

# Lifespan inequalities among Mexican states, 1990-2015: deterioration in adult survival

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Abstract:	<p>Background. After sizable improvements in the second half of the 20th century, Mexican life expectancy stagnated in the first decade of the 2000s. At the state level, discrepancies in epidemiological patterns have been documented: While child and maternal mortality, associated with healthcare interventions, has improved, mortality at older ages has increased. The effects of causes of death amenable to public health interventions in Mexican states and the potential gains in life expectancy remain to be assessed.</p> <p>Methods. Mortality data for years 1990 to 2015 by age, sex, and cause-of-death by state were extracted from publicly available data sets. Life expectancies for three large age groups (0-14, 15-49, &amp; 50-84), and a low mortality benchmark based on the lowest observed mortality levels were calculated. Deaths were classified according to the concept of 'avoidable/amenable' mortality and decomposition techniques were used to disentangle age-cause-specific effects on survival.</p> <p>Results. The population below age 15 shows improvements in survival. Average survival below 15 over states was 14.82 (95% CI, 14.76-14.88) and 14.78 years (14.70-14.86) in 2015, for females and males respectively. However, the adult population aged 15 to 49 shows deterioration among males after 2006 in almost every state due to an increase in homicides and a slow recovery thereafter. Our of 35 potential years females and males live on average 34.57 (34.48-34.67) and 33.80 (33.34-34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deterioration in both females and males with average survival of 28.59 (27.43-29.75) and 26.52 (25.33-27.73) out of 35, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.</p> <p>Conclusions. Mexico has succeeded in reducing mortality and between-state inequalities in children. However, the adult population is becoming vulnerable as it has not been able to reduce the burden of conditions amenable to health services and some related to public policies (e.g. homicides). This has led to large health disparities between Mexican states in the last 25 years.</p>
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## RESEARCH

# Lifespan inequalities among Mexican states, 1990-2015: deterioration in adult survival

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## Abstract

**Background:** After sizable improvements in the second half of the 20th century, Mexican life expectancy stagnated in the first decade of the 2000s. At the state level, discrepancies in epidemiological patterns have been documented: While child and maternal mortality, associated with healthcare interventions, has improved, mortality at older ages has increased. The effects of causes of death amenable to public health interventions in Mexican states and the potential gains in life expectancy remain to be assessed.

**Methods:** Mortality data for years 1990 to 2015 by age, sex, and cause-of-death by state were extracted from publicly available data sets. Life expectancies for three large age groups (0-14, 15-49, & 50-84), and a low mortality benchmark based on the lowest observed mortality levels were calculated. Deaths were classified according to the concept of 'avoidable/amenable' mortality and decomposition techniques were used to disentangle age-cause-specific effects on survival.

**Results:** The population below age 15 shows improvements in survival. Average survival below 15 over states was 14.82 (95% CI, 14.76-14.88) and 14.78 years (14.70-14.86) in 2015, for females and males respectively. However, the adult population aged 15 to 49 shows deterioration among males after 2006 in almost every state due to an increase in homicides and a slow recovery thereafter. Our of 35 potential years females and males live on average 34.57 (34.48-34.67) and 33.80 (33.34-34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deterioration in both females and males with average survival of 28.59 (27.43-29.75) and 26.52 (25.33-27.73) out of 35, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.

**Conclusions:** Mexico has succeeded in reducing mortality and between-state inequalities in children. However, the adult population is becoming vulnerable as it has not been able to reduce the burden of conditions amenable to health services and some related to public policies (e.g. homicides). This has led to large health disparities between Mexican states in the last 25 years.

**Keywords:** life expectancy; Mexico; health inequalities; adult health; causes of death; homicides

## Background

The second half of the 20th century was marked by sizable improvements in mortality, living conditions, and health in most Latin American countries [1]. In Mexico, these improvements have slowed down recently due to opposing trends in particular causes of death. For instance, homicide and diabetes increased during the first

decade of the 2000's, even as infectious and respiratory diseases continued to fall over the same period. While life expectancy at birth increased by 4.3 years for males (from 67.6 to 71.9) and 3.4 years for females (from 73.8 to 77.2) between 1990 and 2000 [2], between 2000 and 2010, life expectancy at birth entered into a period of stagnation for males and slowed progress for females [3].

This period coincides with ongoing public health interventions, such as the Universal Vaccination Program, and with the implementation of a Universal Health Coverage program (Seguro Popular). The latter program provides primary and secondary health care to the uninsured population and allocates funds to cover catastrophic health expenditures [4]. Further, since 1997 conditional cash transfer programs were introduced to supply incentives for poor families to invest in education, health, and nutrition [5]. Some evidence suggests that Mexico experienced substantial decreases in infant and child mortality, and with the prevalence of acute malnutrition, between 1980 and 2000 thanks partially to these interventions [6]. Similarly, by 2012 Seguro Popular had provided health insurance coverage to an additional 52 million people in Mexico (or 44.4% of the population), leading to increase access to public health care and protection from the financial consequences of disease [7].

Conditional cash transfers have focused on the poorest states, and Seguro Popular was introduced at different times in different states. Although these actions underscore broad progress in public health interventions, they mask disparities between Mexican states and the epidemiological patterns for different age groups. For instance, Mexico faces a rapid aging process in which the interaction between infectious diseases and noncommunicable conditions can be anticipated in the adult population. [8]<sup>[1]</sup> Therefore, it is necessary to assess the varied impacts that these interventions may have had on mortality in Mexican states at different ages [10].

One approach to approximate the impact of health care and other interventions, and to reveal potential areas of improvement is by operationalizing the concept of Avoidable or Amenable Mortality (hereafter abbreviated AM) [11, 12, 13]. This categorization of mortality aims to measure the quality of health service systems by selecting certain causes of death that should not occur in the presence of effective and timely health care. Therefore, improvements in AM mortality are expected over time, as it has been observed in several countries. For example, among 19 industrialized countries, including 14 countries from western Europe, USA, Canada, Australia, New Zealand and Japan, a reduction in AM rates was observed over the past 20 years [12]. Avoidable mortality rates fell, on average, by 17% for males and 14% for females in these countries between 1997 and 2003. However, USA lagged behind the rest of the countries, while Japan, France and Australia were the top performers. Despite mortality reductions from cancers and circulatory diseases for both sexes, disparities between countries persist, with the United States showing the smallest reductions (around 5%) for both sexes [12].

In Mexico, the components of avoidable mortality had different trends since the late 1990's. Mortality from infectious diseases and nutrition-related conditions decreased between 2000 and 2004 [14], while deaths related to diabetes and ischemic

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<sup>[1]</sup>The percentage of the population aged 65 or older is projected to go from 6.0% in 2015 to 10.2% in 2030 [9].

heart diseases increased in the first decade of the new century [15]. Importantly, increases in the latter causes of death were concentrated in the poorest states of the country [15].

We extend previous analyses by using the most recent available data to study mortality trends by cause of death for all 32 Mexican states, by sex, and over the full period from 1990 to 2015. This choice of period covers several public health interventions and captures several major trends in state and cause-of-death variation. We further segment AM into health intervention-related and behavior-related AM causes that capture the epidemiological patterns of Mexico [16]. In addition, our work differentiates from earlier studies by comparing state mortality patterns with an easy-to-understand low-mortality benchmark calculated for large age groups (i.e. 0-14, 15-49 and 50-84). This concept has been previously used in mortality studies [17, 18, 19]. Deviations from the low-mortality benchmark indicate a strong potential for improvement.

We hypothesize age-dependent variations in mortality outcomes. In particular, we expect convergence between states and improvement in survival for young people, since public health interventions are mainly focused on infant and child health. For instance, the vaccination program and Seguro Popular aim to fully cover children in the entire country, and recent evidence suggests a decrease in mortality below age 15 due to a decline in infectious and respiratory diseases [20]. On the contrary, we expect little improvements in survival for the young-adult population due to the sudden and egregious rise in homicide mortality [21]. We foresee health deterioration among older adults due to documented increases in diabetes mortality [20]. Although every state has the commitment to provide universal coverage and equitable access to health care, we anticipate disparities in mortality improvements between states due to heterogeneous epidemiological transitions among states [22], and differences in how health care programs have been delivered to the population [23].

## Data & Methods

Our analyses are based on publicly available anonymized datasets. We used death register microdata files produced by the Mexican Statistical Office (INEGI) from 1990 to 2015 [24]. From these data, information on causes of death by single age, sex, and state of residence at the time of death was extracted. Population estimates from 1990 to 2015 came from the Mexican Population Council (CONAPO) [9]. These population estimates adjust for age misstatement, undercounting, and interstate and international migration. Death counts and estimates of the population exposed to risk were used to calculate cause-age-specific death rates by sex for each state from 1990 to 2015.

### Classification of Causes of Death

To classify deaths we use the concept of “Avoidable/Amenable” Mortality (AM) [11, 12]. We group causes of death into eight categories based on a previous classification [13] that has recently been adapted to the case of Mexico [16]. The first category refers to those conditions that are susceptible to medical intervention, such as infectious and respiratory diseases, and it is labeled “Causes amenable to medical service”. We separate diabetes, ischemic heart diseases (IHD), lung cancer, and

cirrhosis because these causes are susceptible to both health behavior and medical service, and because the first two represent major causes of death in Mexican adults [22]. We also separate homicide and road traffic accidents because they have emerged as leading causes of death among young people, and the first one recently had a sizeable impact on life expectancy in Mexico [16]. Remaining causes were grouped into a single category labeled “Other causes”.

Death data was originally classified according to the International Classification of Diseases (ICD), revision 9 for years 1990 to 1997 and revision 10 for 1998 to 2015 (see Additional file 1 Table 1 for details on ICD codes for each category). To check the validity of these cause-of-death codes in Mexico, we performed a sensitivity analysis and did not find major ruptures in mortality trends by AM classification (See Additional file 1, Figure 1).

Comorbidity in the old age population has increased in Mexico [25]. As a result inaccuracies may arise in cause of death registration due to problems associated with medical diagnosis, and selection and coding of the main cause of death. Although analyses in these ages should be treated with multiple causes of death to better represent old age mortality, it is out of the scope of this study since we focus on the primary cause of death. Therefore, we truncated our analysis at age 85 to avoid misinterpreting results related to inaccurate cause of death coding practices.

### Age Groups

We calculate life expectancy in three large age groups to capture mortality differences along the lifecourse. Life expectancy in each age group simply refers to the average years of life lived between two ages conditional on survival to the lower age bound. This measure is also known in demographic analysis as temporary life expectancy [26]. The first age group refers to people aged 0-14. This group is likely to represent improvements in causes amenable to medical service (e.g. infectious diseases and conditions of perinatal period) [3]. The second group, aged 15-49, is used to capture the effect of homicide mortality and external causes historically related to the young-adult mortality hump. This age group had an important impact on changes in state life expectancy in the first decade of the 2000s [16]. The third group covers older adults aged 50-84. Older adults are likely to represent a vulnerable group due to deterioration in non-communicable diseases and injury-related mortality in recent years [22, 27].

### Low mortality benchmark

Our low-mortality benchmark is calculated on the basis of the lowest observed mortality rates over all states by age, year, cause and sex. This value is a practical reference because it is based neither on a projection of improvements into the future nor on an arbitrary and likely dissimilar population. The resulting minimum mortality rate schedule has a unique age profile, and it determines our benchmark temporary life expectancy. It can be treated as the best presently achievable mortality assuming perfect diffusion of the best available practices and technologies in Mexico [19].

## Methods

Cause-specific death rates are the basis of all calculations in this work. To mitigate random variations, these rates are adjusted in two steps. First, we smooth cause-specific death rates over age and time for each state and sex separately using a 2-d p-spline [28]. Second, we rescale the smoothed cause-specific death rates to sum to the raw all-cause death rates for each sex and state. Period life tables up to age 84 for males and females from 1990 to 2015 and their benchmarks were calculated following standard demographic methods [29]. Temporary life expectancies were calculated [26] (see Additional file 1 for a technical overview) and cause-specific contributions to the difference between each state and the low mortality benchmark were estimated using standard decomposition techniques [30]. Finally, the coefficient of variation of the gap between temporary life expectancy in each age group with the low mortality benchmark was calculated to measure the level of disparity between states over time. This indicator is relative and has the property that even if temporary life expectancy refers to different age-ranges, i.e. 0-14, 15-49, and 50-84, the values are still comparable over age-groups and time. In addition, we performed two-way ANOVA and post hoc tests to analyze disparities in temporary life expectancy between states and age groups in Mexico.

## Limitations

Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages [31]. To mitigate this, we focus on ages below 85 and broad groups of causes of death. Our estimates regarding homicide mortality are likely to be underestimated due to inaccurate practices regarding counting, reporting, and due to the large number of missing individuals in Mexico [32].

Avoidable mortality should be understood as an indicator of potential weaknesses with respect to health care and some public health policies and not as a definitive assessment [12]. The amount of deaths that should be considered within the avoidable classification is not clear [33]. For instance, some researchers consider only 50 percent of heart disease mortality to be avoidable [34, 35]. There is no direct information to precisely measure percentages of avoidable mortality within cause groups in Mexico. Nonetheless, the difference between a given mortality schedule and the best mortality schedule of the same year can be conceived of as a minimal definition of avoidable mortality. The benchmark mortality schedule sets a lower bound to how much mortality could have been avoided. Certainly, even the best mortality schedule will contain elements of mortality that most would consider avoidable. To the extent that the components of the benchmark schedule were indeed attained somewhere in Mexico, one can view any excess mortality with respect to the benchmark schedule as avoidable. We believe this perspective improves on the AM concept by giving a directly measurable standard against which to estimate avoidable deaths.

## Results

### Trends in life expectancy for Mexican states by age-groups

Figure 1 presents the temporary life expectancies by state for three large age groups: the youngest (ages 0-14), young adults (15-49) and older adults (50-84), over the

period 1990-2015. Grey lines refer to each of the 32 states; the black lines represent the average over states; and the blue lines represent the low mortality benchmark. The black line at the top of each panel indicates the maximum livable years in each age group: 15 for the youngest, and 35 for young and older adults conditional on surviving to ages 15 and 50, respectively. Any gap between a state line and the blue line represents potential additional years of life if mortality were to achieve the low mortality benchmark.

All states show improvements in the youngest age group since 1990, approaching the low mortality benchmark, which itself is very close to maximum survival below age 15. This was observed even in the southern states such as Puebla, Chiapas and Tabasco which have lagged behind in reducing mortality at these ages throughout the entire period.

Life expectancy between ages 15 and 49 shows a sudden drop after 2005 among males in almost every state in Mexico. In 2005, young males in this age group had a temporary life expectancy of 33.9 years (95% CI, 33.5-34.2) averaged over states. By 2010, the number of states below this level had increased from 14 to 23. Chihuahua, Sinaloa and Durango, in the northern region, experienced a substantial mortality shock in 2010 in this age group, and consequently recorded the largest departures from the low mortality benchmark. In 2015, the state average (33.8 years, 33.3-.34.3) had almost recovered to its 2005 level. Trends for females are closer to the low mortality benchmark.

Among older adults, life expectancy between ages 50 and 84 shows stagnation and deterioration over the entire period of observation. Even the low mortality benchmark exhibits a gradual downward trend, pointing to a generalized mortality increase. The female state average life expectancy declined from 28.8 years (27.4-30.2) in 1990 to 28.3 years (27.4-29.2) in 2010. By 2015, this average only managed to recover to 28.6 years (27.4-29.8). Among males, the average over states decreased from 26.7 years (24.7-28.8) in 1990 to 26.3 years (24.9-27.6) in 2010, and 26.5 years (25.3-27.7) in 2015. Furthermore, we fitted three linear models to both sexes, combined and independently, and the slope coefficient was significant in all of them at the level of  $p < .005$ . These results suggest that the decline observed was significant. As with young adult males, some states experienced a deterioration after 2005, with a minor recovery since 2010.

[Figure 1 about here]

#### Health disparities between states and age groups

Figure 2 shows the trends in inequalities between states in Mexico for males in the three age groups, as measured by the coefficient of variation (results for females are reported in Additional file 1, Figure 2). This indicator measures the variation in the gap of temporary life expectancy with the low mortality benchmark between states within the three age groups. Larger values are related to higher disparities between states. Trends show mixed patterns of convergence with temporary divergence, and with females in all cases showing less between-state inequality than males over the entire period studied.

There are important differences in inequality levels and trends between age groups. Since 1990, state inequality in life expectancy in the youngest age group has been



decreasing. Among females, young adults show even lower values than the population in the youngest age group. However, for males in the young adult age-group a crossover in the early 2000's is seen, with inequality increasing after 2005. The highest values are observed in the period 2009-2011. By 2015, state inequalities among young adults had decreased substantially, but still remain higher than that of the youngest age group. Older adults show substantially higher inequality than the other age groups over the entire period studied, but also show steady convergence between states. From 2013, both males and females show a potential rise in disparities between states (Additional file 1 Figure 2).

[Figure 2 about here]

To illustrate discordance between age groups within each state, Figure 3 shows the state ranking of temporary life expectancy for the years 2010-15 for males in each age group (see Additional file 1, Figure 3 for females' results). States at the top show the highest values in temporary life expectancy, while states in the bottom refer to the lowest values. We chose to highlight the states with most discordant age-rankings. Green and purple lines refer to selected states that show drastic changes in the ranking between different age groups. For example, Sinaloa, in the northern part of Mexico, holds the record life expectancy below age 15; however, young adults (15-49) show one of the lowest values, while older adults are in the sixth position out of 32. Similar trajectories are shown with green lines for Nayarit and Michoacán in the central region, Zacatecas in the North, as well as Morelos and Guerrero from the southern region. Conversely, the pattern of age discordance in Hidalgo, Querétaro and Mexico City from the central region, and Yucatan and Puebla in the South (purple lines) is summarized by changing from a low rank in the youngest age group to a high rank in young adults, followed by low rank in older adults.

We performed a two-way ANOVA on temporary life expectancy by state and age-groups controlling for year. There was a statistically significant interaction between the effects of states and age groups [ $F = 12.25, p < .001$ ]. Indicating, as shown in Figure 3, part of the existing variation in the country is due to within-variability in each state. There were also significant differences in temporary life expectancy between age groups [ $p < .001$ ] and states [ $p < .001$ ] reflecting between-state variability, as shown in Figure 2.

[Figure 3 about here]

### Cause-decomposition analysis

In Figures 4 and 5, the Mexican states in each region are arranged according to the largest gap with the low mortality benchmark among older adult males in 2015. Figure 4 shows how causes amenable to medical service, diabetes, ischemic heart diseases (IHD), lung cancer, cirrhosis, homicide and road traffic accidents contributed to the gap between each state and the low mortality benchmark from 1990 to 2015 for male older adults (ages 50-84). These are the causes of death that contributed the most to holding states back from achieving the low mortality benchmark. Light-yellow colors indicate negligible contributions, which means that are very close to the low mortality benchmark within each category. Darker red hues

indicate larger contributions to the gap. If a particular state is improving during the period, it shows a transition from red to light-yellow.

Medically amenable causes of death show gradual improvements in most states from 1990 to 2015, bringing them closer to the benchmark in this category. However, large disparities between states and potential for improvements remain. For example, Baja California, Sonora, Chihuahua and Coahuila from the northern region show substantial contributions to the gap. Diabetes mortality has increasingly contributed to widening the benchmark gap in several states, including Coahuila and Tamaulipas in the North, Mexico City, Guanajuato, Mexico state and Tlaxcala in the central region, and Puebla, Veracruz and Tabasco in the South. Similarly, IHD significantly affects the northern part of the country, while cirrhosis is mostly concentrated in the South. Lung cancer and road traffic accidents have lower contributions to the benchmark gap, but these remain important causes of death. Homicides increased the gap in this age group in some states after 2005, such as Chihuahua, Durango and Sinaloa in the North, Colima, Michoacan and Nayarit in the central region, and Guerrero in the South.

[Figure 4 about here]

Females show similar regional patterns to males, albeit with lower magnitude. As for males, causes amenable to medical service, diabetes, and IHD contributed the largest share to the gap with the low mortality benchmark among older adult females. In the youngest age group, improvements in life expectancy and in reducing the gap with the low mortality benchmark were mainly driven by causes amenable to medical service among both females and males. Finally, homicide mortality and road traffic accidents are the main drivers of the gap with the benchmark among young male adults (ages 15-49). Importantly, homicides contributed more than 2.5 years to the gap with the low mortality benchmark in 2010 in the northern state of Chihuahua, and several states from the North and South of Mexico showed substantial impact of homicide after 2005. Results for all age-groups are shown in Additional file 1, Figures 4-9.

#### Potential gains and causes of death in 2015

Figure 5 breaks down the state-specific low mortality benchmark gap for males aged 50-84 into potential gains and their cause of death composition. The left panel shows the potential gains for older adults if the low mortality benchmark were achieved for each state in 2015. The right panel shows the proportion of potential gains due to specific causes of death in the same year.

Every state in Mexico could increase survival by at least one year in older adult ages if they were to achieve the low mortality benchmark. However, for 17 of them the gap with the benchmark is higher than 2 years, and for 3 states in the northern region it is greater than 3 years. For females, with the exception of Sinaloa and Nayarit, all the states show the potential to gain over an additional year of life between ages 50-84.

More than half of these potential gains in life expectancy between ages 50 and 84 are due to medically amenable causes, diabetes, IHD and cirrhosis in every state in

Mexico (right panel). This is true also for females. Although older males show lower impact of homicide mortality on potential gains compared to young adult males (15-49), its effect is present in almost every state, particularly in Guerrero, Morelos in the South, Nayarit and Colima in the central region, and Sinaloa in the North. Results for all the age groups for the years 2005, 2010, and 2015 are shown in the Additional file 1, from Figure 10.

[Figure 5 about here]

## Discussion

In Mexico since 1990, life expectancy in three large age groups has followed discordant patterns of rise, deterioration, and stagnation. Such patterns have been driven mainly by causes of death that are amenable to medical service (such as infectious and respiratory diseases) and health behaviors (such as homicides, diabetes, IHD, and cirrhosis). Patterns in these two large cause-of-death categories led to contrasting levels of inequality in the country. Our research disentangles these patterns by measuring the impact of medically amenable mortality and behavior-related mortality on life expectancy relative to a low mortality benchmark in three large age groups.

Life expectancy below age 15 converged towards the low mortality benchmark and maximum survival in all 32 Mexican states. These results underscore public health interventions aimed at youngest ages. This is supported by evidence that vaccination coverage has been achieved for the entire young population, and that health insurance coverage has improved, due to vaccination programs and the implementation of Seguro Popular, respectively [10]. Causes amenable to medical service are at the heart of such improvements, consisting of decreases in infectious and respiratory diseases associated with public health interventions targeting children [6]. For example, Puebla and Tlaxcala (in the South and central regions respectively) were the states with the lowest life expectancy below age 15 in 1990 and have improved by more than half a year since then. Moreover, the average over states improved from 14.5 in 1990 to 14.8 in 2015, with no state below 14.7. As a result of continuous and nationwide convergence towards the low mortality benchmark, inequalities between states in life expectancy below age 15 have been reduced.

Opposing the optimistic trend in the under-15 population, increases in homicide mortality reversed gains in male life expectancy, particularly between ages 15-49. These results are consistent with previous studies quantifying the effect of homicide mortality on the stagnation of national life expectancy at birth in the first decade of the 21st century [3], and with the reversal experienced in life expectancy in most states between 2005 and 2010 [16]. Our results extend such findings by adding five years of data and segmenting by specific age groups. We found that after ten years of the unexpected rise in homicide mortality, most states have experienced a slow and partial recovery since 2010. However, the impact of homicide is still higher than the levels observed in 2005. Between 2010 and 2015, this cause of death accounted for most of the gap between states and the low mortality benchmark in ages 15-49. For this age group, the states that show the greatest benchmark gap for homicide in 2015 are Guerrero in the South, and Sinaloa and Chihuahua in the

North, which could gain one year, and half a year (each) respectively if homicides were reduced to the level of the southern state of Yucatán, which in this case makes up 100% of the benchmark. Importantly, these figures are likely to be underestimates caused by under-registration and mis-classification of homicides and missing individuals, particularly in Guerrero [32, 36]. Moreover, health inequalities in life expectancy between states followed the rise in homicides after 2005 (Figure 2), and the considerable discordance between age-groups (Figure 3) was likely due in great part to homicide mortality in ages 15-49. Beyond the mortality implications of the rise in homicide, violence has had a toll on perceived vulnerability in the country [37]. The recent increase in homicides in some states could trigger an increase in the perception of vulnerability, which would result in a higher average lifetime fear in specific states. Although we are not able to link the trends in mortality among young adults in Mexico with specific public policies, some evidence suggests that the propagation of homicide mortality is not only a result of the war between drug cartels, but also because of the implementation of specific policies aimed to mitigate drug cartel operations after 2006 [38]. There is no simple way to lessen the impact of homicide mortality, but it is clear that the government has not been able to reduce its burden back to levels observed before 2005. Furthermore, state homicide rates may underestimate the effect of violence in particular localities. For example, Guerrero in the South, has two of the most dangerous cities in the world [<http://www.economist.com/blogs/graphicdetail/2017/03/daily-chart-23>], but no information is available on the heterogeneity in homicide mortality for the rest of the state.

The population aged 50-84 shows the largest low mortality benchmark gap in both females and males. Out of 35 livable years in this age group, females lived on average 28.6 years and males 26.5 in 2015 without any clear improvement in the 26 years since 1990. Even the low mortality benchmark itself shows a downward trend for males and stagnation for females (Figure 1). Moreover, this age group exhibits the highest inequality between states in the last 26 years. Our results show that causes of death holding states back from the low mortality benchmark vary between regions. Causes amenable to medical service showed gradual improvements in almost every state since 1990. However, in some states of the northern region such as Baja California, Sonora, and Chihuahua, these causes of death still show large room for improvements among older adults. Diabetes, Ischemic Heart Diseases (IHD) and cirrhosis account for the majority of the gap with the benchmark mortality with large regional differences. For example, IHD is mostly concentrated in the North (Figure 4), while cirrhosis and diabetes show a stronger impact in the central and southern regions. These results are supported by previous evidence documenting an increase in adult mortality rates from chronic kidney disease, diabetes and cirrhosis since 2000 [22]. Lung cancer and homicides had a lower impact on life expectancy for this age group, and both are higher in the northern part of the country.

The fact that in 2015 the older adult population of Mexico could add more than one year of life in every state for males, and in 30 states for females by achieving the benchmark mortality levels, underscores vulnerability in these ages. Public health interventions targeting specific causes of death for this age group according to the epidemiological profile of each state, would not only increase life expectancy, but it

would also forge a path towards more equality between states in health outcomes. More than 50% of the potential gains in life expectancy between ages 50 and 84 are due to avoidable mortality, and to a large extent mortality related to health behaviors. For instance, obesity and overweight, risk factors for diabetes and IHD, have dramatically increased since the 1990s in developing countries because of the consumption of cheap, energy-dense food and reduced physical activities [39]. In this sense, Mexico, along with the USA, has the highest rates of overweight and obesity among all OECD countries [20] and one of the highest in Latin America, along with Chile, El Salvador, Honduras, and Paraguay [40]. However, obesity prevalence is not homogeneous across Mexico. The highest rates of obesity are concentrated in the northern and central regions [20] and in urban areas of the country [41], which roughly matches our regional pattern of IHD and diabetes mortality.

## Conclusion

Mexico stands today at an advanced stage of the epidemiological transition [22]. However this transition was achieved rapidly and the health system is ill-prepared for the burden of non-communicable diseases [42]. The cardiovascular mortality reductions that brought the developed world into advanced levels of life expectancy [43], still are in progress in Mexico. Nevertheless, no single solution is available to reduce behavioral mortality in this country since, as we show, great heterogeneity in mortality levels exist among its states.

Signs of a fragile situation in the health and mortality of the oldest age groups is observed in the decline in the low mortality benchmark used in our analysis. The aging of the population could scale up this situation if timely preventive measures are not put in place. Furthermore, a resurgence of violent deaths [21, 16] has created a new burden in Mexican society.

As many developing countries, Mexico will have to face these new challenges with a broad strategy. This should include a continuous and adaptable health system ready for the current and future health adversities at the physical, mental and societal levels. Many other institutions will also have to coevolve including importantly the development of an education system that embraces and encourages physical and healthy activities in younger and future generations.

## List of abbreviations

AM: Avoidable/Amenable mortality

## Declarations

### Ethics approval and consent to participate

This study involved secondary data analysis of public sources, which did not have any individual identifiers. As such, ethical approval for human subject research from the Institutional Review Board of the respective institutions was exempted.

### Consent to publish

Not applicable

### Availability of data and materials

The data that support the findings of this study are publicly available from the National Institute of Statistics in Mexico [<http://www3.inegi.org.mx/sistemas/microdatos>] and from the Mexican Population Council [<http://conapo.gob.mx/es/CONAPO/Proyecciones>].

### Competing interests

The authors declare that they have no competing interests.

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### Author's contributions

TR and JMA conceived the study and performed the demographic and statistical analyses. All authors interpreted results. JMA and TR drafted the initial manuscript. The three authors contributed to revising the manuscript. All authors approved of the final version.

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# Figures

**Figure 1** State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015.

Source: calculations based on INEGI and CONAPO files.

**Figure 2** Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015.

Source: calculations based on INEGI and CONAPO files.

**Figure 3** Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84).

Source: calculations based on INEGI and CONAPO files.

**Figure 4** Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015.

Source: calculations based on INEGI and CONAPO files.

**Figure 5** State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015.

Source: calculations based on INEGI and CONAPO files.

#### Additional Files

Additional file 1 — Supplemental material



Figure 1

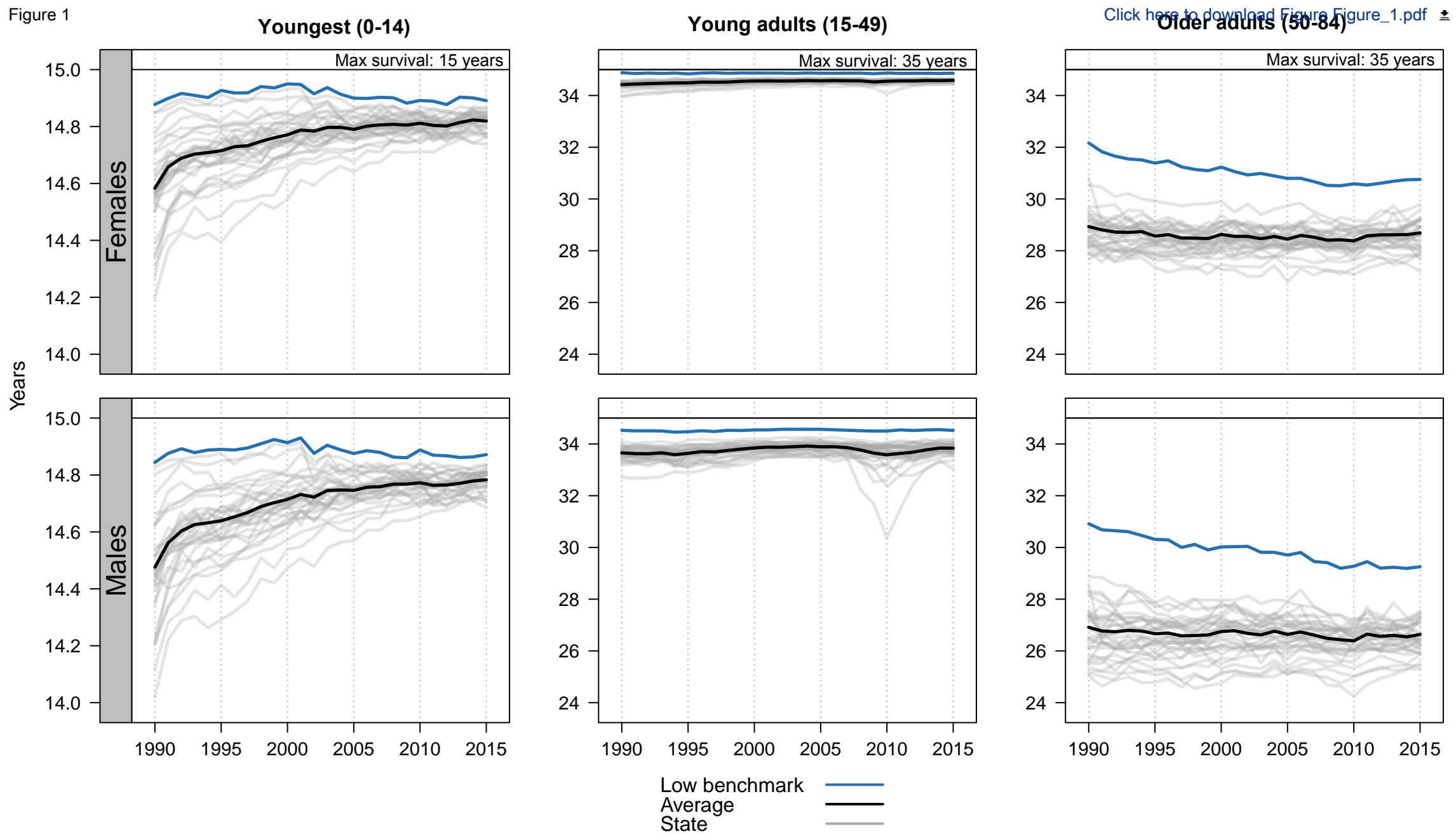
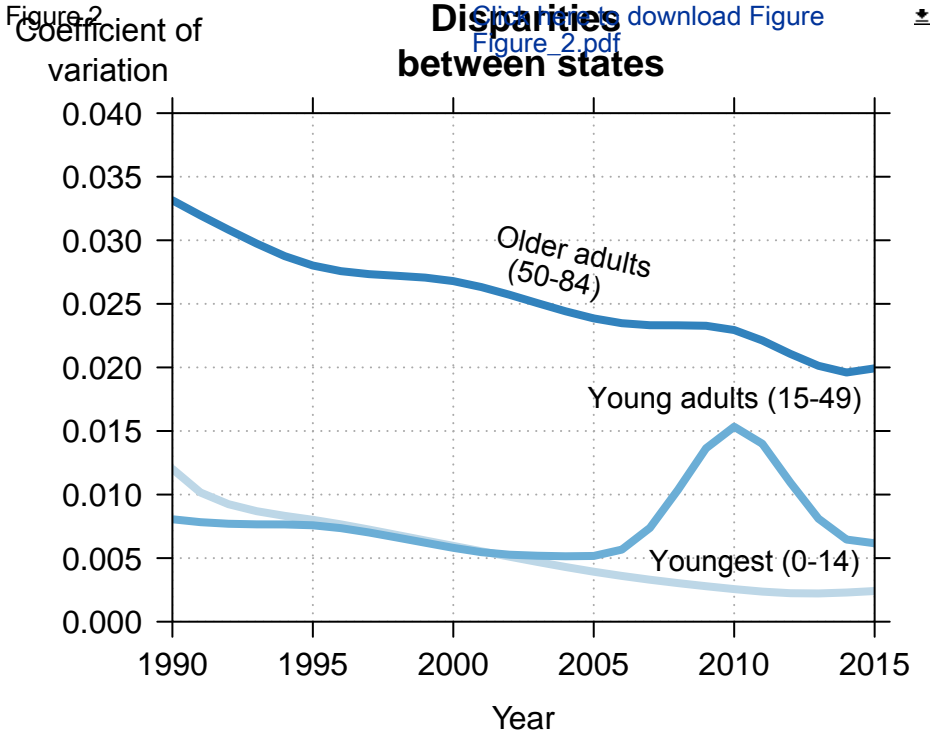
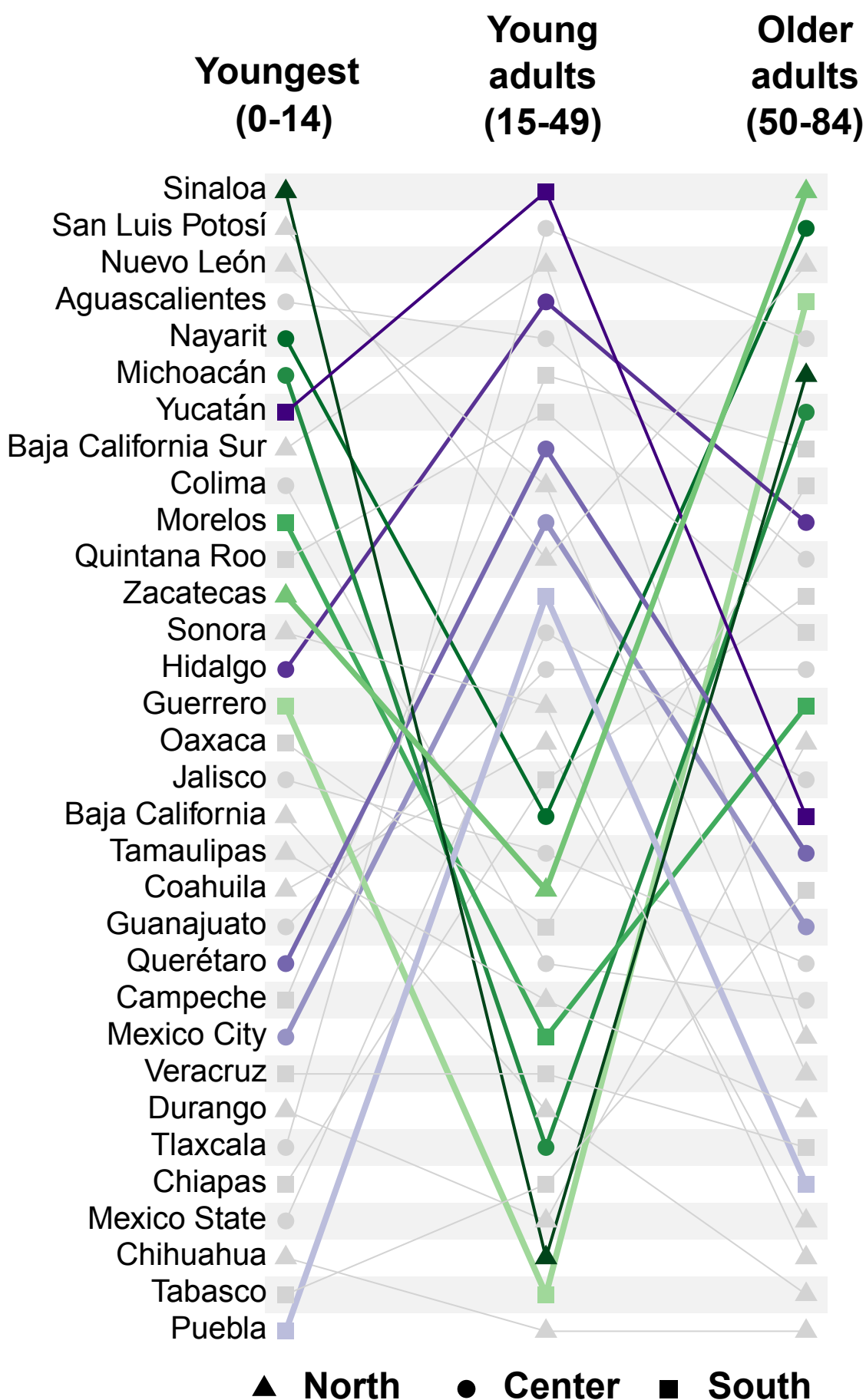


Figure 2



# Discordant age-rankings



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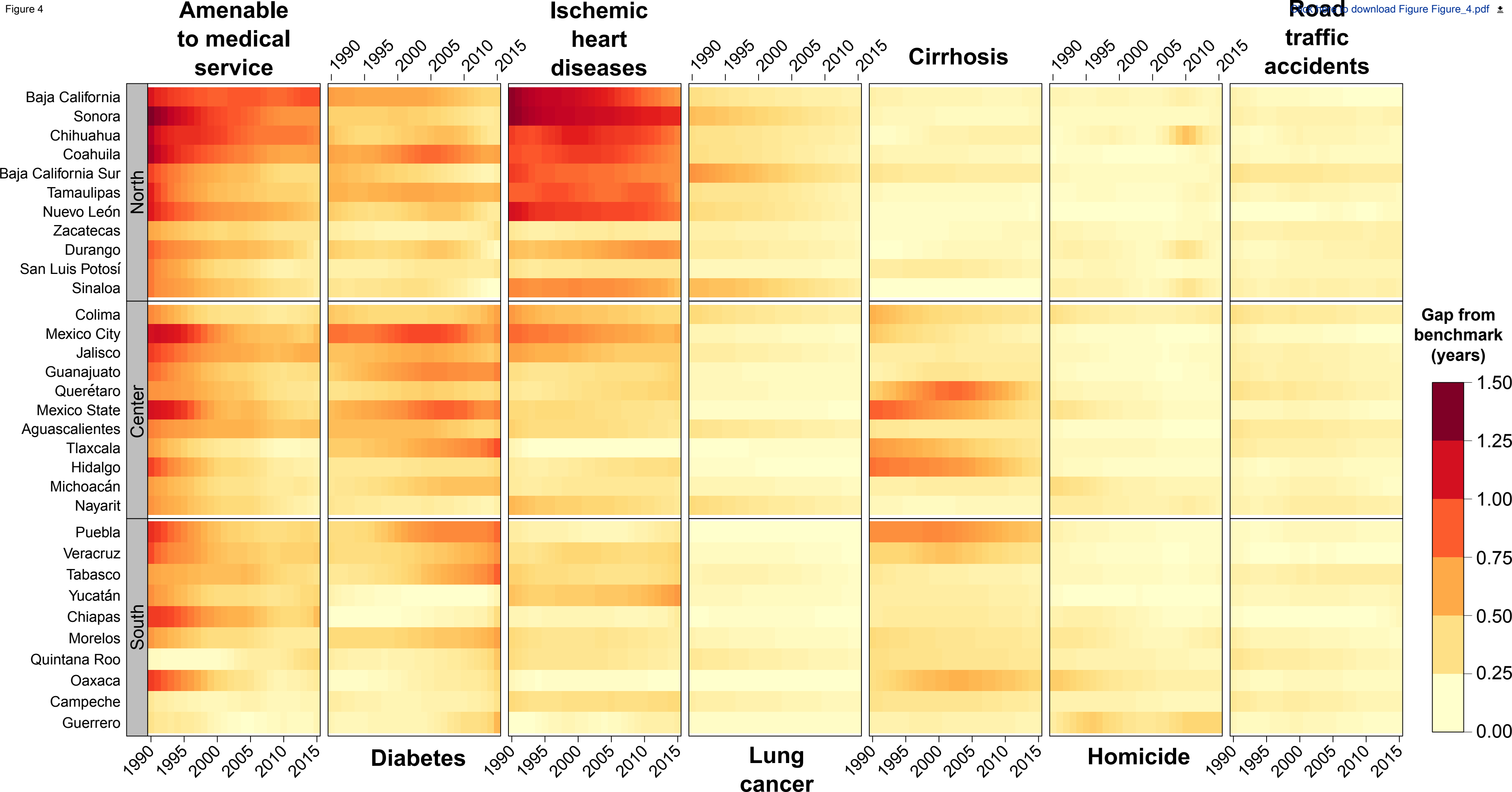
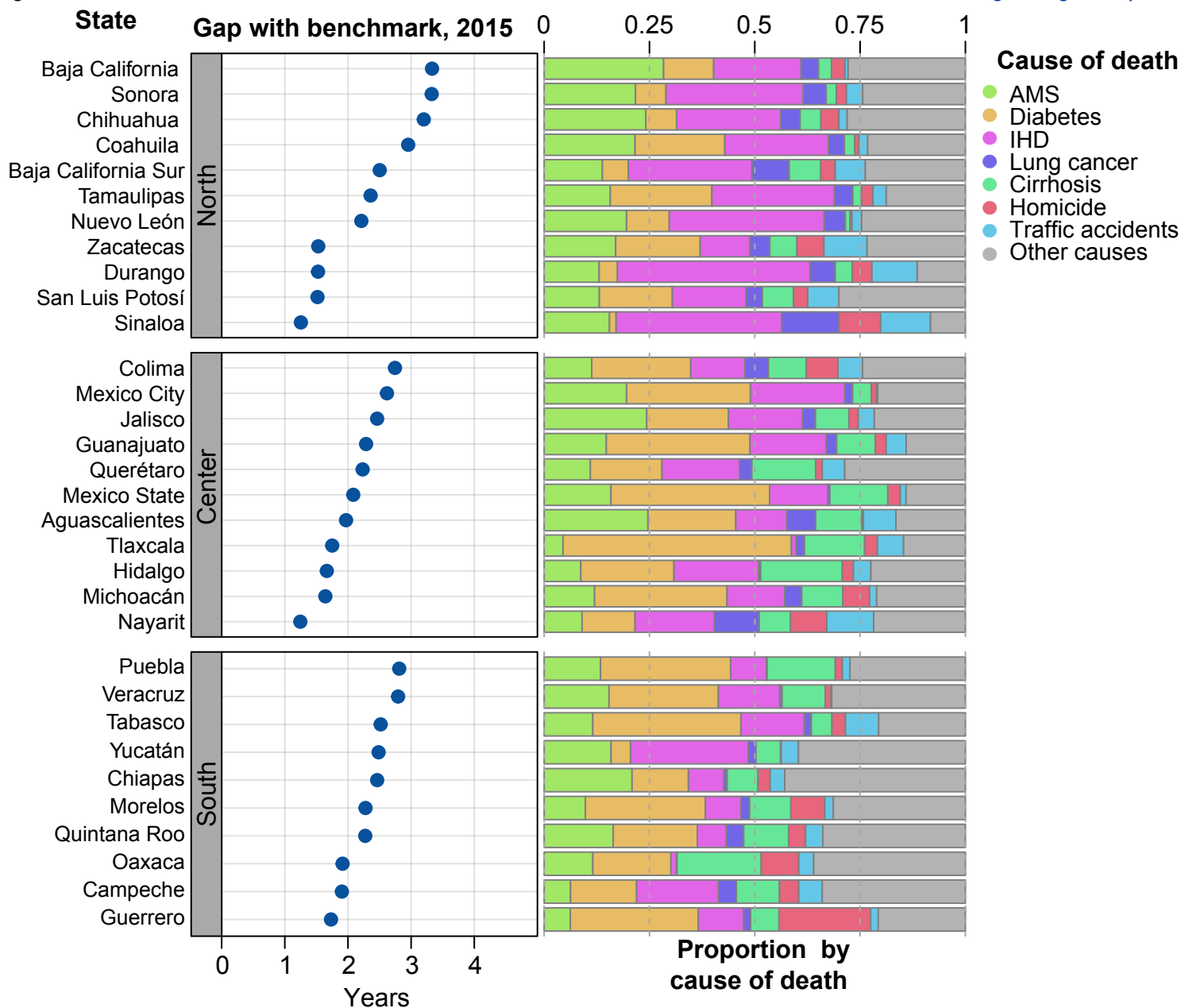



Figure 5

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