	3.257	8853	3.840
95	1705	2.647	1067	2.487	2592	2.922
100	257	2.024	141	1.903	476	2.264

Table 55: Abridged life tables for Addis Ababa, 2019

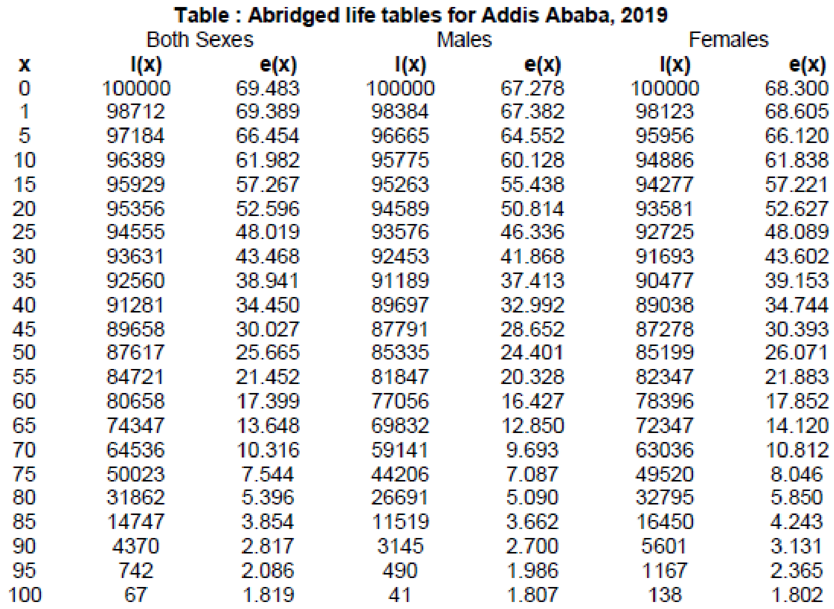
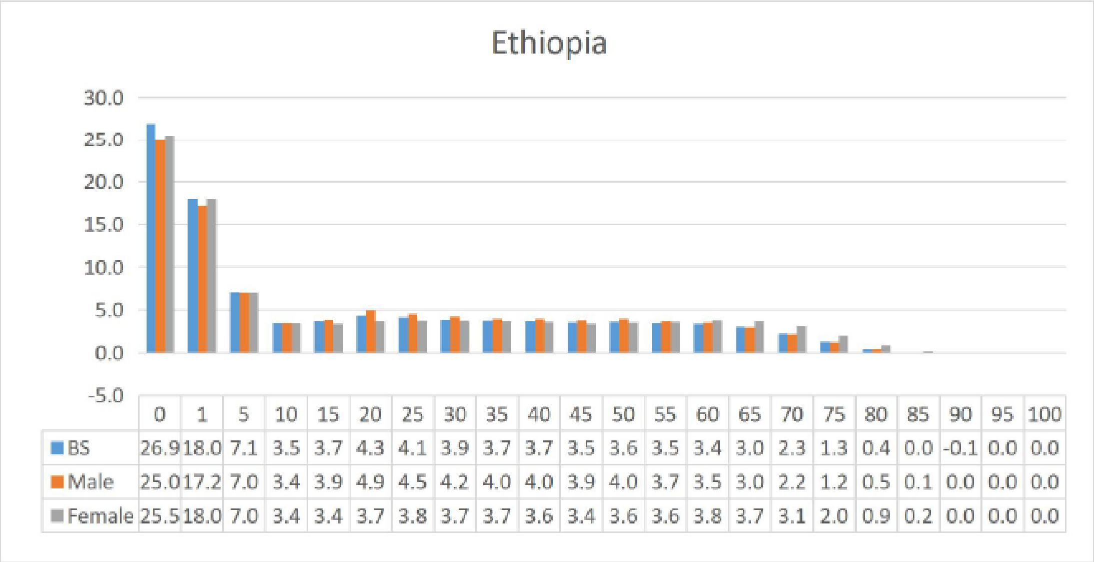


Table : Abridged life tables for Addis Ababa, 2019

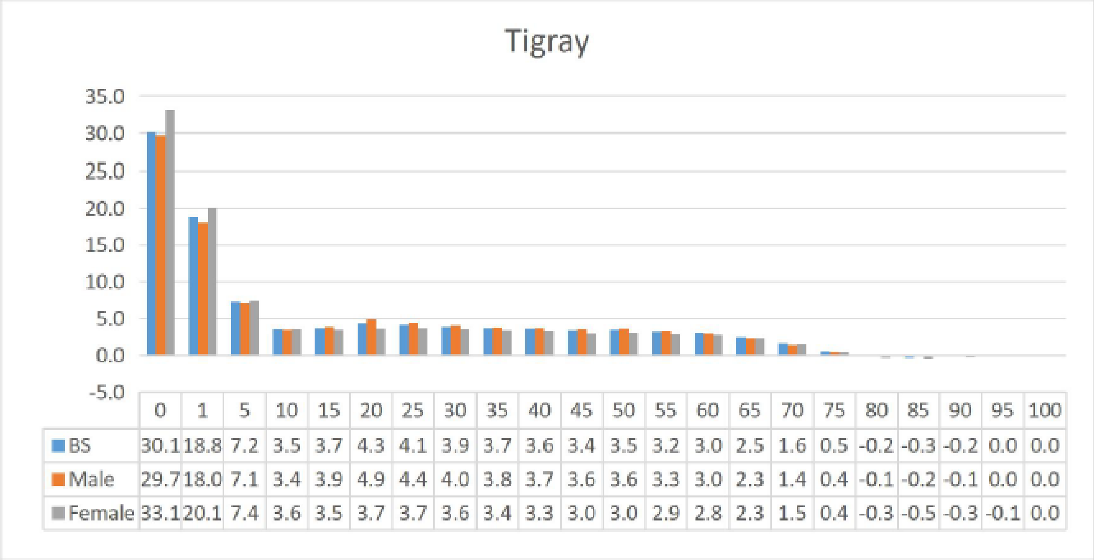
	Both Sexes		Males		Females	
x	**l(x)**	**e(x)**	**l(x)**	**e(x)**	**l(x)**	**e(x)**
0	100000	69.483	100000	67.278	100000	68.300
1	98712	69.389	98384	67.382	98123	68.605
5	97184	66.454	96665	64.552	95956	66.120
10	96389	61.982	95775	60.128	94886	61.838
15	95929	57.267	95263	55.438	94277	57.221
20	95356	52.596	94589	50.814	93581	52.627
25	94555	48.019	93576	46.336	92725	48.089
30	93631	43.468	92453	41.868	91693	43.602
35	92560	38.941	91189	37.413	90477	39.153
40	91281	34.450	89697	32.992	89038	34.744
45	89658	30.027	87791	28.652	87278	30.393
50	87617	25.665	85335	24.401	85199	26.071
55	84721	21.452	81847	20.328	82347	21.883
60	80658	17.399	77056	16.427	78396	17.852
65	74347	13.648	69832	12.850	72347	14.120
70	64536	10.316	59141	9.693	63036	10.812
75	50023	7.544	44206	7.087	49520	8.046
80	31862	5.396	26691	5.090	32795	5.850
85	14747	3.854	11519	3.662	16450	4.243
90	4370	2.817	3145	2.700	5601	3.131
95	742	2.086	490	1.986	1167	2.365
100	67	1.819	41	1.807	138	1.802

LEB decomposition results for Ethiopia and its regional states



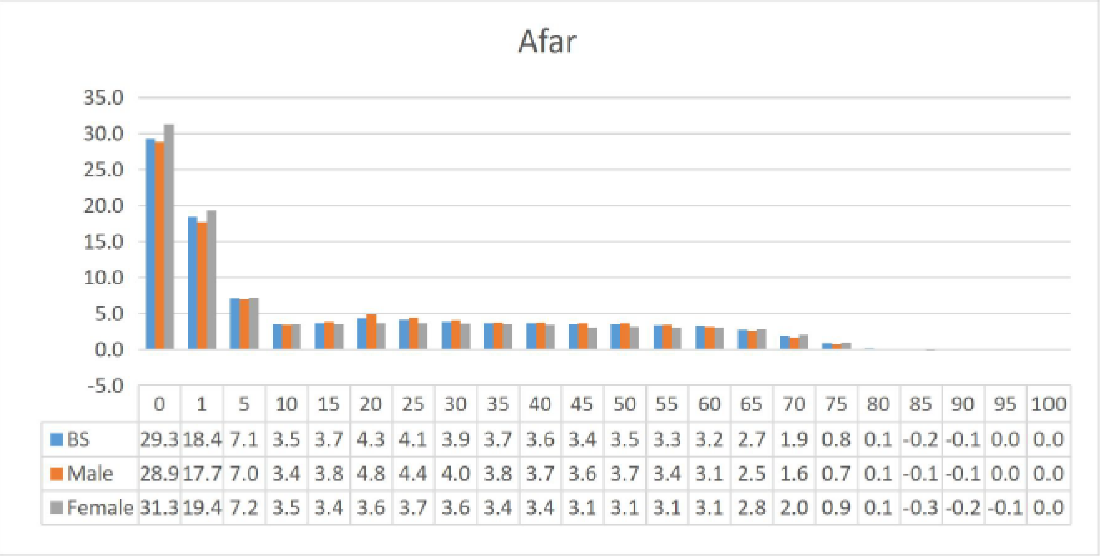
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	26.9	18.0	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.7	3.5	3.6	3.5	3.4	3.0	2.3	1.3	0.4	0.0	-0.1	0.0	0.0
🟧 Male	25.0	17.2	7.0	3.4	3.9	4.9	4.5	4.2	4.0	4.0	3.9	4.0	3.7	3.5	3.0	2.2	1.2	0.5	0.1	0.0	0.0	0.0
■ Female	25.5	18.0	7.0	3.4	3.4	3.7	3.8	3.7	3.7	3.6	3.4	3.6	3.6	3.8	3.7	3.1	2.0	0.9	0.2	0.0	0.0	0.0

Figure 32: LEB decomposition result of Ethiopia: 1990 - 2019



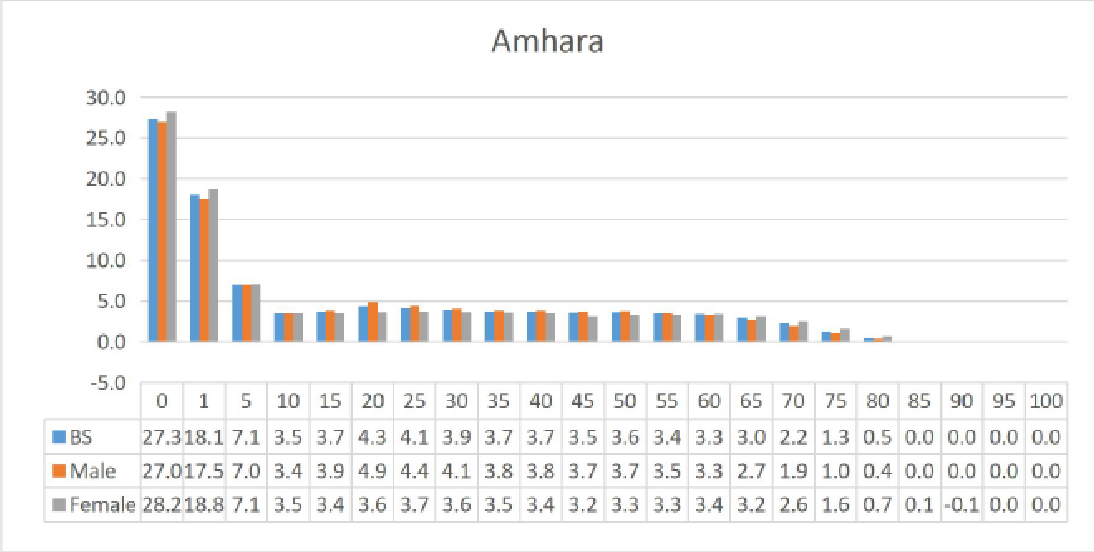
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	30.1	18.8	7.2	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.5	3.2	3.0	2.5	1.6	0.5	-0.2	-0.3	-0.2	0.0	0.0
🟧 Male	29.7	18.0	7.1	3.4	3.9	4.9	4.4	4.0	3.8	3.7	3.6	3.6	3.3	3.0	2.3	1.4	0.4	-0.1	-0.2	-0.1	0.0	0.0
■ Female	33.1	20.1	7.4	3.6	3.5	3.7	3.7	3.6	3.4	3.3	3.0	3.0	2.9	2.8	2.3	1.5	0.4	-0.3	-0.5	-0.3	-0.1	0.0

Figure 33: Age Vs LEB decomposition result of Tigray: 1990 - 2019



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	29.3	18.4	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.5	3.3	3.2	2.7	1.9	0.8	0.1	-0.2	-0.1	0.0	0.0
■ Male	28.9	17.7	7.0	3.4	3.8	4.8	4.4	4.0	3.8	3.7	3.6	3.7	3.4	3.1	2.5	1.6	0.7	0.1	-0.1	-0.1	0.0	0.0
■ Female	31.3	19.4	7.2	3.5	3.4	3.6	3.7	3.6	3.4	3.4	3.1	3.1	3.1	3.1	2.8	2.0	0.9	0.1	-0.3	-0.2	-0.1	0.0

Figure 34: Age Vs LEB decomposition result of Afar: 1990 - 2019



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	27.3	18.1	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.7	3.5	3.6	3.4	3.3	3.0	2.2	1.3	0.5	0.0	0.0	0.0	0.0
■ Male	27.0	17.5	7.0	3.4	3.9	4.9	4.4	4.1	3.8	3.8	3.7	3.7	3.5	3.3	2.7	1.9	1.0	0.4	0.0	0.0	0.0	0.0
■ Female	28.2	18.8	7.1	3.5	3.4	3.6	3.7	3.6	3.5	3.4	3.2	3.3	3.3	3.4	3.2	2.6	1.6	0.7	0.1	-0.1	0.0	0.0

Figure 35: Age Vs LEB decomposition result of Amhara: 1990 - 2019

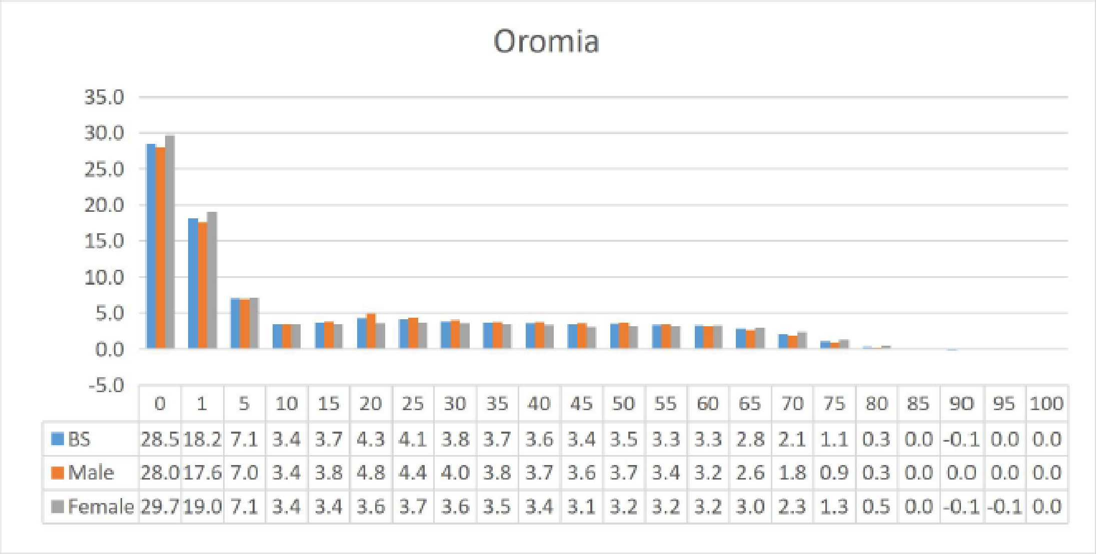


Figure 36: Age Vs LEB decomposition result of Oromia: 1990 - 2019

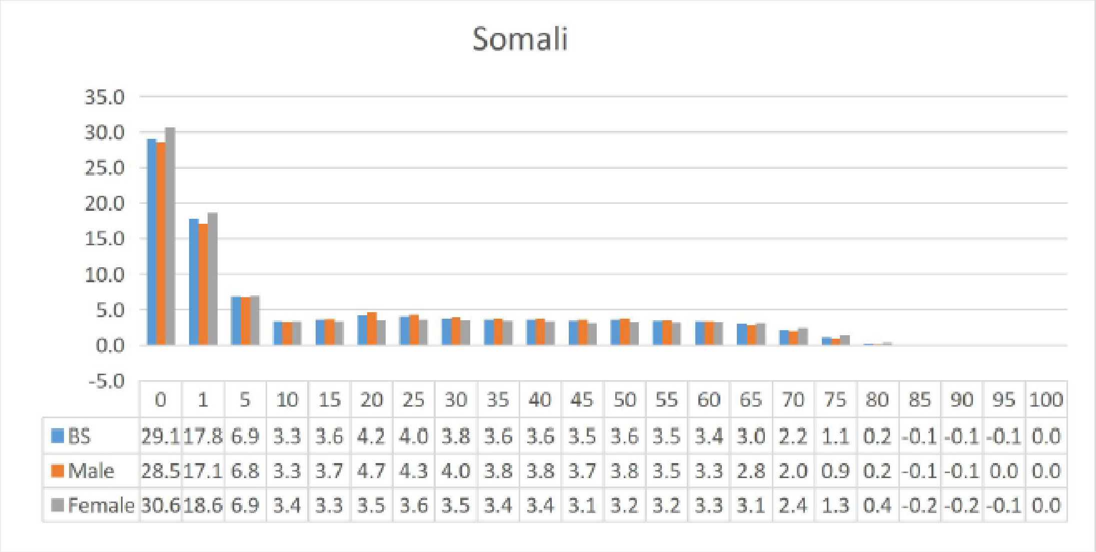
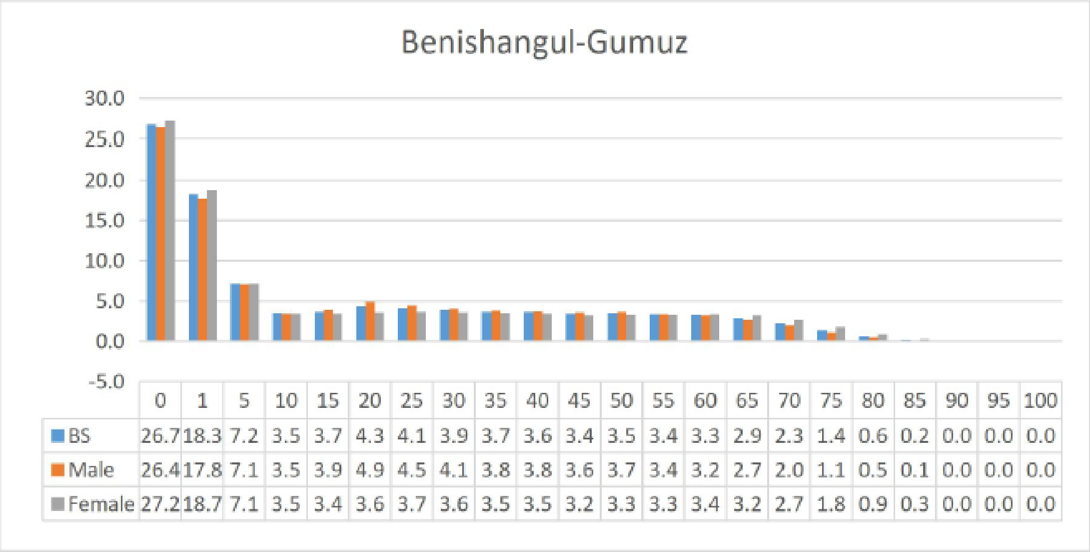
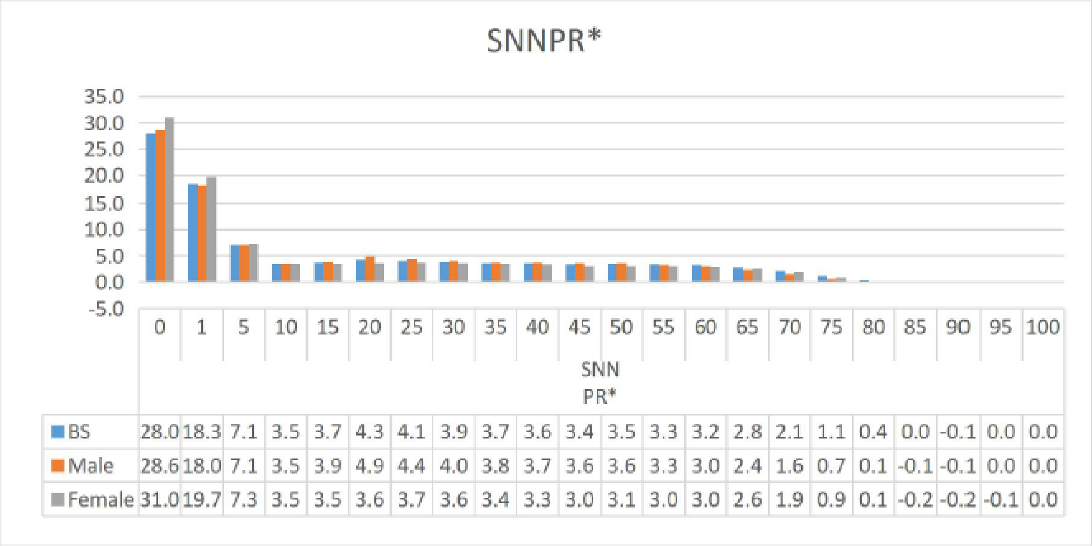


Figure 37: Age Vs LEB decomposition result of Somali: 1990 - 2019



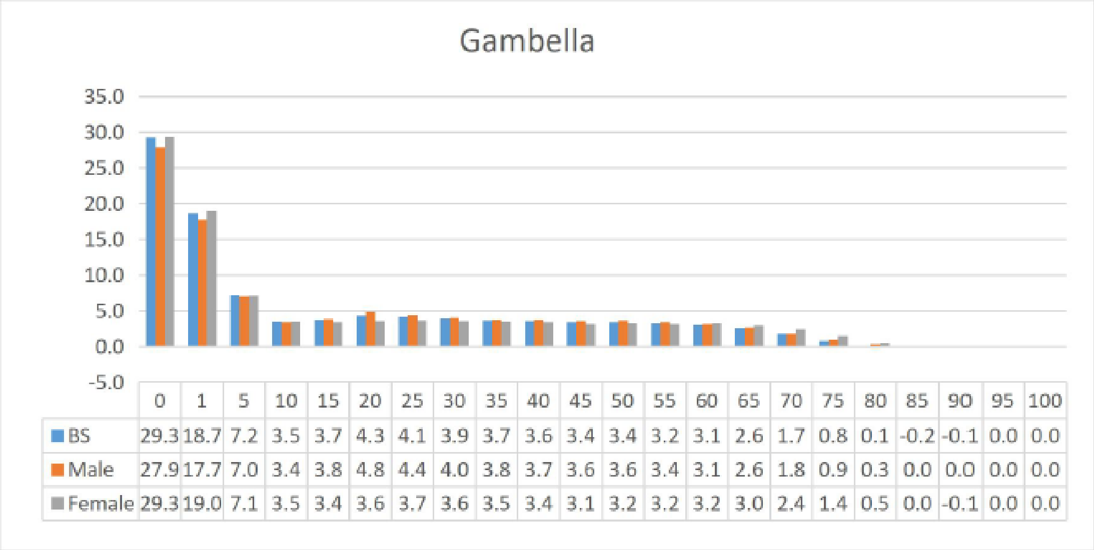
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
BS	26.7	18.3	7.2	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.5	3.4	3.3	2.9	2.3	1.4	0.6	0.2	0.0	0.0	0.0
Male	26.4	17.8	7.1	3.5	3.9	4.9	4.5	4.1	3.8	3.8	3.6	3.7	3.4	3.2	2.7	2.0	1.1	0.5	0.1	0.0	0.0	0.0
Female	27.2	18.7	7.1	3.5	3.4	3.6	3.7	3.6	3.5	3.5	3.2	3.3	3.3	3.4	3.2	2.7	1.8	0.9	0.3	0.0	0.0	0.0

Figure 38: Age Vs LEB decomposition result of Benshangul - Gumuz: 1990 - 2019



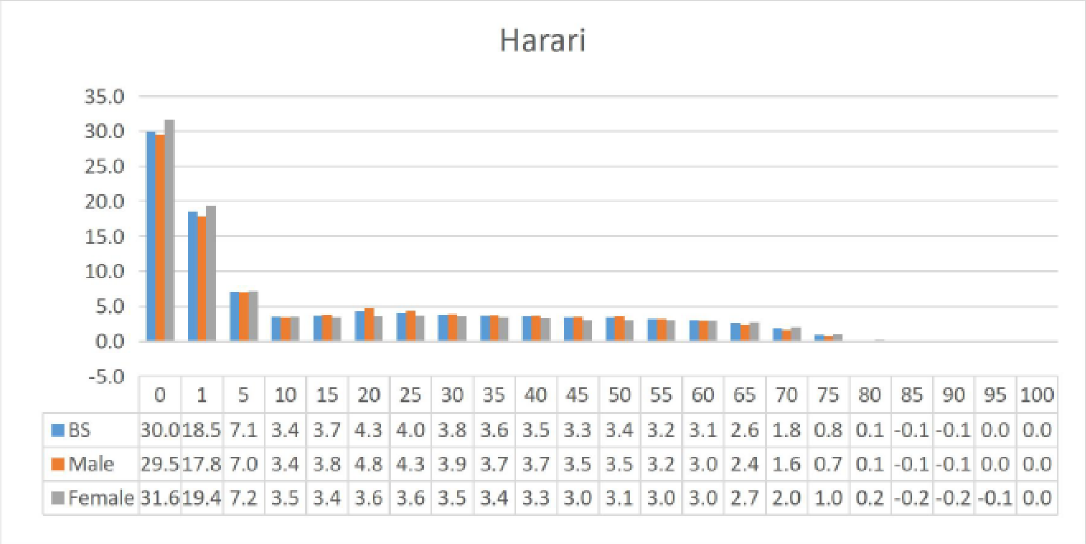
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
BS	28.0	18.3	7.1	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.5	3.3	3.2	2.8	2.1	1.1	0.4	0.0	-0.1	0.0	0.0
Male	28.6	18.0	7.1	3.5	3.9	4.9	4.4	4.0	3.8	3.7	3.6	3.6	3.3	3.0	2.4	1.6	0.7	0.1	-0.1	-0.1	0.0	0.0
Female	31.0	19.7	7.3	3.5	3.5	3.6	3.7	3.6	3.4	3.3	3.0	3.1	3.0	3.0	2.6	1.9	0.9	0.1	-0.2	-0.2	-0.1	0.0

Figure 39: Age Vs LEB decomposition result of SNNRP*: 1990 - 2019



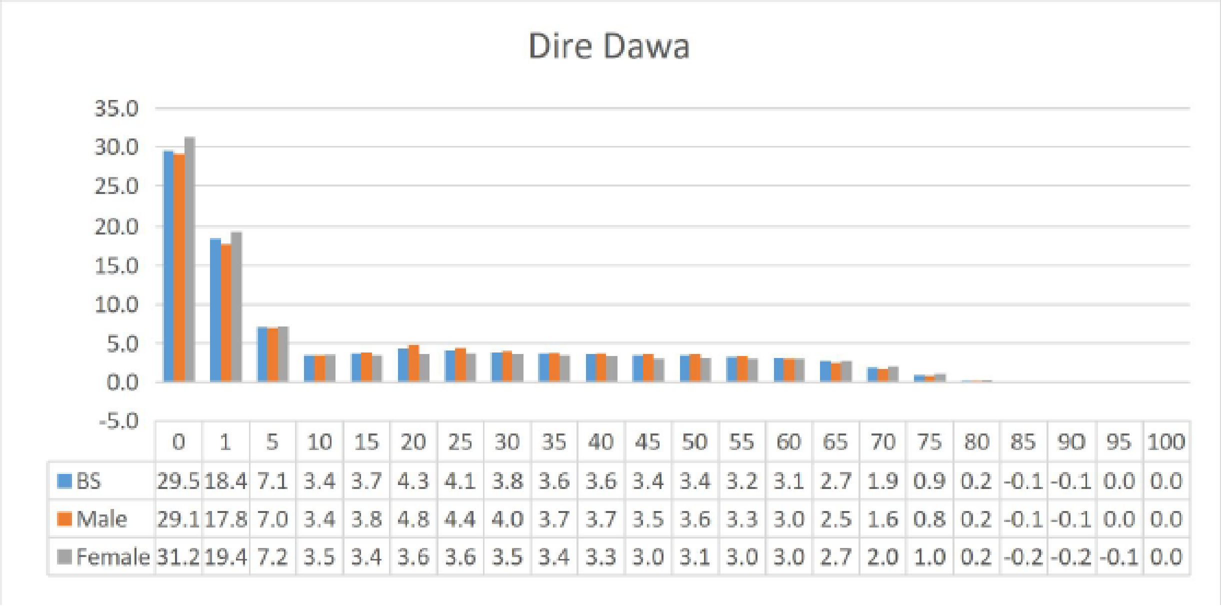
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	29.3	18.7	7.2	3.5	3.7	4.3	4.1	3.9	3.7	3.6	3.4	3.4	3.2	3.1	2.6	1.7	0.8	0.1	-0.2	-0.1	0.0	0.0
■ Male	27.9	17.7	7.0	3.4	3.8	4.8	4.4	4.0	3.8	3.7	3.6	3.6	3.4	3.1	2.6	1.8	0.9	0.3	0.0	0.0	0.0	0.0
■ Female	29.3	19.0	7.1	3.5	3.4	3.6	3.7	3.6	3.5	3.4	3.1	3.2	3.2	3.2	3.0	2.4	1.4	0.5	0.0	-0.1	0.0	0.0

Figure 40: Age Vs LEB decomposition result of Gambella: 1990 - 2019



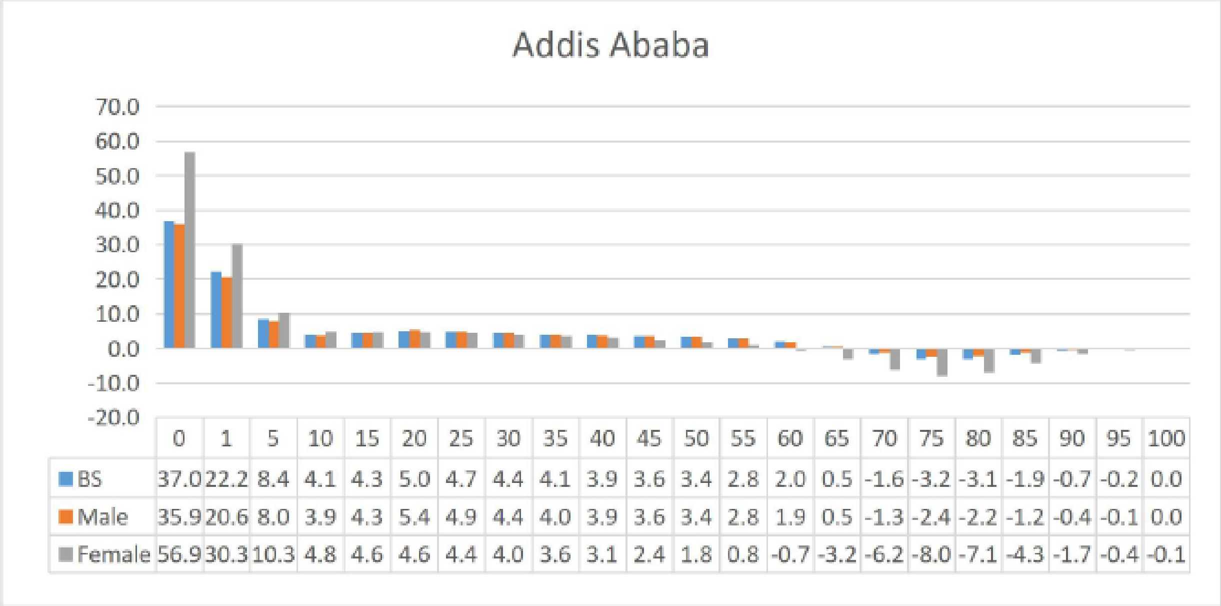
	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
■ BS	30.0	18.5	7.1	3.4	3.7	4.3	4.0	3.8	3.6	3.5	3.3	3.4	3.2	3.1	2.6	1.8	0.8	0.1	-0.1	-0.1	0.0	0.0
■ Male	29.5	17.8	7.0	3.4	3.8	4.8	4.3	3.9	3.7	3.7	3.5	3.5	3.2	3.0	2.4	1.6	0.7	0.1	-0.1	-0.1	0.0	0.0
■ Female	31.6	19.4	7.2	3.5	3.4	3.6	3.6	3.5	3.4	3.3	3.0	3.1	3.0	3.0	2.7	2.0	1.0	0.2	-0.2	-0.2	-0.1	0.0

Figure 41: Age Vs LEB decomposition result of Harari: 1990 - 2019



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	29.5	18.4	7.1	3.4	3.7	4.3	4.1	3.8	3.6	3.6	3.4	3.4	3.2	3.1	2.7	1.9	0.9	0.2	-0.1	-0.1	0.0	0.0
🟧 Male	29.1	17.8	7.0	3.4	3.8	4.8	4.4	4.0	3.7	3.7	3.5	3.6	3.3	3.0	2.5	1.6	0.8	0.2	-0.1	-0.1	0.0	0.0
⬜ Female	31.2	19.4	7.2	3.5	3.4	3.6	3.6	3.5	3.4	3.3	3.0	3.1	3.0	3.0	2.7	2.0	1.0	0.2	-0.2	-0.2	-0.1	0.0

Figure 42: Age Vs LEB decomposition result of Dire Dawa: 1990 - 2019



	0	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
🟦 BS	37.0	22.2	8.4	4.1	4.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	2.8	2.0	0.5	-1.6	-3.2	-3.1	-1.9	-0.7	-0.2	0.0
🟧 Male	35.9	20.6	8.0	3.9	4.3	5.4	4.9	4.4	4.0	3.9	3.6	3.4	2.8	1.9	0.5	-1.3	-2.4	-2.2	-1.2	-0.4	-0.1	0.0
⬜ Female	56.9	30.3	10.3	4.8	4.6	4.6	4.4	4.0	3.6	3.1	2.4	1.8	0.8	-0.7	-3.2	-6.2	-8.0	-7.1	-4.3	-1.7	-0.4	-0.1

Figure 43: Age Vs LEB decomposition result of Addis Ababa: 1990 - 2019

Articles produced (only their abstracts attached here)

Developing a system of model life tables for Ethiopia to improve mortality analysis: A Brass' logit approach

Hailay Mebrahtom Gebreegziabiher1, Kinfe Abraha Gebre-Egziabiher2, Girmatsion Fisseha3

1, 2: Institute of Population Studies, Mekelle University, Tigray, Ethiopia

3: College of Health Sciences, Mekelle University, Tigray, Ethiopia

Abstract

This study aimed to develop a system of Brass' logit model life tables for Ethiopia to enhance mortality analysis. Data were taken from the UN and the Global Burden of Disease Study 2019. The results showed that Ethiopia's healthcare system made notable strides in general between 1990 and 2019. With 7.7% increase in the likelihood of survival at birth, life expectancy increased by 16.977 years. Infant and under five mortality rates (IMRs and U5MRs) decreased by 69.5% and 66% respectively. Among the regions, IMRs ranged from 12.88 in Addis Ababa to 43.94 in Benshangul - Gumuz. U5MRs also exhibited sizeable variations among the regional states with the lowest in Addis Ababa (28.16) and the highest in Benshangul - Gumuz (77.32). The substantial increase in life expectancy was primarily driven by the declining mortality among infants and under five children. Although overall survival in Ethiopia has improved over the past three decades, more work is still needed to further reduce mortality, meet the global average to the lowest possible level, and achieve the global Sustainable Development Goals to the greatest extent possible.

Key words: Brass' logit model, Ethiopia, Life expectancy, Life table, Survival probability

Comparative Analysis of Mortality Trends and Life Expectancies in Ethiopia: Insights from Model – Based Abridged Life Tables over 1990 - 2019

Hailay Mebrahtom Gebreegziabiher1, Kinfe Abraha Gebre-Egziabiher2, Girmatsion Fisseha3

1, 2: Institute of Population Studies, Mekelle University, Tigray, Ethiopia

3: College of Health Sciences, Mekelle University, Tigray, Ethiopia

Abstract

Essential information regarding population dynamics and health outcomes can be obtained from life tables. Directly creating abridged life tables is not feasible in Ethiopia due to the absence of accurate and current mortality data. Therefore, a useful substitute for estimating mortality experiences is to use model-based abridged life tables. The purpose of this study was to estimate the mortality experience of Ethiopia's regional states by creating model-based abridged life tables. We used information from the Global Burden of Disease Study 2019 and the United Nations World Population Prospects 2022 web source. The abridged life tables were produced using the UN Population Division's MORTPAK LITE software and Brass' logit method. The findings indicated that during the previous three decades, life expectancy at birth had significantly increased in all regional states, and age-specific mortality rates had dropped for both sexes and all age groups. The study came to the conclusion that disparities in mortality patterns still exist among the regions and that they will take decades to catch up to the current global average life expectancy standard of 73 years.

Key words: Brass' logit method, Ethiopia, Model based abridged life tables, Life expectancy

Decomposing and Measuring the Change in Life Expectancies of Ethiopia and Its Regional States Age - Wise: 1990 – 2019

Hailay Mebrahtom Gebreegziabiher1, Kinfe Abraha Gebre-Egziabiher2, Girmatsion Fisseha3

1, 2: Institute of Population Studies, Mekelle University, Tigray, Ethiopia

3: College of Health Sciences, Mekelle University, Tigray, Ethiopia

Abstract

This study aimed to break down the life expectancies of Ethiopia and its regional states age wise, and to evaluate the relative contributions of different age groups, regions, and effect types. Data were collected from the UN-World Population Prospects 2022 online source and the Global Burden of Disease Study 2019 and a system of Brass' logit model life tables that allowed for the estimation of abridged life tables and the subsequent extraction of life expectancies was built. Consequently, Arriaga method was used to break down the life expectancies age-wise into direct and other effects over 1990-2019. Results revealed life expectancy in Ethiopia rose by 16.977 years from 49.3 years in 1990 to 66.2 in 2019. Of the types of effect, the other effect, and of the age groups, infants and under five children, were the primary positive contributors to this increase. Regionally, no significant contribution differences were observed but Addis Ababa exhibited a negative other effect contribution in the old ages. Direct effect contribution was negligible in the 0 - 4 age group warns that improvements in life expectancy were due to indirect and interaction effects and thus further intervention is required to achieve direct effect improvements.

Key words: Arriaga method, Ethiopia, Life Expectancy decomposition, Life Expectancy at Birth

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

Hailay Mebrahtom Gebreegziabiher1, Kinfe Abraha Gebre-Egziabiher2, Girmatsion Fisseha3

1, 2: Institute of Population Studies, Mekelle University, Tigray, Ethiopia

3: College of Health Sciences, Mekelle University, Tigray, Ethiopia

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

Order of the Regional States of Ethiopia as used in this material

1. Tigray
2. Afar
3. Amhara
4. Oromia
5. Somali
6. Benshangul Gumuz
7. SNNRP
8. Gambella
9. Harari
10. Addis Ababa
11. Dire Dawa

Declaration Page

I, the under signed, declare that this is my own original work, has never been presented in this or any other university, and that all the resources and materials used for the dissertation, have been fully acknowledged.

Candidate Signature Date

This dissertation work has been submitted for examination with my approval as university supervisor.

Supervisor Signature Date