Causes of Death Inequality and Diversity Determines Progression in Mortality Transition: A Empirical Test to Evaluate the Rise in Life Expectancy in 45 Countries across 23 Regions of the World

Abstract

Background:

Developed nations have shown high e_0 on the account of low G0 and low H and F indices. Whereas, LMICs and LICs showed increase in e_0 mainly contributed by reduction in the burden of infectious diseases; however, with increasing causes of death diversity.

Objective

The study aims to examine the cause of death inequality and diversity for assessing the progression in mortality transition in HICs versus LMICs versus LICs.

Methods

Age-cause-specific decomposition of life expectancy at birth (e_0), Gini coefficient at birth (G_0), Shannon entropy (H) and Fractionalization index (F) by sex were performed using mortality rates of highest and lowest income countries in 23 GBD regions selecting 45 countries retrieved from the GBD (2021) study.

Results

The HICs countries of America, Asia, Australasia and Europe gained momentum in their pace of e0 and G0 which was attributable to single reduction in cardiovascular diseases attaining a low causes of death diversity. On the other hand, LMICs countries of Asia, Oceania, North and South America, Africa show large reduction in infectious diseases for their pace in mortality transition. UMICs show similarity with LMICs. LICs of Africa showed large improvement in infant and children but not in adult mortality.

Conclusion

The significant contribution of NCDs to ΔH and ΔF in middle through old age groups supported by the considerable contribution of CDs confirms their role in increasing diversity in causes of death in selected LMICs. NCDs in adult through old age groups show a negligible role in causes of death diversity, as evident in inequality in age at death.

Contribution

The outcomes of the study unravel a high level of causes of death diversity responsible for the slow pace of mortality transition in LMICs and LICs. A significant contribution from the NCDs is lacking in the progression of life expectancy, inequality in age at death in LMICs and LICs.

Keywords: Diversity, Disparity, Causes of death, Inequality in age at death, disparity in lifespan, life expectancy at birth, mortality, mortality transition, Gini, Inequality, Epidemiological transition, Communicable diseases, Noncommunicable diseases.

Introduction

Worldwide, the challenge of the epidemic of noncommunicable diseases (NCDs) is upfront [1-3]. Many developed and developing countries deal with the huge burden of NCDs with an understanding of public health cognisance [4,5]. The inequality features associated the demographic developments [6], apart from a public health concern, are crucial for understanding the challenges of the prolonged burden of NCDs [7], especially in low-middle-income countries and low-income countries (LICs) [8]. Low mortality and high morbidity is now recognised as a transitioning phase of health transition in developing countries which partly explains the apace in the epidemiological transition [9-12]. At the same time, the diversity in causes of death has been higher in HICs and UMICs but lower in LMICs and LICs.

The rapid increase in life expectancy at birth (e_0) underneath conceals the inequality in mortality and morbidity as well as structural changes in causes of death. Also, the phenomenon of high e_0 and high disparity in lifespan eludes the interpretation of a better e_0 [13]. In this regard, the scrutinisation of causes of death from the perspective of changes e_0 and inequality in age at death as measured by the Gini coefficient at birth (G_0) [14] and diversity in causes of death as measured by Fractionalization index (F) and Shannon entropy index (H), provides a robust understanding of the role of many causes of death for a persistent high burden of NCDs in LMICs, LICs and HICs[15].

The study explores the demographic contributions of many causes of death by age and sex in reference to the pattern of mortality of communicable diseases (CDs) and NCDs [16-18]. In LMICs such as India, major programs and policies are for mother and their children that have been considered successful in the light of improvised demographic indicators such as infant mortality rate (IMR) and Maternal Mortality Ratio (MMR) [19,20]. Further, it has been expected that such health interventions would also benefit adult mortality decline in men and overall health in the population. However, the causes of death in women are majorly related to pregnancy, childbirth, and post-partum periods in adult ages, whereas it has been injuries and NCDs in adult and old men. So, the reverberation of health practices and care and percolation of knowledge did not pass on to the other age groups and male counterparts. This has been found true for many LMICs and LICs. The prompt reasoning could be the large and persistent burden of CDs together with escalating burden of NCDs in these countries. The health interventions in LMICs and LICs require more understanding in terms of beneficiaries and target populations and gender differentials in mortality and morbidity. The causes of death greatly vary by age and sex, and importantly, by regimes of mortality and morbidity in these countries. The case of inequality in mortality and morbidity regimes remains utmost crucial [21]. The progress in mortality and epidemiological transition alone partly explain the structural changes in causes of death in a population [22,23].

LMICs to set the target of a 25% reduction in premature mortality from NCDs by the year 2025 [24], in compliance with the United Nations [25]'s Sustainable Development Goals (SDGs) Goal 3 and Target 3.4. An important concern is the inequality in mortality and morbidity contributed by the causes of death and age groups over a period of time. The inequality in mortality is contributed by many causes of death[26,27] as well as premature mortality [28,29] or acceleration in old age mortality[30]. The decomposition analysis [31] of the changes in e_0 and G_0, F and H [32] by causes of death describes developments in mortality and morbidity over time. Specifically, the cause-age-specific contributions to ΔG_0 unveil the causes of death responsible for the reduction in premature mortality owing to a

threshold age that separates premature deaths and old deaths and contributions to ΔF and ΔH describe the diversity as a barrier or supplement to epidemiological transition [33,34]. The distinguishing feature of threshold age in the decomposition analysis of G_0 is an advantage compared to that of e_0. Compared to developed countries, developing shows a lower G_0, F and H values[35,36]. A low threshold age provides a narrow age-interval for the reduction of premature mortality in LMICs and LICs population[37]. Hence, the causes of death in combination with age groups where NCDs and CDs vary in dominance are more consequent for lowering the causes of death inequality as well as diversity. The study examines the role of CDs and NCDs for Δe_0, ΔG_0, ΔF and ΔH using cause-age-specific mortality data from GBD study between 1990-1994 and 2017-2021. The specific objectives of the study are (i) to assess the age-specific contributions to Δe_0, ΔG_0, ΔF and ΔH (ii) to scrutinise the causes of death to Δe_0, ΔG_0, ΔF and ΔH by age and sex. The study focuses on 23 causes of death by quinquennial age groups and sex to comprehend the varying progression in mortality transition in highest and lowest income countries in 23 GBD regions selecting 45 countries using HBD (2021) study.

2 Data and Methods

In the study, we used GBD (2021) study as the main data source and many methods to assess the progression of mortality transition primarily by examining the contribution of causes of death to Δe_0, ΔG_0, ΔF and ΔH between 1990-1994 and 2017-2021. We aim to examine the change in causes of death inequality and diversity in 45 countries across 23 GBD regions interjectionally with their income level, i.e. HICs, UMICs, LMICs, and LICs.

2.1 Global Burden of Disease (GBD) (2021) Study

The Global Burden of Disease (GBD) (2021) [38,39] study, coordinated by the Institute for Health Metrics and Evaluation (IHME), provides data on the burden of diseases, injuries, and risk factors for two sexes, and for 204 countries and territories, including the South Asian country India as a whole. For selected countries across the seven regions of the world, this study used age-cause-specific mortality rates by sex and 18 countries for 23 major causes of death at level 2 available in the GBD (2021) study for analytical outcomes (see Appendix: Table 1). In this study, we have separated maternal disorders from neonatal and maternal disorders, and hence we have, in total, 24 causes of death to analyse. The age-cause-specific mortality rates by sex are additive to overall mortality rates (Global Burden of Disease Collaborative Network 2020).

2.2 Life expectancy, Inequality in age at death, Fractionalization Index, and Shannon entropy Index

2.2.1 Life expectancy (e_x)

We used overall age-specific death rates (ASDR) by quinquennial age groups up to the open age group of 75+/95+ years for both sexes from the GBD (2021) study for constructing life tables for 45 countries for the period of 1990-1994 to 2017-2021. Assuming ASDR follow Gompertz's law of mortality, new life tables were constructed based on the methodology recommended by the United Nations (United Nations 1982: 31, see Annex I). Five-year moving average of ASDR was used to construct life tables. The difference between the estimated e_0 and published e_0 by World Bank (2023) is small.

2.2.2 Inequality in age at death (G_0)

We computed the Gini coefficient at the age of zero (G_0) as a measure of inequality in age at death[14,36,40], based on the newly constructed life table. The G_0 for an abridged life table is expressed as:

$$G_0 = 1 - \frac{1}{e_0 * [l_0]^2} \sum_{x=0}^{w-1} n * [(l_{x+n})^2 + \hat{a}_x((l_x)^2 - (l_{x+n})^2)] \dots\dots\dots\dots (1)$$

where,

$$\hat{a}_x = \frac{1-\frac{2}{3}q_x + \ C_x\left(2-q_x-\frac{6}{5}C_x\right)}{2-q_x}$$

$$c_x = a_x - \frac{1}{2}$$

$$_1\hat{a}_0 = \ _1a_0\left(1-{}_1q_0\frac{3+0.831*{}_1a_0}{2+{}_1q_0}\right)$$

$\hat{a}_x$ is the adjusted a_x for deviation in the pace of ${}_nq_x$ by age, and $a_x \left[= \frac{({}_nL_x/n)-l_{x+n}}{(l_x-l_{x+n})}\right]$ is the person-years lived by the individuals who have died within the given interval [41,42].

2.2.3 Fractionalization Index (F)

We computed Fractionalization Index (F) as a measure of diversity in causes of death[43]

$$F(x) = 1 - \sum P_{xi}^2$$

where, P_{xi} is the share of ith causes of death in xth age group.

2.2.4 Shannon Entropy Index (H)

We computed Shannon entropy Index (H) as a measure of diversity in causes of death[44]

$$H(x) = -\sum P_i \ log(P_i \ )$$

where, P_i is the share of ith causes of death.

2.3 Decomposition of e_0 and G_0 by age groups

The decomposition techniques were applied to analyse the contribution of many age groups to Δe_0 ΔG_0, ΔF and ΔH between 1990-1994 and 2017-2021 [45]. The contribution of many age groups attests to the change in age-specific mortality between population subgroups and over time. We applied Kitagawa [46] method of replacement or standardisation to decompose Δe_0, ΔG_0, ΔF, and ΔH.

The application of the decomposition technique based on standardisation of ASDR is expressed as

$$\delta_i = e_0\left(M^{[x_i+n]}\right) - e_0(M^{[x_i]})$$

where,

δ_i is the contribution of i^{th} age-interval $[x, x+n)$ to the difference in e_0 between two populations. $M^{[x_i]}$ is a vector of age-specific mortality rates with its elements in the first population for $x \leq x_i$ and in the second population for $x \geq x_i$ [14]. The decomposition technique is applied over the permutations of populations and time, running from age 0 to the oldest age.

2.4 Decomposition of e_0 and G_0 by causes of death and age groups

The Kitagawa [46] method of decomposition technique was applied to calculate cause- and age-specific contributions to e_0 and G_0. Specifically, the contribution of j^{th} cause of death to the contribution δ_i in i^{th} age-interval $[x, x+n)$ is calculated as

$$\delta_i^j = \left(\frac{{}^{a}m^{j}_{x_i|x_{i+n}} - {}^{b}m^{j}_{x_i|x_{i+n}}}{{}^{a}m_{x_i|x_{i+n}} - {}^{b}m_{x_i|x_{i+n}}}\right)\delta_i$$

where, ${}^{a}m^{j}_{x_i|x_{i+n}}$ and ${}^{b}m^{j}_{x_i|x_{i+n}}$ are cause- and age-specific mortality rates of j^{th} cause of death in i^{th} age-interval $[x, x+n)$ in the population a and b, respectively, and ${}^{a}m_{x_i|x_{i+n}}$ and ${}^{b}m_{x_i|x_{i+n}}$ are age-specific mortality rates in i^{th} age-interval $[x, x+n)$ in the population a and b, respectively [14]. This decomposition analysis provides age-cause-specific contributions to Δe_0, ΔG_0, ΔF, and ΔH for both sexes between 1990-1994 and 2017-2021, which are comparable across population subgroups and over time.

3 Results

3.1 Changes in e_0, G_0, F and H of selected 18 countries, 1990-1994 and 2017-2021

Fig. 1 shows the change in e_0, Fig. 2 show the change in G_0, F, and H between 1990-1994 and 2017-2021. Amongst the selected countries, India shows a concomitant increase in e_0 and a decline in G_0; the F and H indexes showed a decline. For India, e_0 increased for men and women from 59.4 and 60.8 years, respectively, in 1990-1994 to 67.7 and 70.7 years, respectively, in 2017-2021 (Fig. 1). Contemporaneously, the G_0 values for men and women declined from 0.219 and 0.225 in 1990-1994, to 0.154 and 0.146 in 2017-2021. The high e_0 and low G_0 are evident, attesting to strong progress in mortality transition. The diversity indices F and H decreased from 0.867 and 0.729 in 1990-1994 to 0.844 and 0.711 in 2017-2021. Similar to India, many LMICs, LICs and HICs showed a rise in e0 values concomitant with a fall in G0 values, but actually they differ in the change in causes of death diversity, i.e. F and H, for eg., China, Nepal, Burundi, Botswana, Sudan, Bangladesh, Bhutan, and Pakistan showed a decline in the diversity index F and H whereas HICs such as Australia, New Zealand, Luxembourg, UK, etc. showed a rise in F and H values (Fig. 2).

3.2 Age-specific contributions to Δe_0, ΔG_0, ΔF, and ΔH in selected 18 countries, between 1990-1994 and 2017-2021

Fig 3 and 4 show the age-specific contribution to Δe_0 and ΔG_0 for 45 countries between 1990-1994 and 2017-2021. For India, the most significant contribution to Δe_0 and ΔG_0 is from the infant (0-1 years) age group for both sexes, followed by the child (1-4 years) age group. The 0-1 age group contributed around 54% in men and 40% in women for their increase in Δe_0 and approximately 65% and 69%to ΔG_0 by men and women, respectively, between 1990-1994 and 2017-2021. The 0-1 and 1-4 age groups contributed around 76% and 67% to Δe_0 and 81 and 76% to ΔG_0 in men. This remarkable increase in e_0 and G_0 was mostly contributed by the infant and child mortality decline. There was a large contribution from the 0-4 age groups to the fall in F and H indices for India. Similar to India, many LMICs and LICs showed a large contribution of 0-4 age groups.

Most of the LMICs and LICs reveals that adult (15-49 years) mortality decline showed a sizeable contribution in men and women. Adult mortality decline in men is almost half that in women, so

men did show a smaller contribution to Δe_0 and ΔG_0 than women. Nevertheless, men and women in their adult age group contributed 15 and 18% to Δe_0 and 19.5 and 25.5% to ΔG_0. The middle age group of 50-69 years in men and women contributed 19.47 and 13.96% to Δe_0 and 4.75 and 5.37% to ΔG_0. The older age group of 70 plus in men and women contributed 14.6 and 17.2% to Δe_0 and -13.5 and -12.9% to ΔG_0. The decline in F and H was majorly contributed by the middle and old age groups. For China, the middle age group contributed 27%, and for India, it was 32% to F, with similar contributions to H. The oldest of the old age group contributed 42% and 51% to F and H (Fig. 5 and 6).

3.3 Age-specific contribution of 24 causes of death to Δe_0 and ΔG_0, India, 1990-1994 and 2015-2019

The age-specific contributions to Δe_0, ΔG_0, ΔF, and ΔH for India and 17 other countries between 1990-1994 and 2017-2021 by three broad causes of death. A major contribution to changes in Δe_0 and ΔG_0 for India and other LMICs and LICs was from CDs. Specifically, for India, CDs contributed 71.5 and 78.3% to Δe_0 and 85.6 and 86.8% to ΔG_0 by men and women, and noncommunicable diseases (NCDs) contributed 20.4 and 14.8% to Δe_0 and 4.6 and 4.8% to ΔG_0 by men and women, respectively; injuries contributed only 8.1 and 6.9% to Δe_0 and 9.8 and 8.3% to ΔG_0 by men and women. Many LMICs and LICs countries showed similar contributions of broad causes of death to Δe_0 and ΔG_0. The contribution to ΔF and ΔH was mainly from the adult, middle and old age groups in India and other LMICs and LICs. On the other hand, HICs showed contribution to ΔF and ΔH by older and oldest of old age groups.

The contribution of 24 causes of death to Δe_0, ΔG_0, ΔF, and ΔH for India and 42 other countries were analysed between 1990-1994 and 2017-2021. Specifically, for China, amongst CDs, respiratory infection and tuberculosis, together with enteric (diarrhea and typhoid) infections, contributed a share of 43.2 and 45.7% to Δe_0 and 39.1 and 38% to ΔG_0 in men and women, respectively. Other communicable diseases and neonatal and maternal disorders also contributed majorly to Δe_0 and ΔG_0. Among NCDs, cardiovascular diseases and chronic respiratory diseases contributed 7.7 and 6.4% to Δe_0 and 0.0 and -1.3% to ΔG_0 in men and women, respectively. Amongst NCDs, the other noncommunicable diseases contributed the largest contribution of 2.8 and 2.1% to ΔG_0 (Table A1 and A2). Therefore, it is apparent that the advances in mortality transition are contributed by the mortality decline in CDs, not NCDs and injuries. Sudan, Botswana, India, Central African Republic showed similar age-cause-specific contributions to ΔG_0, ΔF, and ΔH. Among LMICs and LICs, the contributions were similar but it varied for UMICs and strikingly for HICs. The contribution of cardiovascular diseases was 5.22, 5.61, 5.12, 7.53 and 2.72 years to the rise in e_0 for Australia, Japan, Luxembourg, Singapore and the USA. Whereas, LMICs other than India such as Brazil, Nepal, Botswana showed moderate contribution of 3.98, 1.28, 1.21 years. The Upper middle income countries such as China and Malaysia showed contributions of 2.32 and 0.89 years (Fig. 3).

Fig. 3, 4, 5, and 6 elucidates the age-specific contributions of 24 causes of death to Δe_0, ΔG_0, ΔF, and ΔH for India and 42 other selected countries between 1990-1994 and 2017-2021 by quinquennial age groups. On an average, the cause-age-specific contributions by quinquennial age groups reveal that contributions of CDs were sizeable in infant through old age groups for contributing to e_0 for LMICs. By age group, CDs show a significant contribution in the infant and child age groups. Apart from these age groups, CDs have shown significant contributions for women in the reproductive age group, followed in the old age group. LICs showed strong contributions of infant and children age groups but lack mortality decline in adult and old ages.

On an average, in the age group of 0-1 year for LICs, neonatal disorders followed by enteric infections and respiratory infections and tuberculosis show the largest contribution of 9 and 7% to Δe_0 in men and women, respectively. Other infectious diseases followed by enteric infections and respiratory infections and tuberculosis show large contributions of 4.7 and 5.8% to Δe_0 in male and female children, respectively. Among the adolescent age group of 5-14 years, the contribution of many causes of death was small as the mortality rates have been lowest compared to other age groups with progressive mortality changes.

The adult age group of 15-49 years show a moderate contribution in men and a large contribution in women, although men than women show a two-fold higher mortality rate. Given that the adult mortality decline is greater in women, the contribution of maternal disorder was 4.5% to Δe_0 and 6.2% to ΔG_0 followed by respiratory infections and tuberculosis and enteric infections. In adult men, respiratory infections and tuberculosis and enteric infections contributed respectively 4.5 and 2.6% to Δe_0 and 5.5 and 3.5% to ΔG_0.

Many causes of death in the middle age group of 50-69 years showed a considerable contribution to Δe_0 but small contribution to ΔG_0. Enteric infections, cardiovascular diseases, respiratory infections and tuberculosis, and chronic respiratory diseases contributed 5.7, 3.6, 3.3, and 3.0% to Δe_0 and 1.8, 0.63, 0.75, and 0.55% to ΔG_0 by men in the middle age group. The contribution of NCDs to Δe_0 was considerable in this middle age group of 50-69 years. However, the contribution of NCDs to ΔG_0 was marginal and insignificant. At the same time, results showed that contribution to Δe_0 and ΔG_0 in the middle age group varies widely by the same causes of death.

Further, these four causes of death, namely enteric infections, cardiovascular diseases, respiratory infections and tuberculosis, and chronic respiratory diseases in the age group of 70+ years, showed the contribution of 7.94, 2.61, 2.31, and 2.3% to Δe_0 and -6.32, -1.89, -1.61, and -1.79% to ΔG_0. While the contribution of enteric infections in the middle and old age groups was large and significant, the contribution of cardiovascular diseases and chronic respiratory diseases were smaller to ΔH as well as ΔF in LMICs and LICs as well as UMICs.

Specifically, CDs show an essential role in adding significant points to increase e0, whereas NCDs add only a few points to e_0 in LICs followed by LMICs. It is noteworthy that the contribution of NCDs to ΔG_0 is small compared to its own contribution to Δe_0 as well as to that of CDs to Δe_0 and ΔG_0. It confirms that NCDs show negligible contribution to the decline in G_0 values over time. The significant contribution of CDs to ΔG_0 in infant through old age groups confirms their role for reducing inequality in age at death.

The Shannon entropy index revealed a large contribution by the oldest of old age groups, especially in females. The contributions were stronger in HICs compared to UMICs, LMICs and LICs. Among males, a large contribution was also from the middle age groups and slightly less by adult age groups. By gender, males experience large positive as well as negative contributions in adults through old age, whereas females experience dominant, positive contributions in the middle and oldest of old ages and slightly lower contributions in the middle age groups compared to their male counterparts. The Fractionalization index also conforms with the Shannon entropy index with some variation. Australia, Luxembourg, Brazil, Japan, Kazakhstan, Singapore, and the USA showed large contributions in the oldest of old age groups; these contributions were stronger in females compared to males. China showed contributions similar in both Shannon entropy as well as fractionalization index.

4 Discussion:

The progress of epidemiological transition in LMICs and LICs is characterised by mortality decline mainly for communicable diseases (CDs) in infant (0-1 year) and child (1-4 years) age groups[47] and intrusion of noncommunicable diseases (NCDs)[11] at adult (15-49 years), middle (50-69 years) and old (70+ years) ages[48-50]. Meanwhile, HICs have shown large contributions to the advances in mortality transition attributable to chronic diseases (Fig. 3, 4, 5, and 6). With a decline in IMR and U5MR, the many LMICs such as India, Bhutan, Bangladesh, Burundi, Kazakhstan, Nepal, and Pakistan have transcended from the high mortality regime in the early 1990s to a mid/low mortality regime in the late 2010s. Despite showing a significant decline in the burden of CDs, mainly among infants and children and women of childbearing ages[51,52], adults and old, more likely in men than in women, are enduring the heavy burden of NCDs together with CDs[10]. The progress in mortality and epidemiological transition in these LMICs is strongly supported by low inequality in age at death, as measured by the Gini coefficient at birth (G_0) with the linear increase in life expectancy at birth (e_0)[35]. On the other hand, LICs and to some extent in LMICs endure a phenomenal phase of the dual burden of diseases characterized by morbidity expansion[5] which indicates limited progress in mortality and epidemiological transition. They are burdened with tolls of deaths in infant, child, and adult age groups. Acknowledging such contrasting views, researchers in the study analysed the contribution of 24 causes of death to the inequality in age at death, and diversity indices such as Fractionalization and Shannon entropy to understand the complexities in the progress of the epidemiological transition[43]. The study aims to unravel the inequalities as well as diversity in mortality in the progression of epidemiological transition[51]. The decomposition analyses were performed to assess cause-age-specific contributions to $\Delta e_0, \Delta G_0, \Delta F,$ and ΔH , using GBD data between 1990-1994 and 2017-2021.

For men and women, the e_0 values increased for LICs, LMICs and HICs; more in LMICs compared to HICs and LICs; contemporaneously, the G_0 values declined strongly in LMICs and HICs compared to LICs (Fig. 1). Results of the decomposition analyses showed many CDs significantly contributed to an increase in e_0 and G_0 (Fig. 2). A significant contribution of CDs to $\Delta e_0, \Delta G_0, \Delta F,$ and ΔH is evident over age and time, especially in LMICs and LICs (Fig. 3 and 4) whereas HICs showed large contributions of chronic diseases. The reductions in the toll of deaths caused by CDs are in infant, child, and adolescent age groups and adult women in the reproductive age group advantaged LMICs more than LICs. The reduction in the toll of deaths caused by CDs has been possible in India and other South Asian countries; specifically for India it was possible with the implementation of long-term women and child-specific health policies and programs such as Reproductive and Child health (RCH)-I and -II[19], Intergraded Child Development Services (ICDs), Janani Suraksha Yojana (JSK), Janani Shishu Suraksha Karyakaram (JSSK)[20] etc. which successfully orchestrated a consistent decline in IMR, U5MR, and maternal mortality ratio (MMR) since the mid-1990s. However, such specific health programmes have not been available for men.

On the other hand, many NCDs marginally contribute to an increase in e_0 between 1990-1994 and 2017-2021; however, does not contribute to inequality in age death (Fig. 3). They show negligible contributions to the decline in G_0 values over time; however, Fractionalization and Shannon entropy indices showed the contribution of chronic diseases in LMICs and LICs countries as well. By virtue of equalising and disequalising effects in the decomposition analysis of the Gini coefficient, the diseases showing affirmative results before the threshold age do not contribute to a better G_0 after that threshold age[52]. Chronic NCDs show conventional disequalising contributions at old ages; however, they show marginal equalising contributions in adult and negligible contributions in the middle age groups (Fig. 4). So, a wide age-interval from adult to old ages does not make a conducive

contribution to ΔG_0 which in turn is reflected in ΔH and ΔF indices. The negligible contribution at the middle ages confirms a lack of mortality decline, which is utmost necessary for a shift in the threshold age and has serious affirmative results against the usual toll of deaths in old ages. The low threshold age has repercussions on the Fractionalization index as the square of the share of causes of death is affected by the threshold age that flips the age-specific contributions (Fig. 5 and 6).

Developed countries such as Japan, Australia, Luxembourg, Singapore, and the USA show the strong phenomenon of high e_0 and low G_0 [53] attributable to high threshold age[40,54] and the reduction in the burden of chronic NCDs at adult and middle ages[17,55] attested by high level of F and H diversity indices. In particular, India and other South Asian countries do not show a significant contribution of NCDs in adults through old age. Instead, adult mortality differentials negatively skewed towards men are regressive to the threshold age. Moreover, the middle age group of 50-69 years, entrenching the threshold age in the studied period, will keep showing a negligible role for inequality in age at death. However, the F and H indices showed some contributions of chronic indices responsible for the decline in the indices. Altogether, the progress of inequality in age at death is passive in the light of low threshold age, wide mortality differentials, high diversity of causes of death and slight mortality decline among NCDs. It infers that a wide age range from adult to middle age groups in LMICs is not contributing enough when compared with that of HICs.

Overall, the outcomes of the study reveal that the cause of death diversity and level of inequality in age at death achieved in the studied period is only contributed by the CDs in the LMICs and LICs. Whereas, the HICs were heavily contributed by the chronic diseases. The study emphasises that NCDs are responsible for high inequality in age at death in LMICs and LICs whereas HICs are better in inequality and causes of death diversity. It infers that the level of inequality of age at death is considered high because a significant contribution from the NCDs is lacking in LMICs. Accordingly, the causes of death diversity corroborated the findings[15]. The progress of inequality in age at death is passive on account of the unbalanced contribution between CDs and NCDs in India and many LMICs and LICs. While the low threshold age is one of the barriers, the persistent burden of NCDs remains a major factor for high inequality in age at death and high level of causes of death diversity in LMICs and LICs. Notably, the LMICs and LICs lacked programs and policies, especially for men, and as a consequence, their adult, middle and old mortality rates have been higher compared to women.

5 Conclusion

The Fractionalization and Shannon entropy indices declined for many LMICs and LICs, whereas they increased for HICs. The inequality in age at death has been modest in LMICs and LICs whereas it has been strong in HICs between 1990-1994 and 2017-2021. A decline in the inequality in age at death is concomitant with a linear increase in e_0; however, it varies for F and H indices as they have changed in a narrow range. However, when decomposed by the causes of death versus age group, the outcomes of the study attest to a significant contribution of CDs and a small contribution of NCDs in LMICs and LICs. On the other hand, HICs experienced a large contribution of chronic disease to Δe_0, ΔG_0, ΔF, and ΔH.

A decline in the diversity indices confirms a large number of causes of death to tackle for a rapid pace of mortality transition. The study confirms a high diversity in causes of death and inequality in mortality in LMICs and LICs on account of CDs as well as NCDs. Cardiovascular disease and chronic respiratory diseases with a large burden of deaths are responsible for death and recent changes in diversity indices. On the contrary, CDs have declined for all age groups, from infant to old age groups. Nonetheless, their contribution is significant in LMICs and LICs which increased the diversity in causes of death. In order to achieve a progression in mortality transition, it will be crucial to

reduce the premature mortality caused by infectious diseases that will, in turn, narrow the diversity in causes of death.

6 References

1 Arokiasamy, P. India's escalating burden of non-communicable diseases. *The Lancet Global Health* **6**, e1262-e1263, doi:10.1016/S2214-109X(18)30448-0 (2018).

2 Phillips, D. E. *et al.* Worldwide data on causes of death: a systematic assessment of quality and availability of vital registration. *The Lancet* **381**, doi:10.1016/s0140-6736(13)61366-5 (2013).

3 Smallman-Raynor, M. Late stages of epidemiological transition: health status in the developed world. *Health & Place* **5**, 209-222, doi:10.1016/s1353-8292(99)00010-6 (1999).

4 Boutayeb, A. & Boutayeb, S. The burden of non communicable diseases in developing countries. *International Journal for Equity in Health* **4**, 1-8 (2005).

5 Arokiasamy, P. & Yadav, S. Changing Age Patterns of Morbidity vis-à-vis Mortality In India. *Journal of Biosocial Science* **46**, 462-479, doi:10.1017/S002193201300062X (2014).

6 Mackenbach, J. P. *et al.* Changes in mortality inequalities over two decades: register based study of European countries. *BMJ* **353**, i1732, doi:10.1136/bmj.i1732 (2016).

7 Kumar, R., Kumar, D., Jagnoor, J., Aggarwal, A. K. & Lakshmi, P. V. Epidemiological transition in a rural community of northern India: 18-year mortality surveillance using verbal autopsy. *J Epidemiol Community Health* **66**, 890-893, doi:10.1136/jech-2011-200336 (2012).

8 Gomes, M. *et al.* Nationwide Mortality Studies To Quantify Causes Of Death: Relevant Lessons From India's Million Death Study. *Health Aff (Millwood)* **36**, 1887-1895, doi:10.1377/hlthaff.2017.0635 (2017).

9 India State-Level Disease Burden Initiative Collaborators. Nations within a nation: variations in epidemiological transition across the states of India, 1990–2016 in the Global Burden of Disease Study. *The Lancet* **390**, 2437–2460, doi:10.1016/S0140-6736(17)32804-0 (2017).

10 Yadav, S. & Arokiasamy, P. Understanding Epidemiological Transition in India. *Global Health Action* **7**, 23248, doi:10.3402/gha.v7.23248 (2014).

11 Visaria, L. in *Twenty–First Century India—Population, Economy, Human Development, and the Environment* (eds Tim Dyson, Robert Cassen, & Leela Visaria) Ch. 3, 32–56 (Oxford University Press, 2004).

12 Johansson, S. R. The health transition: the cultural inflation of morbidity during the decline of mortality. *Health Transit Rev* **1**, 39-68 (1991).

13 Bohk-Ewald, C., Ebeling, M. & Rau, R. Lifespan Disparity as an Additional Indicator for Evaluating Mortality Forecasts. *Demography* **54**, 1559–1577, doi:10.1007/s13524-017-0584-0. (2017).

14 Shkolnikov, V. M., Andreev, E. E. & Begun, A. Z. Gini coefficient as a life table function: computation from discrete data, decomposition of differences and empirical examples. *Demographic Research* **8**, 305-358, doi:10.4054/DemRes.2003.8.11 (2003).

15 McMonagle, C. *Diversity in causes of mortality in the measurement of population health in Scotland* PhD thesis, University of Glasgow, (2023).

16 Izsak, J. MEASURING THE SECULAR CHANGES OF THE CONCENTRATION OF DEATH CAUSES. *Genus* **42**, 197-208 (1986).
17 Bongaarts, J. Trends in Causes of Death in Low-Mortality Countries: Implications for Mortality Projections. *Population and Development Review* **40**, 189-212, doi:10.1111/j.1728-4457.2014.00670.x (2014).
18 Kochanek KD, Arias E & Bastian BA. The effect of changes in selected age-specific causes of death on non-Hispanic white life expectancy between 2000 and 2014. *NCHS data brief*, 1-8 (2016).
19 Paul, V. K. *et al.* Reproductive health, and child health and nutrition in India: meeting the challenge. *The Lancet* **377**, 332-349, doi:10.1016/s0140-6736(10)61492-4 (2011).
20 MoHFW (Ministry of Health and Family Welfare). Scheme for Healthcare of Women and Children. (Ministry of Health and Family Welfare (MoHFW), New Delhi, 2014).
21 Varkey, S., Kandpal, E. & Neelsen, S. Why addressing inequality must be central to pandemic preparedness. *BMJ Glob Health* **7**, doi:10.1136/bmjgh-2022-010453 (2022).
22 Sudharsanan, N., Aburto, J. M., Riffe, T. & van Raalte, A. Commentary: Large variation in the epidemiological transition across countries: is it still valuable as a mortality theory? *International Journal of Epidemiology*, doi:10.1093/ije/dyac107 (2022).
23 Santosa, A., Wall, S., Fottrell, E., Hogberg, U. & Byass, P. The development and experience of epidemiological transition theory over four decades: a systematic review. *Glob Health Action* **7**, 23574, doi:10.3402/gha.v7.23574 (2014).
24 MoHFW (Ministry of Health and Family Welfare). National Multisectoral Action Plan for Prevention and Control of Common Noncommunicable Diseases (2017-2022). (MoHFW, GOI, New Delhi, 2017).
25 United Nations. Ensure healthy lives and promote well-being for all at all ages. *Sustainable Development Goal 3* (2015). <https://sdgs.un.org/goals/goal3>.
26 Diaconu, V., Ouellette, N., Camarda, C. G. & Bourbeau, R. Insight on 'typical' longevity: An analysis of the modal lifespan by leading causes of death in Canada. *Demographic Research* **35**, 471-504, doi:10.4054/DemRes.2016.35.17 (2016).
27 Rau, R., Bohk-Ewald, C., Muszyńska, M. M. & Vaupel, J. W. in *Visualizing Mortality Dynamics in the Lexis Diagram* (eds Roland Rau, Christina Bohk-Ewald, Magdalena M. Muszyńska, & James W. Vaupel) 69-80 (Springer International Publishing, 2018).
28 Shiels, M. S. *et al.* Trends in premature mortality in the USA by sex, race, and ethnicity from 1999 to 2014: an analysis of death certificate data. *Lancet* **389**, 1043-1054, doi:http://dx.doi.org/10.1016/S0140-6736(17)30187-3 (2017).
29 Godlee, F. Premature deaths should be the priority for prevention. *BMJ* **341**, c3946, doi:https://doi.org/10.1136/bmj.c3946. (2010).
30 Yadav, A., Yadav, S. & Kesarwani, R. Decelerating Mortality Rates in Older Ages and its Prospects through Lee-Carter Approach. *PLoS ONE* **7**, doi:10.1371/journal.pone.0050941. (2012).
31 Arriaga, E. E. Measuring and Explaining the Change in Life Expectancies. *Demography* **21**, 83-96, doi:10.2307/2061029 (1984).
32 Hanada, K. A formula of Gini's concentration ratio and its application to life tables. *Journal of Japan Statistical Society* **13**, 95-98 (1983).
33 Zhang, Z. & Vaupel, J. W. The age separating early deaths from late deaths. *Demographic Research* **20**, 721–730, doi:10.4054/DemRes.2009.20.29. (2009).

34 Aburto, J. M., Alvarez-Martínez, J.-A., Villavicencio, F. & Vaupel, J. W. The threshold age of the lifetable entropy. *Demographic Research* **41**, 83-102, doi:10.4054/DemRes.2019.41.4 (2019).

35 Yadav, S. Progress of Inequality in Age at Death in India: Role of Adult Mortality. *Eur J Popul* **37**, 523-550, doi:10.1007/s10680-021-09577-1 (2021).

36 Vaupel, J. W., Zhang, Z. & Raalte, A. A. V. Life expectancy and disparity: an international comparison of life table data. *BMJ Open* **1**, 1–6 (2011).

37 Yadav, S. & Perianayagam, A. Mortality Compression and Variability in Age at Death in India. *Comparative Population Studies* **45**, doi:10.12765/CPoS-2020-20 (2020).

38 Global Burden of Disease Collaborative Network Global Burden of Disease Study 2019 (GBD 2019) Results. (Institute for Health Metrics and Evaluation (IHME), Seattle, United States of America, 2020).

39 Global Burden of Disease Collaborative Network Global Burden of Disease Study 2019 (GBD 2019) Cause List Mapped to ICD Codes., (Institute for Health Metrics and Evaluation (IHME), Seattle, United States of America, 2020).

40 van Raalte, A. A. & Caswell, H. Perturbation analysis of indices of lifespan variability. *Demography* **50**, 1615-1640, doi:10.1007/s13524-013-0223-3 (2013).

41 United Nations (Department of International Economic and Social Affairs). Model Life Tables for Developing Countries. (United Nations Publication, New York, 1982).

42 Srinivasa Rao, A. S. & Carey, J. R. Generalization of Carey's equality and a theorem on stationary population. *Journal of Mathematical Biology* **71**, 583-594, doi:https://dx.doi.org/10.1007/s00285-014-0831-6 (2015).

43 Calazans, J. A. & Permanyer, I. Levels, trends, and determinants of cause-of-death diversity in a global perspective: 1990-2019. *BMC Public Health* **23**, 650, doi:10.1186/s12889-023-15502-4 (2023).

44 Trias-Llimos, S. & Permanyer, I. Cause-of-Death Diversity From a Multiple-Cause Perspective in the United States. *Demography*, doi:10.1215/00703370-10410415 (2023).

45 Yadav, S., Yadav, P. K. & Yadav, N. Impact of COVID-19 on life expectancy at birth in India: a decomposition analysis. *BMC Public Health* **21**, 1906, doi:10.1186/s12889-021-11690-z (2021).

46 Kitagawa, E. M. Standardized Comparisons in Population Research. *Demography* **1**, 296-315 (1964).

47 Banthia, J. & Dyson, T. Smallpox in Nineteenth–Century India. *Population and Development Review* **25**, 649–680 (1999).

48 Menon, G. R. *et al.* National Burden Estimates of healthy life lost in India, 2017: an analysis using direct mortality data and indirect disability data. *The Lancet Global Health* **7**, e1675-e1684, doi:10.1016/s2214-109x(19)30451-6 (2019).

49 Joshi, R. A.-O., Pakhare, A. A.-O., Kumar, S., Khadanga, S. & Joshi, A. Improving the capacity of nurses for non-communicable disease service delivery in India: how do they fare in comparison to doctors? *Education for Primary Care*, doi:https://doi.org/10.1080/14739879.2019.1619097 (2019).

50 Quigley, M. A. Commentary: shifting burden of disease--epidemiological transition in India. *Int J Epidemiol* **35**, 1530-1531, doi:10.1093/ije/dyl244 (2006).

51 Strozza, C., Egidi, V., Testa, M. R. & Caselli, G. Ageing and diversity: Inequalities in longevity and health in low-mortality countries. *Demographic Research* **50**, 347-376, doi:10.4054/DemRes.2024.50.12 (2024).

52 Aburto, J. M., Wensink, M., Raalte, A. A. V. & Lindahl-Jacobsen, R. Potential gains in life expectancy by reducing inequality of lifespans in Denmark: an international comparison and cause-of-death analysis. *BMC Public Health* **18**, 831, doi:10.1186/s12889-018-5730-0 (2018).
53 Németh, L. Life expectancy versus lifespan inequality: A smudge or a clear relationship? *PLoS ONE* **12**, e0185702, doi:10.1371/journal.pone.0185702 (2017).
54 Wagner, P. Sensitivity of life disparity with respect to changes in mortality rates. *Demographic Research* **23**, 63-72, doi:10.4054/DemRes.2010.23.3 (2010).
55 Case, A. & Deaton, A. Rising morbidity and mortality in midlife among white non-Hispanic Americans in the 21st century. *Proc Natl Acad Sci U S A* **112**, 15078-15083, doi:10.1073/pnas.1518393112 (2015).

Fig. 1: Change in Life expectancy of 45 selected countries, 1990-1994 and 2017-2021, GBD (2021) study

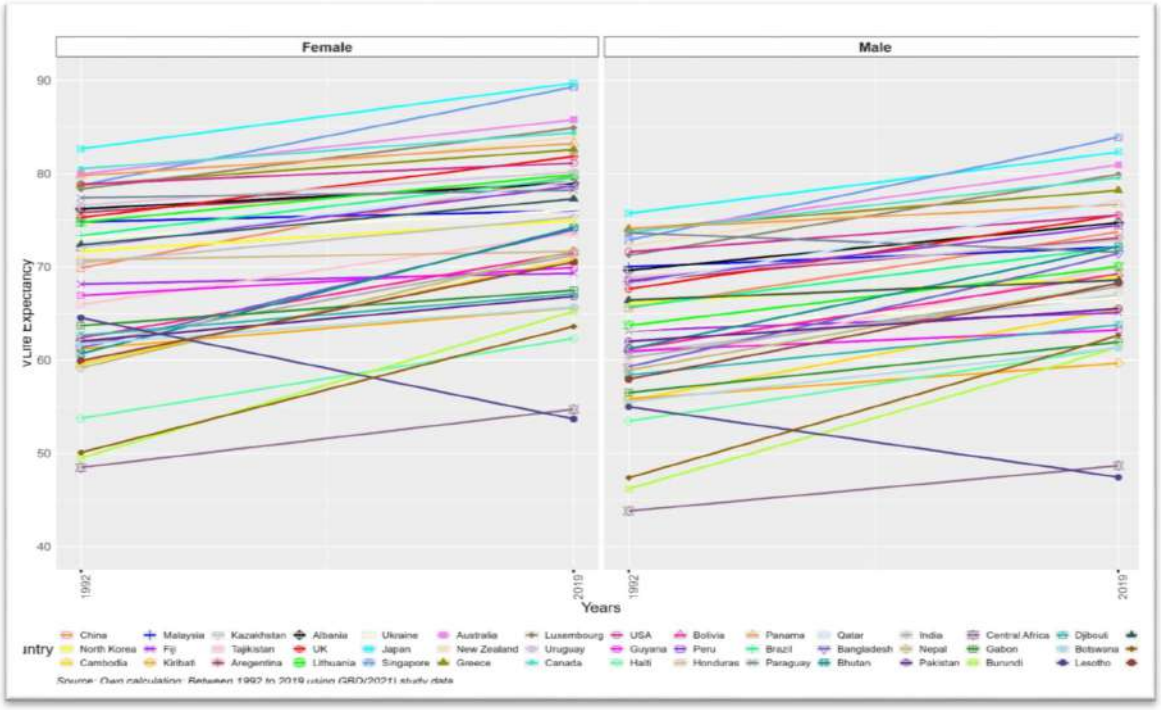


Fig. 2: Change in Gini coefficient, Fractionalization index, and Shannon entropy of 45 selected countries, 1990-1994 and 2017-2021, GBD (2021) study

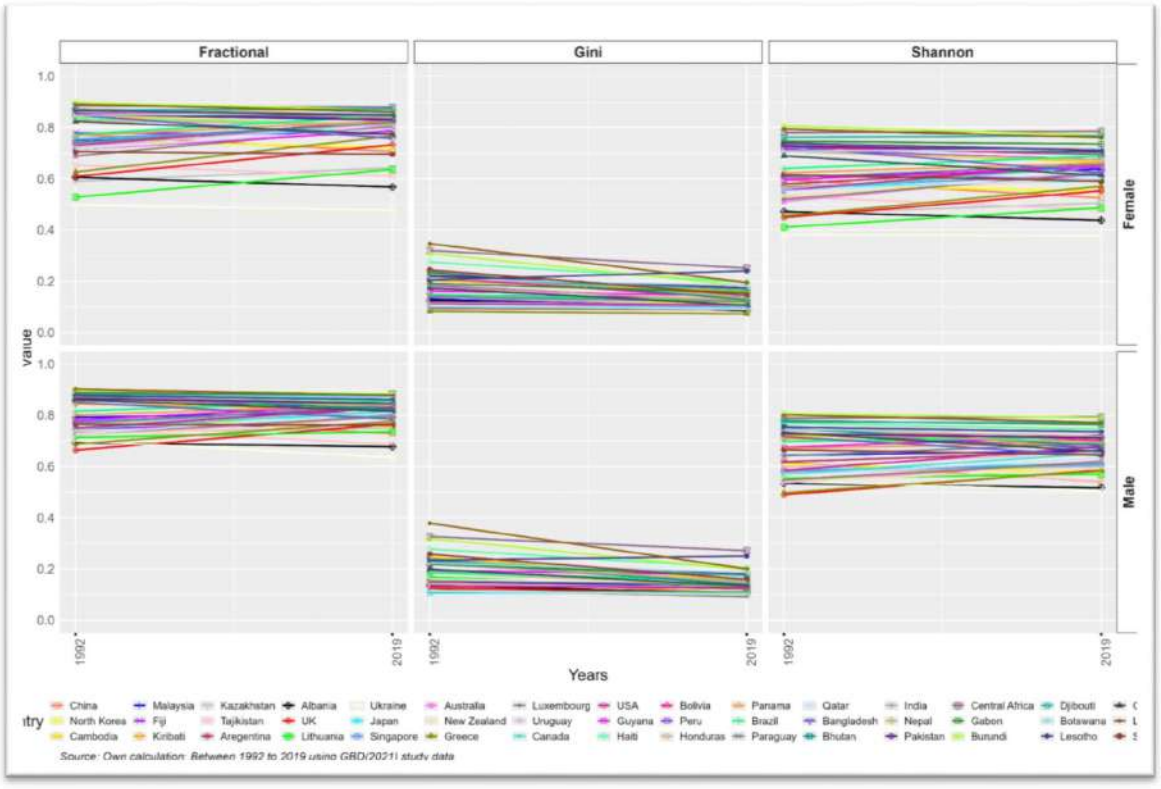


Fig. 3a: Age-cause-specific contributions to life expectancy of continent North and South Americas, 1990-1994 and 2017-2021, GBD (2021) study

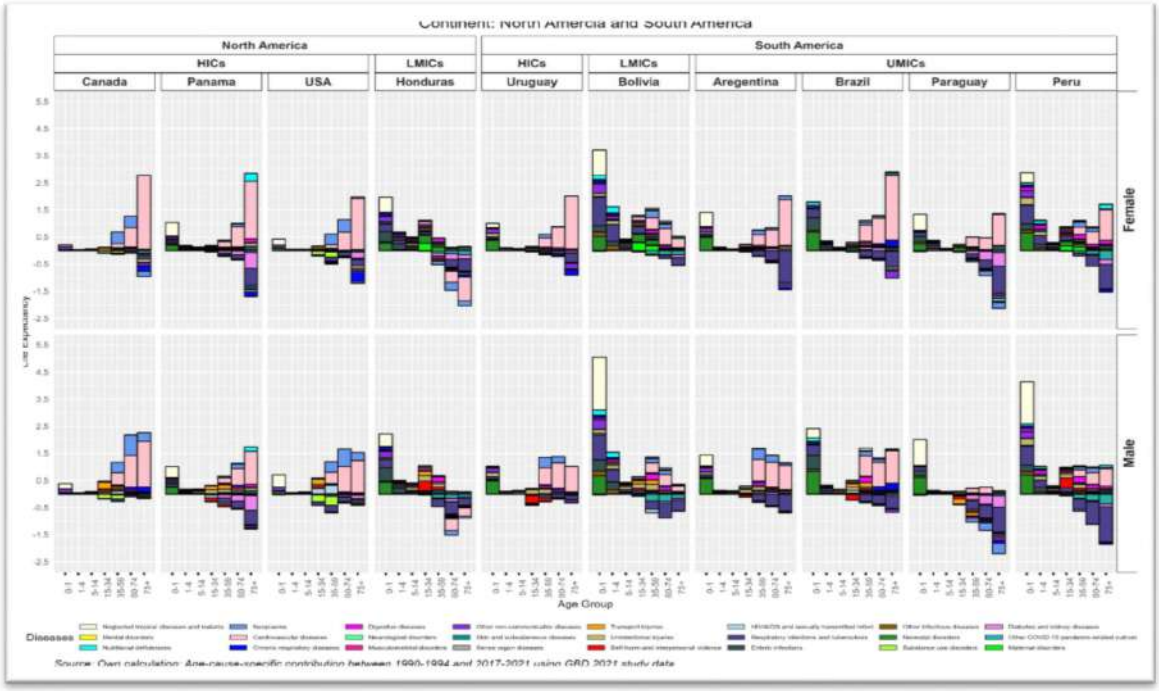


Fig. 3b: Age-cause-specific contributions to life expectancy of continent Asia, 1990-1994 and 2017-2021, GBD (2021) study

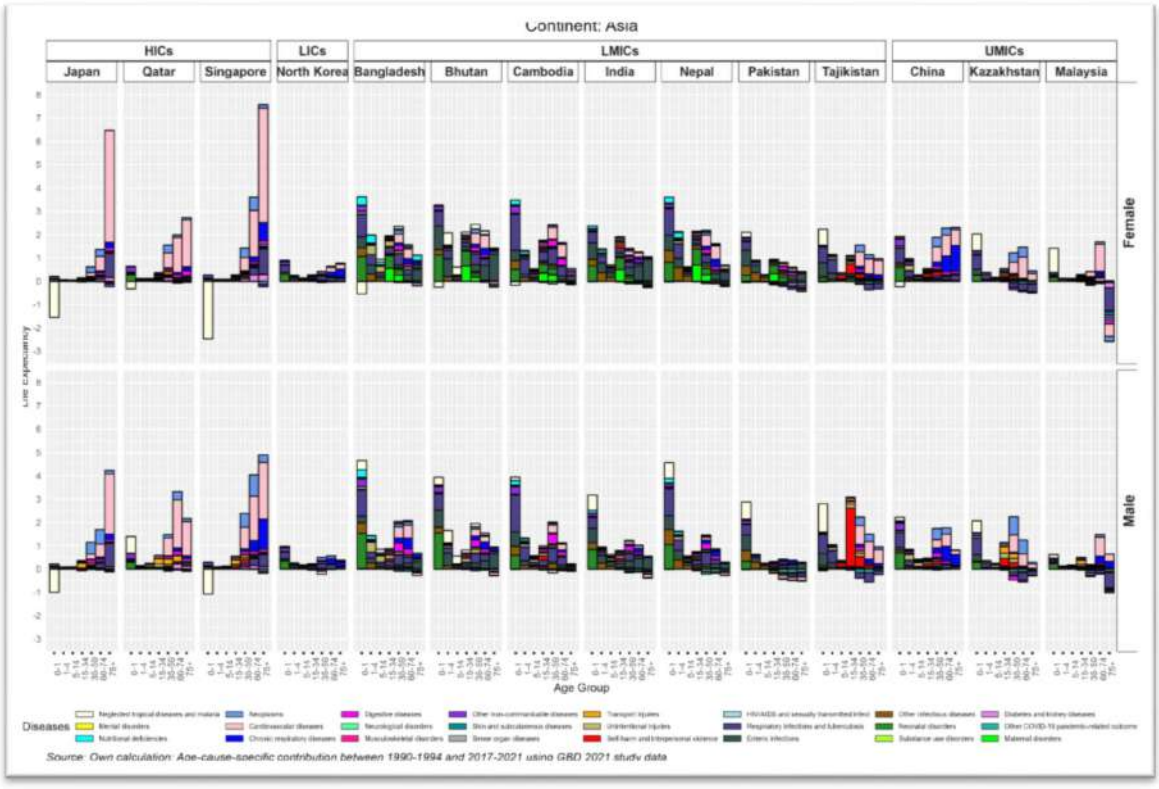


Fig. 3c: Age-cause-specific contributions to life expectancy of continent Australasia, Europe, and Oceania, 1990-1994 and 2017-2021, GBD (2021) study

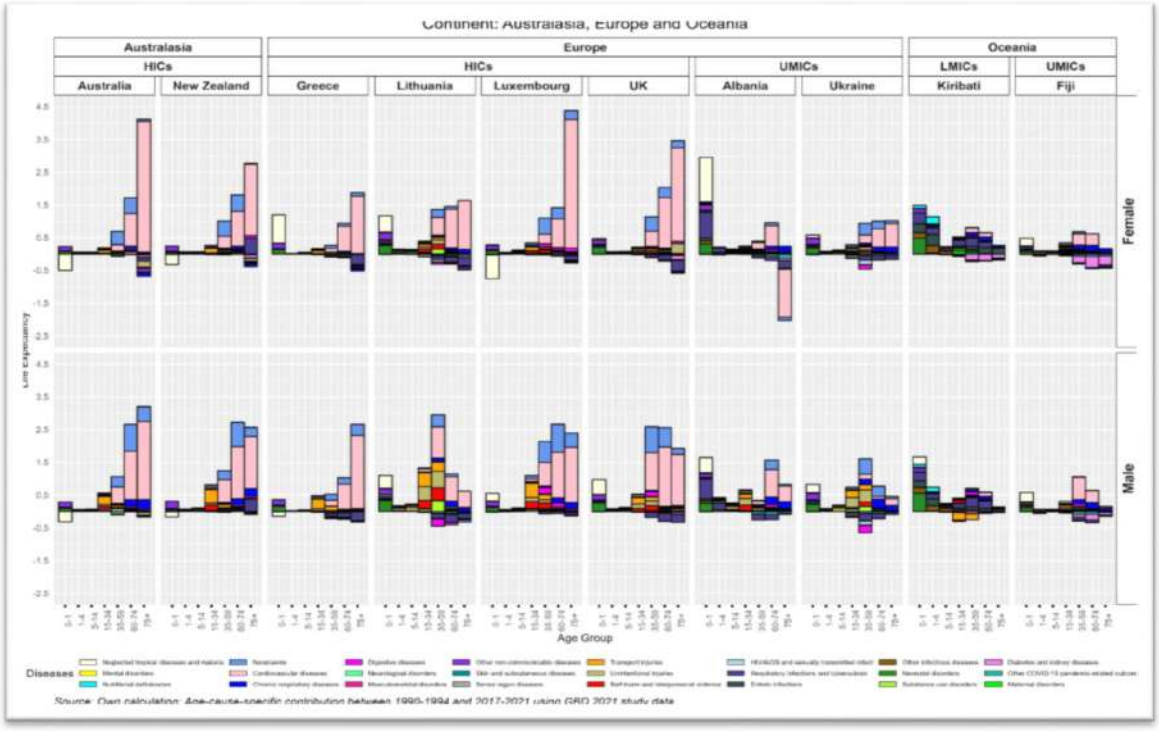


Fig. 3d: Age-cause-specific contributions to life expectancy of continent Africa, 1990-1994 and 2017-2021, GBD (2021) study

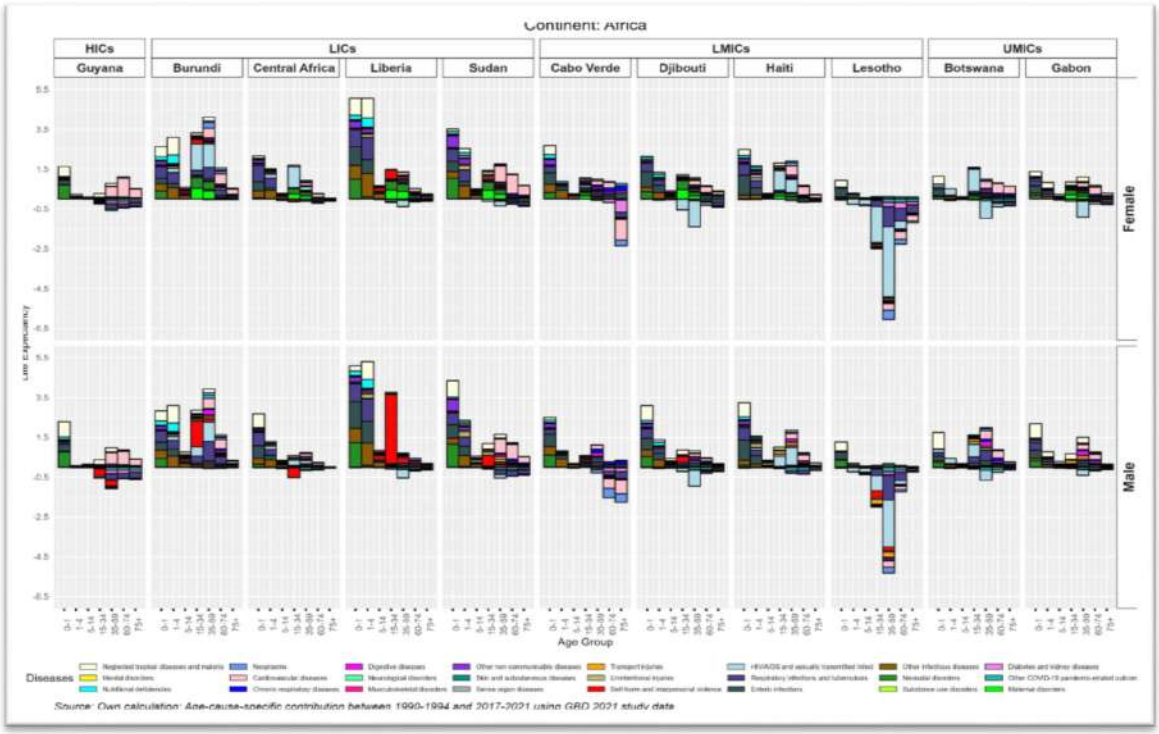


Fig. 4a: Age-cause-specific contributions to the Gini coefficient of continent North and South Americas, 1990-1994 and 2017-2021, GBD (2021) study

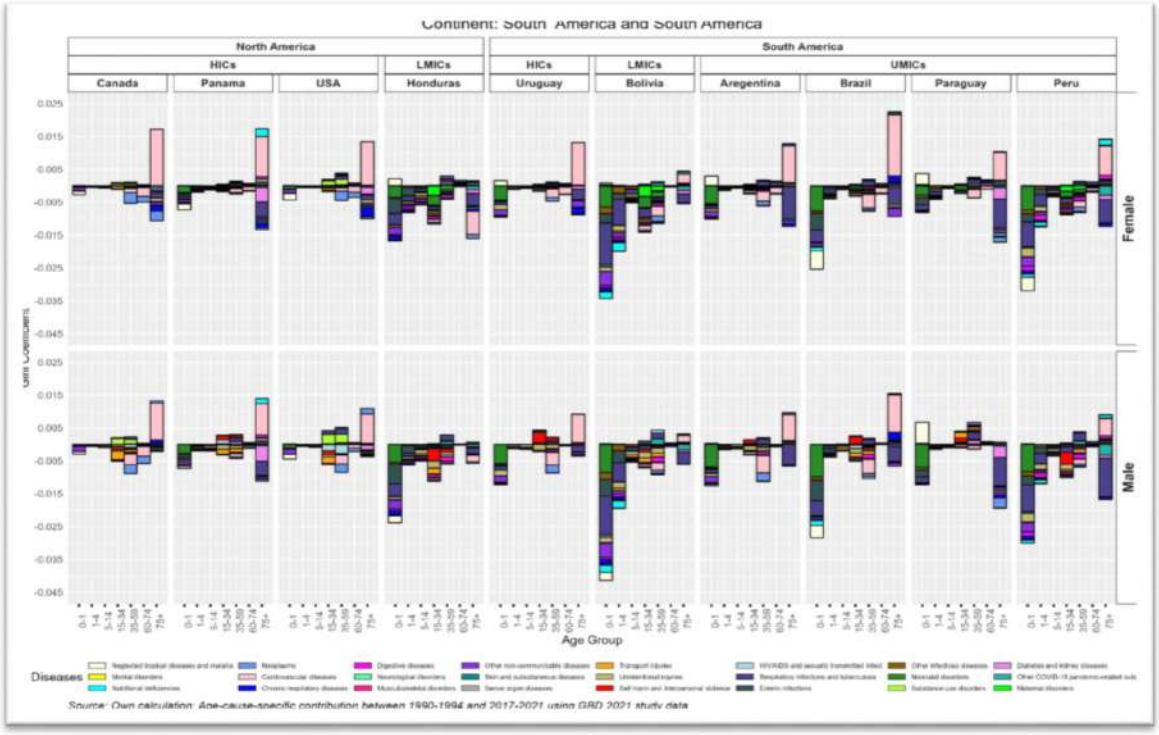


Fig. 4b: Age-cause-specific contributions to the Gini coefficient of continent Asia, 1990-1994 and 2017-2021, GBD (2021) study

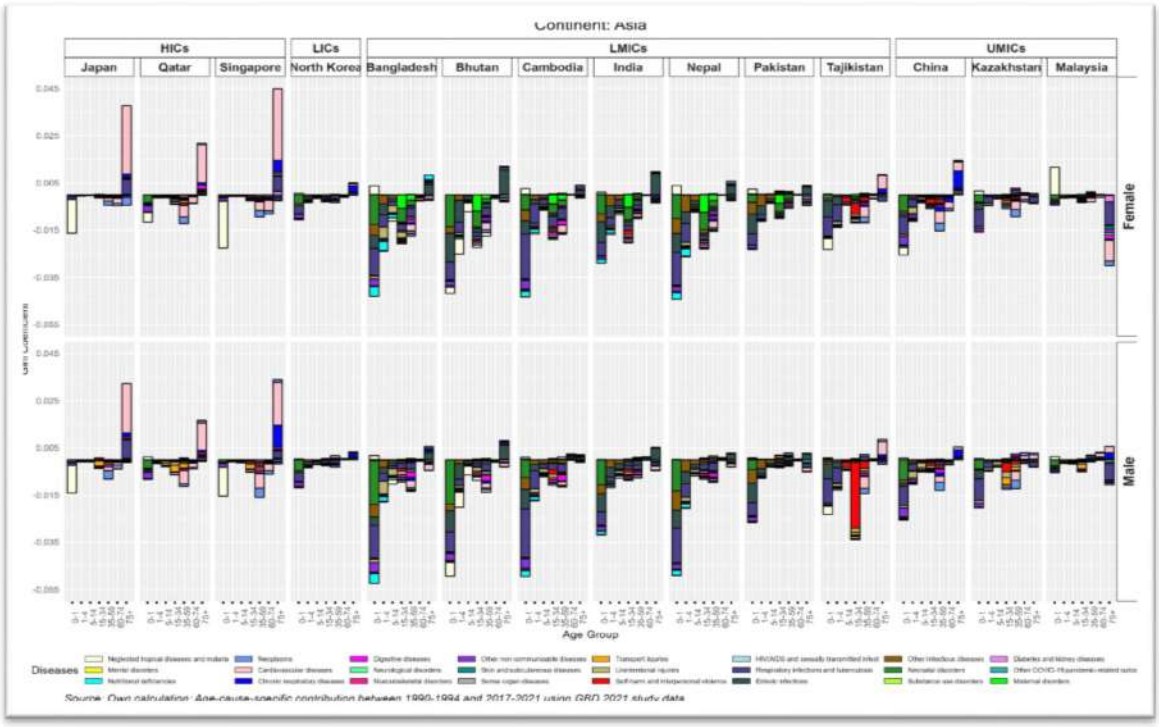
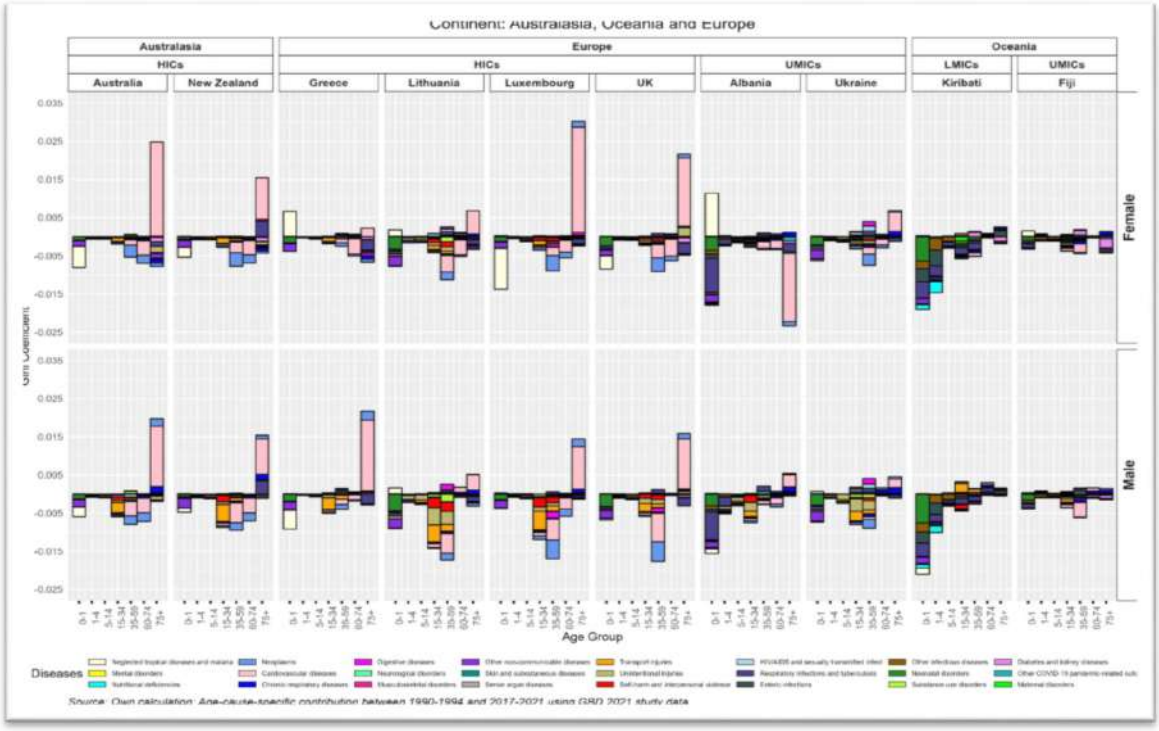


Fig. 4c: Age-cause-specific contributions to the Gini coefficient of continent Australasia, Europe, and Oceania, 1990-1994 and 2017-2021, GBD (2021) study



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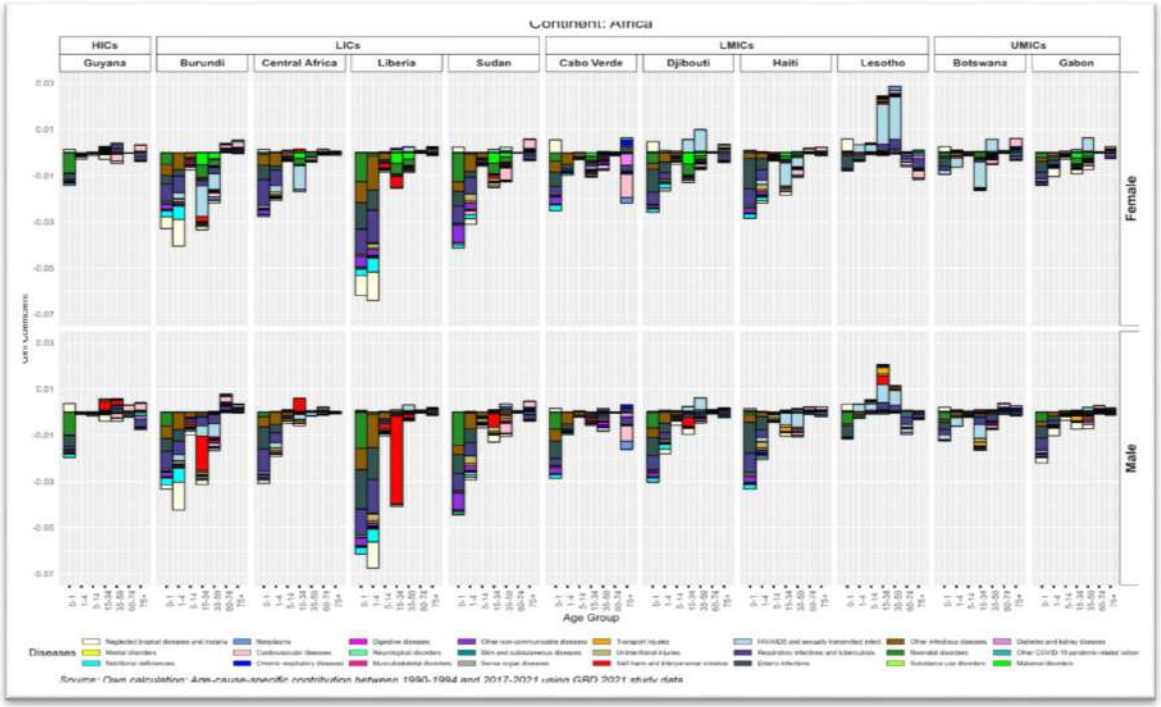

Fig. 5a: Age-cause-specific contributions to the Fractionalization index of continent North and South Americas, 1990-1994 and 2017-2021, GBD (2021) study

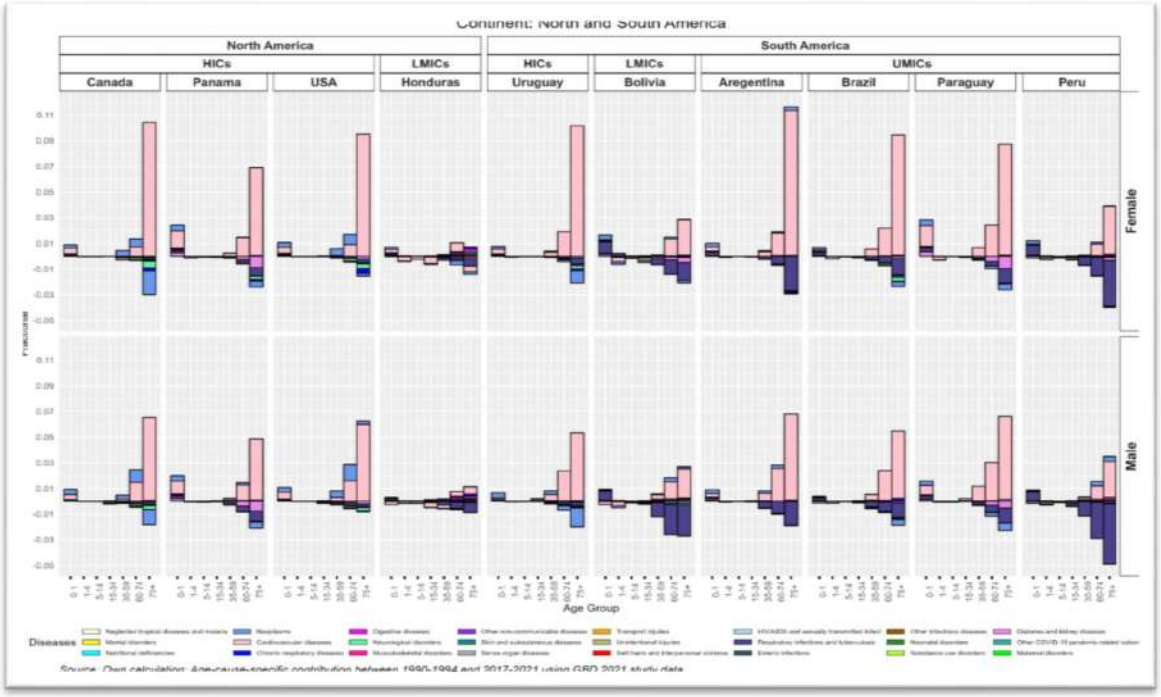

Fig. 5b: Age-cause-specific contributions to the Fractionalization index of continent Asia, 1990-1994 and 2017-2021, GBD (2021) study

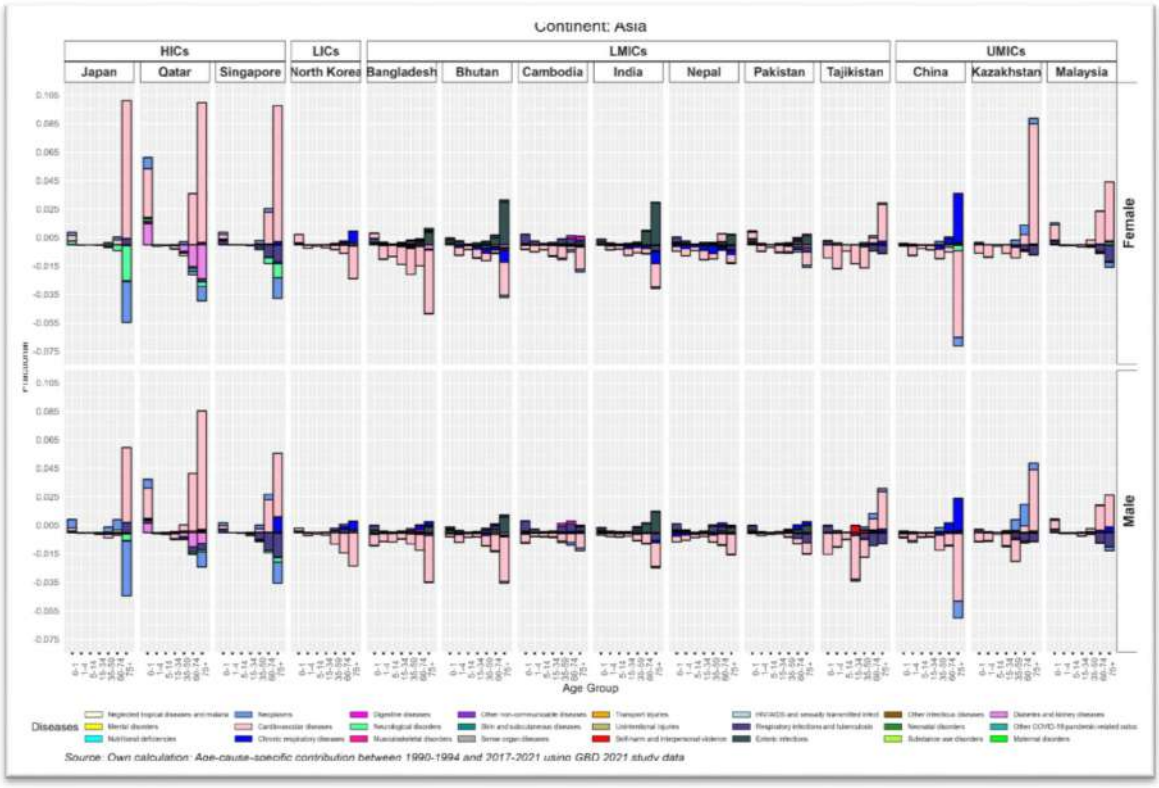

Fig. 5c: Age-cause-specific contributions to the Fractionalization index of continent Australasia, Europe, and Oceania, 1990-1994 and 2017-2021, GBD (2021) study

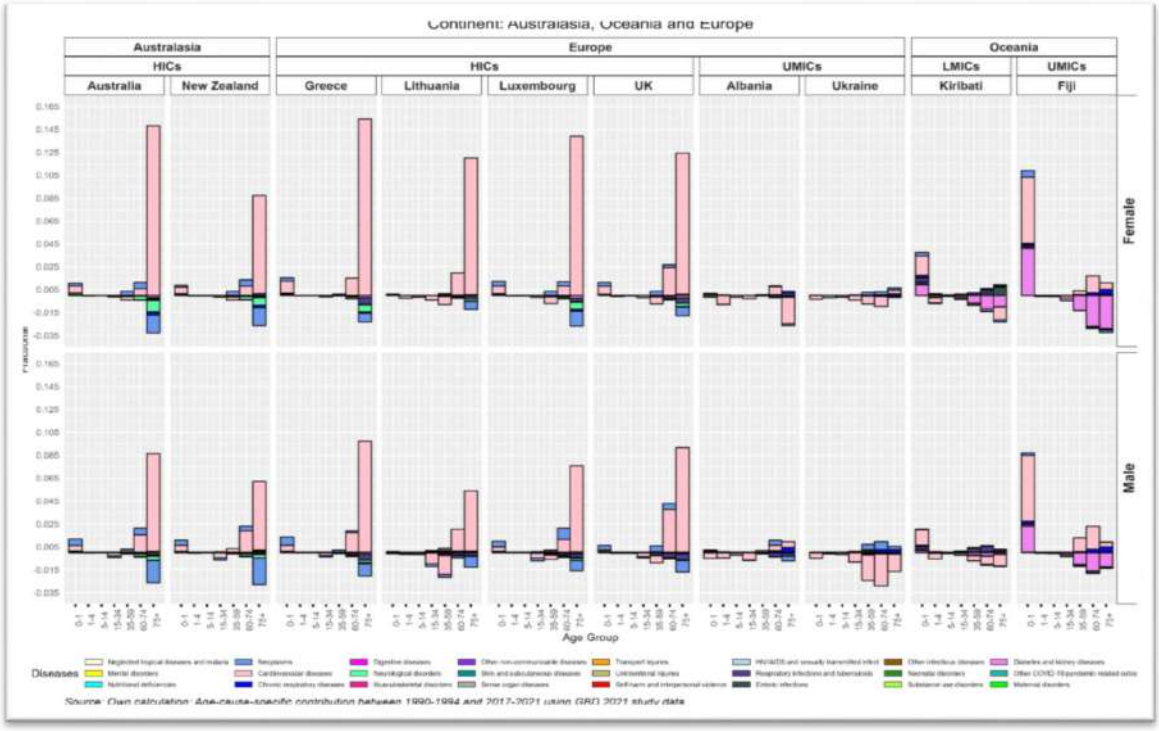

Fig. 5d: Age-cause-specific contributions to the Fractionalization index of continent Africa, 1990-1994 and 2017-2021, GBD (2021) study

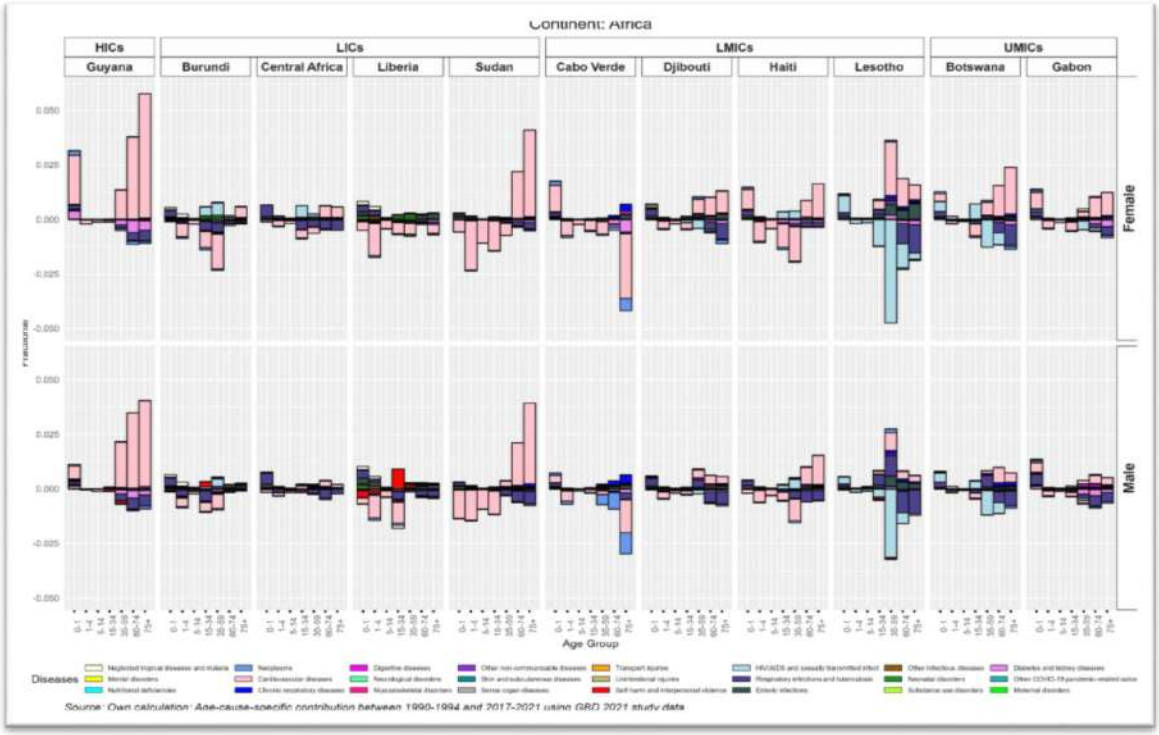

Fig. 6a: Age-cause-specific contributions to the Shannon entropy of continent North and South Americas, 1990-1994 and 2017-2021, GBD (2021) study

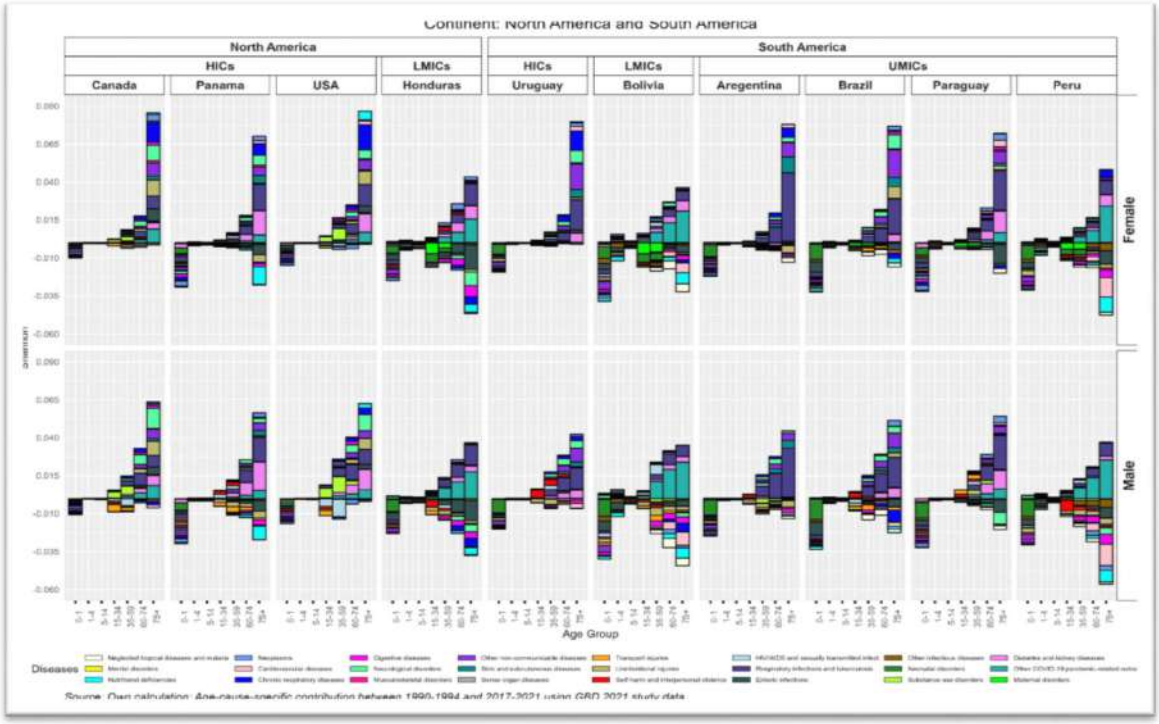

Fig. 6b: Age-cause-specific contributions to the Shannon entropy of continent Asia, 1990-1994 and 2017-2021, GBD (2021) study

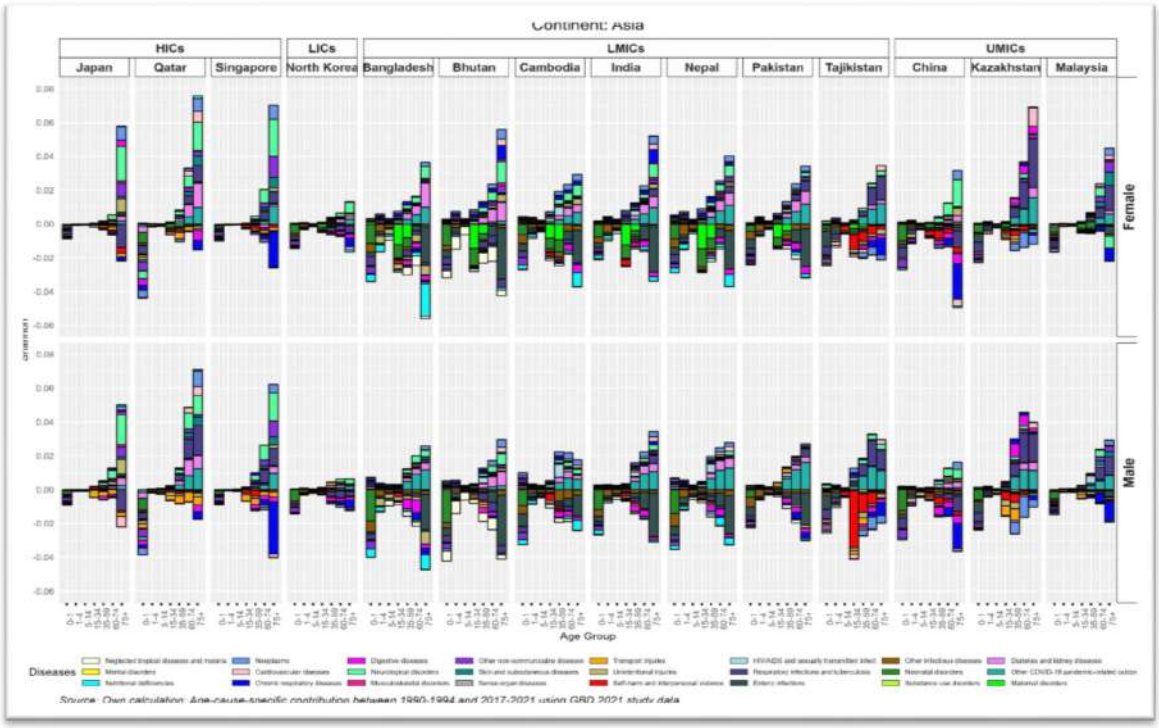

Fig. 6c: Age-cause-specific contributions to the Shannon entropy of continent Australasia, Europe, and Oceania, 1990-1994 and 2017-2021, GBD (2021) study

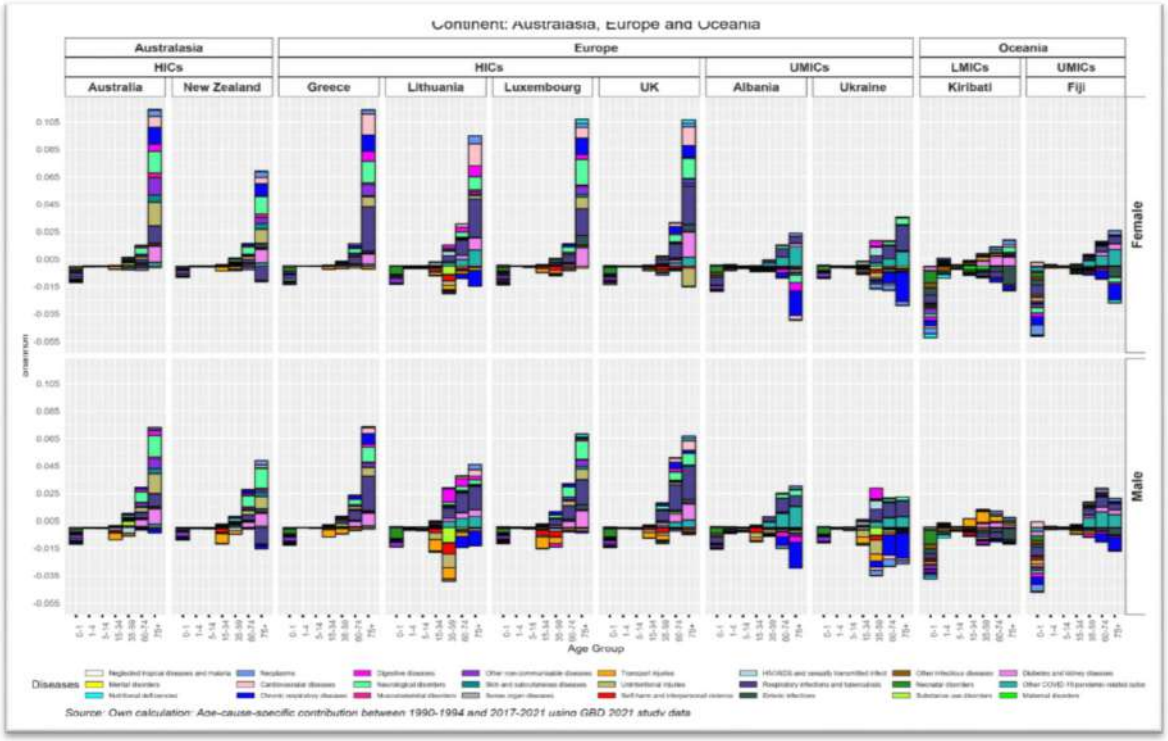

Fig. 6d: Age-cause-specific contributions to the Shannon entropy of continent Africa, 1990-1994 and 2017-2021, GBD (2021) study