Trends and patterns of geographic variation of mortality by causes of death for Small Areas in Brazil, 1990-2010[1]

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Abstract

Background
The efficient planning of public health policies requires, in advance, adequate knowledge of mortality levels. Also, it is important to have patterns and age structure of causes of death by geographical areas. In recent years, several studies have sought to obtain adequate mortality estimates for small areas in Brazil (Queiroz, et.al, 2017, Schmertmann & Gonzaga, 2018, Lima and Queiroz, 2014, among others). Obtaining these estimates allows us to advance in mortality studies in Brazil and to better understand regional and time differentials. A portion of the mortality differential in Brazil is associated with the social and economic conditions of each locality, however, differences in the profile of the causes of death strongly affect the rate of change in mortality.

Objectives
The main objective of the project is to produce estimates of mortality from causes - neoplasms, cardiovascular diseases, external causes, respiratory diseases and infectious diseases - for small areas in Brazil from 1990 to 2016 and to analyze the spatial evolution of mortality by causes of death.

Data and Methods
We use data from the System Data Mortality Information (SIM-DATASUS). We focused on the period from 1990, since as of that date Brazil adopts the and IX th and Xth version of the International Classification of Diseases (ICD). The paper proposes the combination of demographic and statistical methods to obtain robust estimates of mortality by sex, age and causes of death for small areas in the country.

Contributions
In this paper, we investigate the four main causes of death for small-areas in Brazil from 1990 to 2010. We find that despite improvements in overall mortality level for the country, there is a large between-areas differences for every cause of death, although geographic patterns varied substantially by cause of death. The approach to county-level analyses with small area models used in this study has the potential to provide novel insights into Brazilian disease-specific mortality time trends and their differences across geographic regions and could be a valuable contribution to public health planning.

1. Introduction

In the last decades, Latin America has experienced an accelerated decline in infant, child and adult mortality. The median gain in life expectancy at birth between 1950 and 2010 was about 15 years, a much faster process than in developed countries. In 1950, life expectancy at birth in the region was 51 years, reaching 67 years in 1990 and more than 70 years in 2010. However, rates observed around 2000 in several Latin American countries were similar to observed rates in the US and Canada. in the 1950s (Palloni and Pinto, 2011), thus showing that there is still room for improvement in terms of life expectancy in the region. In addition, there is a wide variation in levels of mortality and life expectancy among and within the countries of Latin America.

Brazil followed a similar path. There are signs of convergence in infant mortality among the regions of Brazil, as infectious diseases have reduced their number of deaths, but there are still great differentials in life expectancy at birth and adult mortality in all Brazilian regions (Castro and Simões, 2009; França, et.al, 2017). Recent studies (França, et al, 2017; Borges, 2017) analyzed the states of the federation (UFs) or large regions and also show how changes in the pattern of causes of death impact the evolution of life expectancy at birth and the mortality differential observed in the country. However, the Brazilian regions are also marked by large inequalities and the understanding of this dynamic in smaller areas is fundamental for demographic and public health studies.

Estimates of small areas, however, are affected by data quality problems and the rarity of events. Recent research for small areas mortality by causes of death (Baptista, Queiroz and Rigotti, 2018; Pinheiro and Queiroz, in press) analyze independent causes of death and there is no analysis of the set of causes and compatibility of the results. Ross, et.al (2018) estimate the burden of HIV and TB for municipalities in Brazil under the Global Burden of Diseases project (França, et al, 2017). They use a Bayesian spatially explicit mixed effects regression model (Dwyer-Lindgren, et.al, 2016) and find large inequality across states and regions of the country. We propose in this paper, a methodology that combines a more detailed demographic method (relation model) with spatial analysis.

The main objective of this paper is to produce estimates of mortality by causes of deaths - neoplasms, cardiovascular diseases, external causes, respiratory diseases and infectious diseases - for small areas in Brazil from 1990 to 2016, based on data from the Mortality Information System of Datasus, and analyze trends and patterns overtime and space. We focus on these specific causes for they represent the majortiy of deaths observed in the country and have an interestig variation over the life cycle. That is, we investigate deaths that are concentrated at younger ages, prime-age adults and older ages.

We find that the quality of mortality data in Brazil and regions is improving over time, and a large part of the country shows almost complete coverage of death counts. The improvement is mostly explained by public investments in collection health data. Sex differentials in mortality remained high over the period of analysis due to the increase in external causes of deaths especially among males. This increase also explains the high concentration of male adult mortality in some areas of the country. More important, we observed a convergence process for causes of deaths across regions in the country and our proposed method to estimate complete age profiles for small areas by causes of death seem to be very robust.

2.Literature Review

Followed by a rapid mortality transition from high to low levels, Brazil also experienced a rapid epidemiological transition (Prata, 1992; Borges, 2017). However, the latter process did not follow the same pattern as that verified in most industrialized countries and other Latin American countries, such as Chile, Cuba, and Costa Rica (Prata, 1992; Schramm et al., 2004, France et al. 2017, Borges, 2017). Empirical evidence shows that there is overlap in transitional states of health, the persistence of infectious diseases (eg dengue, cholera, malaria, etc.) in parallel with the increase mortality rates by chronic and degenerative diseases. Thus, there is no linear pathway across all stages of the epidemiological transition, leaving it in the counter-transition state (Schramm et al., 2004; Frenk et al., 1991, França, et al., 2017; Borges, 2017). In addition, the two morbidity-mortality groups are also at high levels, characterizing themselves as a long-term transition process. Also, there are contrasting epidemiological situations in different regions of the country, also creating a scenario of epidemiological polarization (Schramm et al., 2004, Frenk et al., 1991, France, et.al, 2017 and Borges, 2017).

The spatial pattern of mortality by cause, specifically for small areas, is still less well known. Most studies on the causes of death have focused on the whole country, large geographic regions (Southeast, Northeast, etc.), or very specific municipalities in Brazil (Nowbar et al., 2014; Rasella et al., 2014; Guimarães et al., 2015, Borges, 2017, França, et al., 2017). There is an absence and need for studies on the variation of causes of death mortality in time and space. This study is relevant since public health policies and well-being must be spatially designed and focused to serve an aging population subject to varying risk of mortality from different causes.

In recent years, there has been increasing interest in identifying regional differences in mortality, and causes of death. Barbieri et al. (2015) analyzes regional trends in adult mortality in the US from 1959 to 2004. The study shows that the decline in mortality in the late 1960s was unexpected but also widespread and driven by declining mortality from cardiovascular disease. In the same direction, Roth et al. (2017) estimated age-standardized mortality rates for cardiovascular disease among US counties between 1980-2014 and found extensive spatial disparity. They observed large differences among municipalities in mortality rates. Fenelon (2013) investigates the divergence in adult mortality rates for the American states between the 1960s and 2000s. He observes different levels of mortality variation that lead to an increase in the differential between North and South states. The results indicate that part of the divergence is explained by smoking-related mortality. Mokdad et al. (2017) investigate mortality from neoplasms in American counties and note that despite the decline in cancer mortality in the United States, there is substantial regional variation in overall mortality decline patterns and mortality from specific types of cancer. Dwyer-Lindgren et al. (2017) analyze the life expectancy differential in the American counties between 1980 and 2014. The results indicate persistent and large differentials related to issues of health access, health behavior and social and economic differentials.

In the case of Brazil, Baptista, Queiroz and Rigotti (2018) analyze the recent evolution of mortality due to cardiovascular diseases and decompose the effects of changes in levels of mortality rates and age structure of the population. They note an increased concentration of high mortality rates from this disease in the Northeast. Along the same lines, Pinheiro and Queiroz (in press) estimate mortality rates for motorcycle accidents in small areas and observe a concentration in the frontier areas of the country and the interior of less developed states. In common, the two papers on Brazil combine statistical and demographic methods in the analyzes. Schmmertman and Gonzaga (2018) proposes a Bayesian method to estimate data quality and mortality rates for small areas in Brazil in 2010. The methodology allows to properly evaluate the data for small areas and obtain more robust estimates. Queiroz et al. (2018) analyze the differential of adult mortality between 1980 and 2010 in Brazil and observe, as for the US, how social and economic factors influence trends in time and space.

Kulkarni et al. (2011) argue about the importance of regional mortality and health studies as guiding points for public health policy planning and health system coverage. In their analysis, based on recent data from the United States, the authors show that there is an enormous variability in life expectancy between sites, with some showing mortality rates much higher than those observed in other developed countries. Similar research by Kibele, et al. (2015), in Germany, shows that the factors that explain the variation of mortality in the past are still affecting the regional mortality variation present in the country. We argue that small areas in Brazil are, like the United States and Germany, characterized by differences in mortality for various reasons, and there is also a growing demand for adequate health policies given the current aging process of the Brazilian population. Thus, it is important to develop research that seeks to understand the evolution of mortality, its determinants and variations over the last years.

3.Methodology and Data

3.1Death Counts and Population Data

We make extensive use of the Ministry of Health database, DATASUS (http://www2.datasus.gov.br). The database provides information on deaths, causes of deaths, by age and sex at the municipality level. The data are available since 1979, but we use information from 1990 to 2016. Mortality data is organized using codes from the ICD Revision (9th from 1980 to 1995 and 10th from 1996 on). Data cleaning and compilation is done at the municipal, provincial and state level, and an electronic data file is transferred to the national office every 3 months. Population by age and sex, at the local level, comes from the Brazilian Censuses (1980, 1991, 2000 and 2010) and from IBGE estimates for periods after the census.

The original data is available at the municipality level. The main limitation in using city level data in Brazil is that the number and composition of cities change over time. In 1980, there were 3974 municipalities and in 2010 there were 5565. To avoid problems using this information, we aggregated municipalities by comparable small areas, using the IBGE definition of comparable mesoregions. The mesoregions serve only for statistical purpose; therefore, they do not represent a political or administrative entity. The main advantage of working with these geographical areas is that they have not changed their boundaries over the period of analysis and they are areas with regional and socioeconomic similarities. Mesoregions are stable and comparable over the period of analysis. By doing this, we are able to follow and study over 500 small areas in Brazil from 1990 to 2016.

Ministry of Health data, Datasus, is publicly available. Historically, states of the North and Northeast observed lower coverage and worse quality of death declarations in relation to the states of the Southeast and South (Queiroz, et.al 2017, Lima and Queiroz, 2014, Agostinho and Queiroz, 2010). However, since the 2000s, there has been an impressive improvement in both conditions (Queiroz, et.al 2017, Lima and Queiroz, 2014, Agostinho and Queiroz, 2010). The improved quality of mortality information in the North /

Northeast has radically altered the trends, mainly due to noncommunicable diseases. We are using data from 1996 to 2016. Several articles argue and show that the quality of the information has improved since it allows an adequate comparison between the regions (Guimarães, et al., 2015, Borges, 2017; França, et.al, 2017; Ross, 2018)

3.2Mortality Estimates

In a recent paper, Queiroz, et.al (2018) estimated mortality levels for mesoregions in Brazil from 1980 to 2010. The paper uses three-step procedure to estimate mortality in small areas when data is defective. First, we apply a standardization technique to smooth rates in small areas. Second, we obtained measures of completeness of death counts coverage through the Death Distribution Methods (Hill, 2017; Hill, You and Choi, 2009; Queiroz, et.al, 2017, among others). Finally, we perform a bottom-up adjustment to make sure that adding up death counts at the local level we obtain the total number of deaths in each state and the country.

An alternative to indirect standardization technique is more flexible statistical estimation method, as proposed by Gonzaga and Schmertmann (2016), that combines Poisson regression with the TOPALS relational model (De Beer, 2012). The method can be applied for any small areas and allows to built complete schedules of sex and age-specific mortality rates via mathematical adjustments to a specified standard schedule without assuming a fixed age pattern of mortality rates for small areas (Gonzaga and Schmertmann, 2016). Later, Schmertmann and Gonzaga (2018) also proposed a Bayesian model to evaluate quality of data and estimate mortality levels for small areas in Brazil. Their method combines traditional demographic methods and Bayesian statistics to produce robust estimates.

The first step of the analysis is to adjust death counts if there is under-registration. We use the same adjustment factor for each cause of death. We combine a variety of analysis to produce estimates of mortality by sex, age and causes of deaths for small areas in Brazil.

3.3.Indirect Standardization

An additional problem to the quality of death records, especially for studies involving small areas, is the question of random fluctuations and problems arising from small numbers. Typically, estimates of rates in small areas suffer from a small number of events, which subsequently reflects in unstable rates along the age distribution (BERNADINELLI and MONTOMOLI, 1992; ASSUNÇÃO et al., 2005). Such a problem becomes ever larger as the unit of geographic analysis is reduced and the number of events becomes even rarer (POLLARD, 1970; WASHINGTON STATE CENTER FOR HEALTH STATISTICS, 2001). In this sense, it is important to develop new ways of obtaining estimates of the degree of coverage of vital records, free from these fluctuations and problems. The first set of estimates used observed number of deaths and applies a simple indirect standardization. We use state level age-specific mortality rates by causes as standard to estimate local level rates.

Standardization can take place in two ways: direct (direct standardization) or indirect (indirect standardization). Which of the two uses will depend on the information available and, above all, on what is intended to be done.
In the case of direct standardization, it is necessary to have the total of events, distributed by age groups, and the age distribution of the study population. In this paper, the standard age structure will be that of Brazil, year 2010. In this way, it will be possible to compare crude mortality rates obtained by micro-region to conclude on the differential level of the variable studied here, since they will only reflect the differences the specific rates of the variable in the analyzed populations. Therefore, using the direct standardization technique, it is as if the crude rates of the various populations of the Brazilian microregions had the same age composition, but each one maintaining its own specific rates, that is, it standardizes the population structure of the population and leaves the mortality by different causes of deaths observed in each locality.

3.4 Empirical Bayesian Models

For our second set of estimates, we propose the application of the empirical Bayesian estimator, whose initial idea developed by Marshall (1991) was the use of a contraction estimator for under-5 mortality rates in census tracts in Aukland, New Zealand. The central objective of the method is to smooth the random fluctuation of mortality rates by approaching an observed rate in a given area smaller than an average global rate or even at an average rate of the neighboring sectors, considering the population size of the area question.

However, the crude rates observed in small municipalities are not indicated for this type of analysis, since they can be influenced by random fluctuation and complications of calculations due to small numbers. Thus, we incorporate location into the empirical Bayesian estimator by defining neighborhood structures for each area. The definition of the neighbors of each observation will serve as the basis for the definition of a priori parameters. That is, the rates of the small areas, mainly, will converge towards the average of the rates of their neighbors. In relation to the global approaches, the estimate that considers the local average of the neighbors will present a spatial smoothness closer to the reality of the events of interest

In this paper, we chose the James-Stein empirical Bayesian estimators, proposed by Marshall. In this model, the estimators are defined according to equations 1 and 2:

$$\hat{\theta} = \tilde{m} + \tilde{C}_i\,(x_i - \tilde{m}) \quad (1)$$

$$\tilde{C} = s^2 - \frac{\tilde{m}}{\bar{n}} / (s^2 - \tilde{m}/\bar{n} + \frac{\tilde{m}}{n_i}) \quad (2)$$

Where, θ = m, when s^2 <m / n¯. C is the contraction factor; m is the average of xi; xi is the crude rate at i; s^2 is the sample variance of xi; and ni is the number of person-years at risk.

To implement this methodology, we used GeoDa software 1.6.7. Through it a simple neighborhood structure was defined, that is, the criterion "k-Nearest Neighbors" ensures that each microregion has the same k number of neighbors. It is often reasonable to consider that similar areas have similar disease patterns. Thus, the so-called local approach uses the information from the neighbors of each observation as the previous parameters for the adjustment of θ. In this sense, θ is estimated by the contraction of xi towards the mean observed in its neighbors In this paper, we use k = 8. Simulations with different numbers of neighbors did not present significant changes in results.

<u>3.5 Topals Relational Model</u>

Gonzaga & Schmertmann (2016) proposed a model for estimation and smoothing of mortality rates for areas with low numbers of people exposed to death and, therefore, with excessive variation in mortality rates estimated by sex and age. The technique is based on a relational model that estimates and smoothes the specific mortality rates for any municipality in Brazil (Gonzaga & Schmertmann, 2016). Although it requires a standard that describes the behavior of age rates, the proposed technique is not sensitive to the choice of this standard, making the model very flexible for application in any area whose observed rates vary greatly in age.

The proposed method, called TOPALS regression, is a Poisson regression model based on De Beer's (2012) proposal for smoothing and projecting death probabilities. Gonzaga & Schmertmann (2016) proposed a method that estimates the logarithm of mortality rates by sex and age (0, 1, 2, ..., 99+) for all Brazilian municipalities based on the following relational model:

$$\underset{101x1}{\lambda(\alpha)} = \underset{101x1}{\lambda^*} + \underset{101x7}{\mathbf{B}} \underset{7x1}{\alpha}$$

Where λ is a vector of the logarithm of mortality rates in a small area of interest; λ * is a vector of the logarithm of the standard mortality rates; B is an array of constants where each column is a B-Spline linear function (De Boor, 1978, Eilers; Marx, 1996) and α is a vector of parameters to be estimated representing deviations from the mortality curve to be estimated in relation the standard curve. The ages 0, 1, 10, 20, 40, 70, 100 were arbitrarily defined as points of nodes of the Spline function. These ages were defined as cut points characteristic of the function of mortality in view of the typical behavior of the function between each of these ages.

In the relational model in (1), the linear function B-Spline (B) is responsible for smoothing the logarithm of the mortality rates between the points of nodes, considering the α parameters estimated based on the standard function of mortality. Thus, for any set of mortality rates (Dx / Nx) and population exposed to risk (Nx), where D and N represent, respectively, the number of deaths and the population exposed at each age x (for x = 0,1 , 2, ..., 99), it is assumed that deaths are random variables that follow a Poisson distribution, such that the logarithm of its likelihood function is defined as:

$$\log L(\alpha) = \sum_x \left[D_x \lambda_x(\alpha) - N_x \exp(\lambda_x(\alpha)) \right] - \sum_{k=0}^{5} (\alpha_{k+1} - \alpha_k)^2 \quad (2)$$

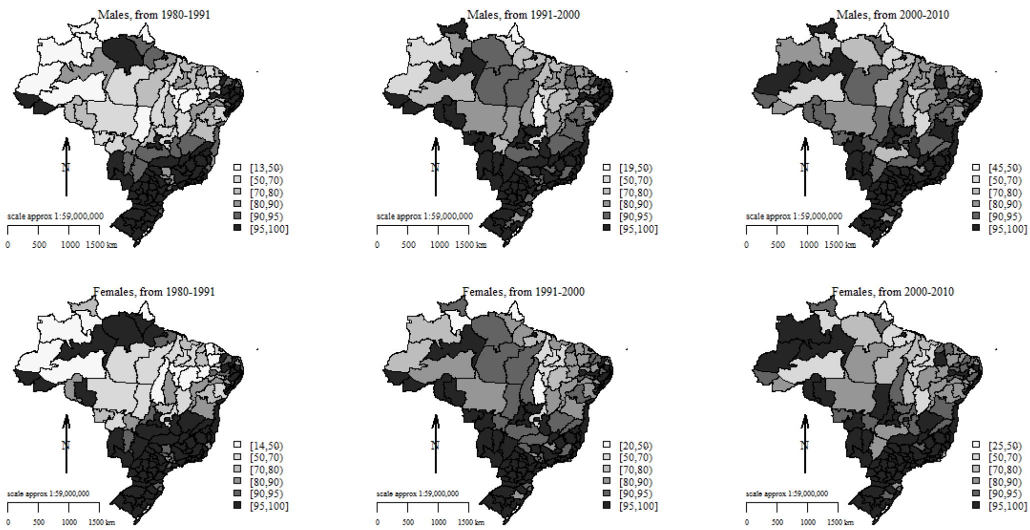
The term given by the summation to the left of (2) aims to penalize very divergent estimates of α thus avoiding an implausible mortality pattern for the area of interest. The assumption translated by the addition of this penalty term into the logarithm of the likelihood function is that very small areas tend to have a structure of mortality rates by age different from the standard, but not too far from what should be a reasonable mortality pattern for human populations and, in particular, to the area of interest.

4. Results

4.1 Evolution of Mortality Data Quality in Brazil

Figure 1 shows the evolution of underreporting of deaths - preliminary estimates - by sex and mesoregion in Brazil from 1980 to 2010. The results were developed from the work of a research group that presented methods and estimates in different publications (Queiroz , et al., 2018, Queiroz et al., 2017, Lima and Queiroz, 2014, Freire, et.al, 2013). We use Death Distribution Methods to obtain the expected number of deaths in the population combined to Topals relationsl model. These methods evaluate coverage of deaths counts in relation to population counts (Hill, You and Choi, 2009). We present the methods briefly, because there is an extensive literature detailing its formalization (Benneth and Horiuchi, 1981; Hill, 1987; Hill, Choi and Timaeus, 2005; Hill, You and Choi, 2009; Dorrington et.al, 2014a; 2014b; Murray et al, 2010). These methods compare the age distribution of deaths with the age distribution of the population and provide the age pattern of mortality for a set period. There are three main methods: general growth balance (GGB), proposed by Hill (1987), synthetic extinct generations (SEG) proposed by Bennett and Horiuchi (1981), and the synthetic extinct generations adjusted (SEG-adj) proposed by Hill, You and Choi (2009). The deaths of distribution methods have strong assumptions: closed population, the degree of coverage of deaths is constant by age, the degree of population count has constant coverage by age and ages of living and deaths declared without errors.

Figure 1 – Quality of Adult Mortality Data, by sex, mesoregions, Brazil 1980-2010.



The results indicate a constant advance in the quality of mortality information in Brazil. The quality of the registry of deaths in Brazil has presented significant improvements in recent years, with coverage of the death registry, for both men and women, above 95%. However, there is still great regional variation. States located in the South and Southeast have records of 100% of deaths, for both men and women. In some states in the Northeast and North, the quality of information is lower, but these have recent significant advances when compared to the period 1991 and 2000. In 2010, all the federative units of the South and Southeast regions, as well as some federative units of the Northeast and Central West, presented complete coverage of the death registry. In addition, there was a great improvement in the quality of mortality information in the poorer federative units of the Northeast and North regions, especially those that had the worst record quality in previous periods.

4.2 Overview of Mortality by causes of deaths in Brazil

Figure 2 shows age-specific death rates by causes of deaths for males in 2010. They highlight the differences of mortality by causes over the life-cycle. We observed a very high level of mortality by external causes of deaths for young adults. Cardiovascular diseases increase rapidly with age.

Figure 3 shows standardized mortality rates by causes of deaths for males, (using Brazilian population age structure as standard). It is quite evident a spatial distribution of mortality by causes across Brazilian small areas. All causes are concentrated in larger and coast cities of the country, specially Neoplasia and external causes. In fact, large Southeast and Northeast cities, especially those in Atlantic Coast has experienced very high violence and transit accident rates (Souza and Lima, 2007; Waiselfisz, 2011; França et al, 2017). Respiratory and Circulatory respond for higher mortality in less urbanized areas.

One should be careful with the scales of each map. They are are different because the aim is to know the Brazilian mortality spatial pattern for some causes of death. We should be cautions with the pattern observed here since data were not adjusted and there are random fluctuation for small areas that might be affecting the observed levels. Figure 3 show a similar spatial pattern for the 4 causes of death presented: mortality rates higher in the extreme northeast, southeast and south. A hypothesis is, except for external causes of death, the other three causes increase with the population ageing.

The problem of the use of crude mortality rates for the analysis of the spatial distribution of diseases, highlighted by authors such as Assunção and colleagues (2012), Carvalho et al. (2012), Justino et al. (2013), Cavalli and Léon (2007), is to a large extent a consequence of the great fluctuation, observed mainly in small municipalities. It is very unlikely that in municipalities with MDRs equal to zero the risk of death of motorcycle occupants is zero. According to Freire (2014), in these cases, a plausible explanation is that the time window was not long enough to record the occurrence of the event of interest. On the other side, we might encounter locations with extremely high mortality rates and a large variations between two points in time. As Assunção and colleagues (1998) point out, due to the small denominator, more or less death can have a significant impact on the estimated rates. This is another indication of the need to other techniques for smoothing rates, the results of which will be presented in the next section.

4.3 Small-areas estimates: empirical Bayesian models

We now present the results of the smoothing process (Spatial Empirical Bayes) of standardized hospitalization and mortality rates. As pointed out before in this paper, the decision to use the local empirical Bayesian estimator for rate smoothing is based on the need to deal with the problem of random fluctuation, which is mainly present in the rates of less populous municipalities. We expect that the estimates of mortality for Brazilian municipalities, after smoothing, will be of superior quality. Thus, the intention is to build better estimates of the risks of dying by different causes of deaths, considering the Brazilian small areas, by sex, to better understand both phenomena. We present the results for the four (4) main causes studied in this paper, for males and focusing on estimates from 1991 and 2010.

Figure 4 shows the estimates for males – but trends for females are quite similar – in 1991 and 2010. We focus on the two extreme years with better data quality. One of the main interesting results is the temporal and spatial trend observed for external causes of deaths. In 1991, highest levels of external causes of deaths were concentrated in Rio de Janeiro, São Paulo and around Brasilia. We also observed very high mortality rates by external causes in frontier areas of the Amazon and Brazilian Cerrado. In 2010, we observed an interiorization of the mortality due to external causes of deaths and an increased in the mortality by this cause in almost all coastal cities of the northeast part of the country.

In relation to cardiovascular diseases, we find that males have higher mortality rates than females in all periods. In addition, for both sexes, mortality rates decline over time, however, while we observe a more homogeneous spatial configuration between sexes, there was a more heterogeneous distribution within the same sex. For males, in the Center-West, South and South-East (except for the northern region of the state of Minas Gerais), we found a decline in mortality by over time. In the North and, specially, across the Northeast regions, and the northern region of the state of Minas Gerais, there was an increase mortality over the years.

In relation to neoplasm, we find that the contribution of neoplasm to overall mortality has increased steadily from 1991 to 2010, for both males and females. The change is closely related to changes in population age structure. Overall, neoplasm are the second major cause of death in Brazil, but from 1990 to 2010 we find that the crude death rate for this cause increased from about 80 per 100.000 to 126 per 100.000. More importantly, if in 1990 the highest level of mortality due to neoplasm was concentrated in the South part of the country, we find a spread of the mortality by this cause to all regions of the country in 2010. In 2010, almost all regions in the South and Southeast parts of the country had very high mortality rate by this particular cause and some areas of the Northeast.

Lastly, for respiratory diseases we find an overall decline in the mortality by this cause for the country. But, most important we observed a convergence process of smoothed crude mortality rate by this cause across different regions of the country. If in 1990, the highest level was concentrated in the more developed areas of the country, we find that in 2010 the levels tend to be very close related instead of the large variations observed in the 1990s.

4.4 Small-areas estimates: Topals relational models

The use of crude death rates, even with a smoother process, might be misleading. In this section, we present alternative estimates of mortality rates by causes by single age of death. Figure 5 presents preliminary TOPALS estimates for males mortality schedules for selected mesoregions within different states in Brazil in 2010. The selection of mesoregions was based on different size of males populations exposed to mortality rates during the period from 2009 to 2010. After smoothing the age-specific rates we correct the level of mortality applying an R package developed by Riffe, Lima and Queiroz (2017). The package called DDM allows to estimate the undercounting of deaths using different Death Distribution Methods (Bennett and Horiuchi, 1981; Hill, 1987; Hill and Choi, 2009). In all graphs of the figure 4 one can see the underlying mortality pattern for each mesoregion. The results confirm that the TOPALS allows estimating the entire schedule of single-year rates even for a relative small exposure (see results for "Norte do Amapá" mesoregion which recorded 28,410 males according to 2010 Census).

Gonzaga and Schmertmann (2016) have demonstrated that TOPALS method is valuable when small areas age pattern of mortality differ. However, they also showed that under the homogeneity assumption about mortality schedule by age, indirect standardization technique works better than TOPALS. In the figure 6 we show the fitted schedule of males mortality rates by age in all mesoregions within four selected Brazilian's state. We choose four states from different large areas of the country. The results showed that assuming equal pattern of mortality rates by age can lead to unreasonable estimates, especially if one is trying to estimate mortality rates by causes that are more prevalent in some specific age interval. On the other hand, using a more simple technique, as indirect standardization, could lead to a similar results.

Figure 7 shows estimates in 2010 for males in Minas Gerais, one of the 27 states in Brazil, for mortality by external causes and cardiovascular diseases. We produced estimates for all states in the country, but due to space limitations we are only showing one state here. We are going to have, in the near future, a web-site with all estimates available to others. The figure shows observed data and adjusted data using the proposed method for single years of age. We also show the standard (Brazil) used in the analysis. The adjusted estimates using Topals is reported with a 95% confidence interval. We observed a very high level of mortality by external causes of deaths for young adults. Cardiovascular diseases increase rapidly with age. For both causes, Minas Gerais mortality rates are below of what was observed in Brazil in 2010.

Figure 8 shows estimates of external causes of deaths by single age in the Sul/Sudoeste de Minas in and the region of Vale do Jequitinhonha in 2010. We also have estimates for all small areas of the country, but opted to show a few examples of how the proposed model fitted to the analysis. The figure shows the Brazilian Standard, the State Adjusted Mortality Rates, the observed mortality rate and the Topal adjusted for the small area. The analysis shows that there are large differences in the mortality by causes across regions both in terms of levels and shapes. This is an important result that helps to explain the difference in life expectancy across regions in the country in recent years.

The model works well for both causes and shows the difference between mortality level at the small-area compared to the state and country. The results also indicates that we can improve our estimates by adjusting the nodes to the profile of the cause-specific mortality. We can also fit with different standard, however Gonzaga and Schmertmann (2016) showed that the model is very stable to the choice of standard.

5. Discussion

In this paper, we investigate the four main causes of death for small-areas in Brazil from 1990 to 2010. We find that despite improvements in overall mortality level for the country, there is a large between-areas differences for every cause of death, although geographic patterns varied substantially by cause of death. The approach to county-level analyses with small area models used in this study has the potential to provide novel insights into Brazilian disease-specific mortality time trends and their differences across geographic regions and could be a valuable contribution to public health planning.

We perform a series of analysis aiming to obtain more robust estimates for cause of death mortality rates for small-areas. First, we use a simple standardize death rates by cause, but this approach has a series of limitations. Second, we used a Spatial Empirical Bayes method trying to obtain more robust estimates, but in this approach we can only focus on crude rates. Lastly, we use the Topals regression approach to try to estimate a complete mortality age profile by causes of deaths for males and females for each small-area of the country. Thus, the results of this study represent more detailed and comprehensive study of Brazilian small-area patterns of cause-specific mortality currently available – as most of studies in Brazil focus on larger areas or one specific cause of death.

We find significative differences over time and regions across causes of deaths in Brazil. This result shows the importance to include a cause-specific analysis for small areas in addition to analyses of all-cause mortality and life expectancy at certain ages. We find, however, that there is a convergence process for non-communicable causes of deaths across regions in Brazil, but there is still a concentration of higher death rates in the more developed and aged parts of the country.

For some causes, we observed an impressive increase in mortality in most areas of the Northeast states. In 1990, there was a concentration of higher mortality rates by cardiovascular diseases in the South and Southeast, but the more recent years observed a rapid increased in the mortality by this cause in less developed areas of the country. More impressive, though, is the spread of mortality by external causes of death (violence and traffic accidents) that were concentrated in the Southeast and are spreading for smaller areas and almost all coastal cities in the Northeast.

The study has some important limitations that have to be taken into account when analyzing the results. First, several regions in Brazil still lack good quality data. There is an issue of under-registration of death counts coverage and limitations in the declaration of the age of the deceased. The quality of mortality data has improved in the period of analysis, but there is still large heterogeneity. Second, information on causes of death have all been improving overtime and across regions in different pace. The percentage of deaths registered as ill-defined has reduced overtime, but they are still quite large for some less developed areas of the country.

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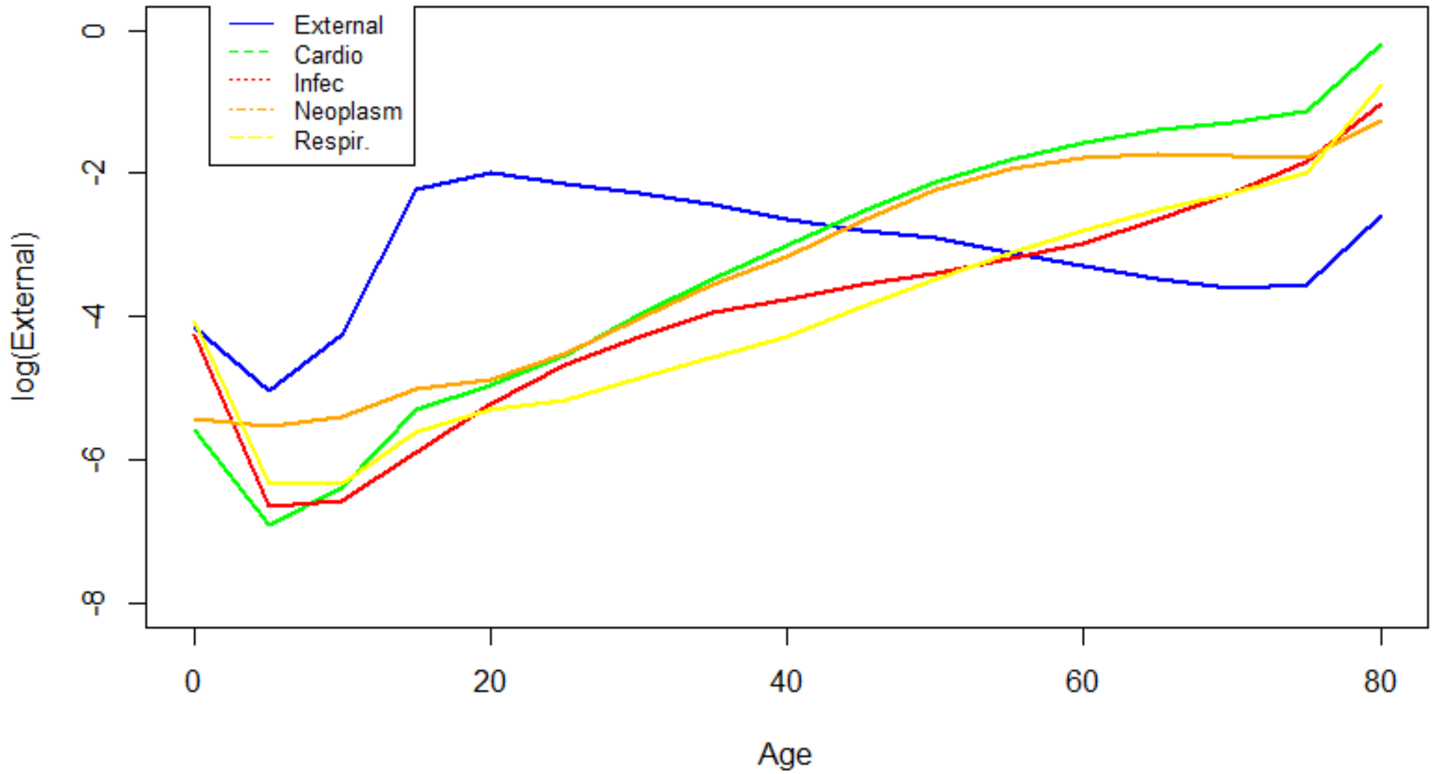
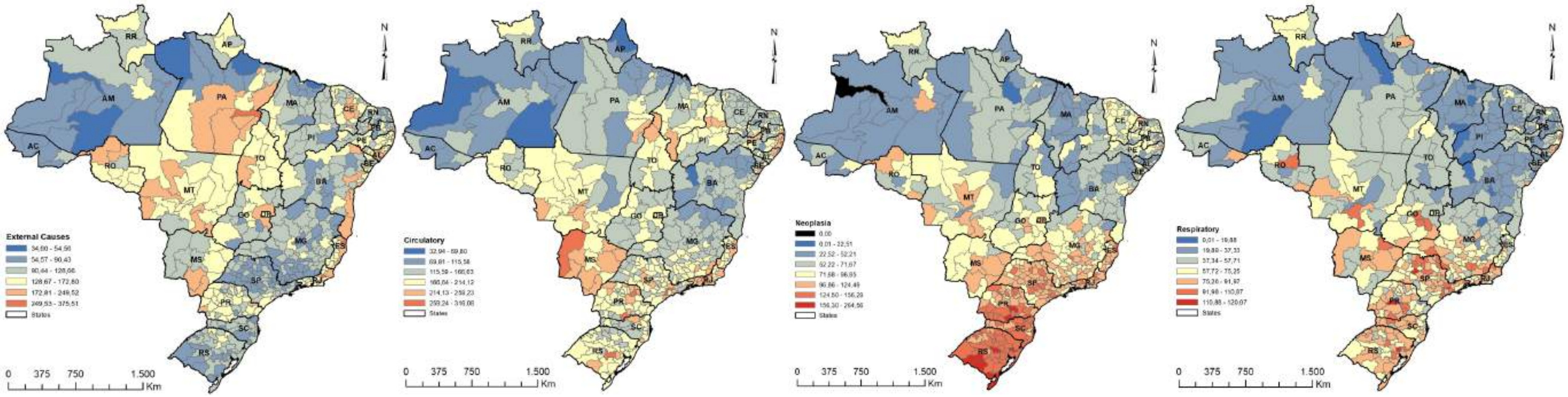
Figure 2 – Age Specific Mortality Rates by causes, Males, Brazil, 2010



Source: Population Censuses (1980, 1991, 2000, 2010), Ministry of Health (http://www.datasus.gov.br).

Figure 3 – Standardized Crude Death Rates, by main causes of deaths (external causes, circulatory, neoplasia, respiratory), Males, Brazil, 2010.



Source: DATASUS, 2018 and Population Censuses (1980, 1991, 2000, 2010).

Figure 4 – Empirical Bayes Mortality rates, by main causes of deaths, males, 1991 and 2010, Brazil and small areas

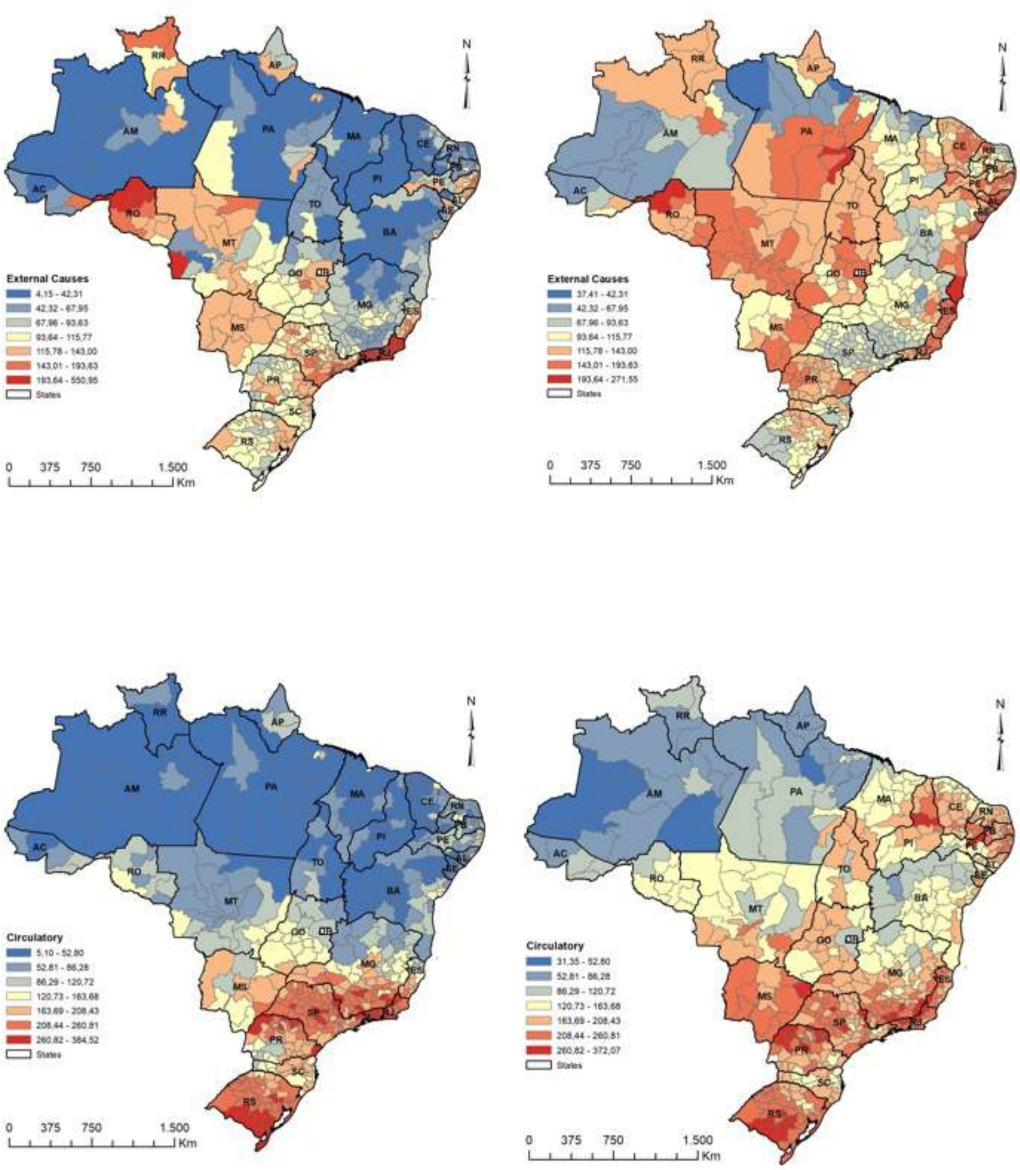


Figure 4 – Empirical Bayes Mortality rates, by main causes of deaths, males, 1991 and 2010, Brazil and small areas (continued)

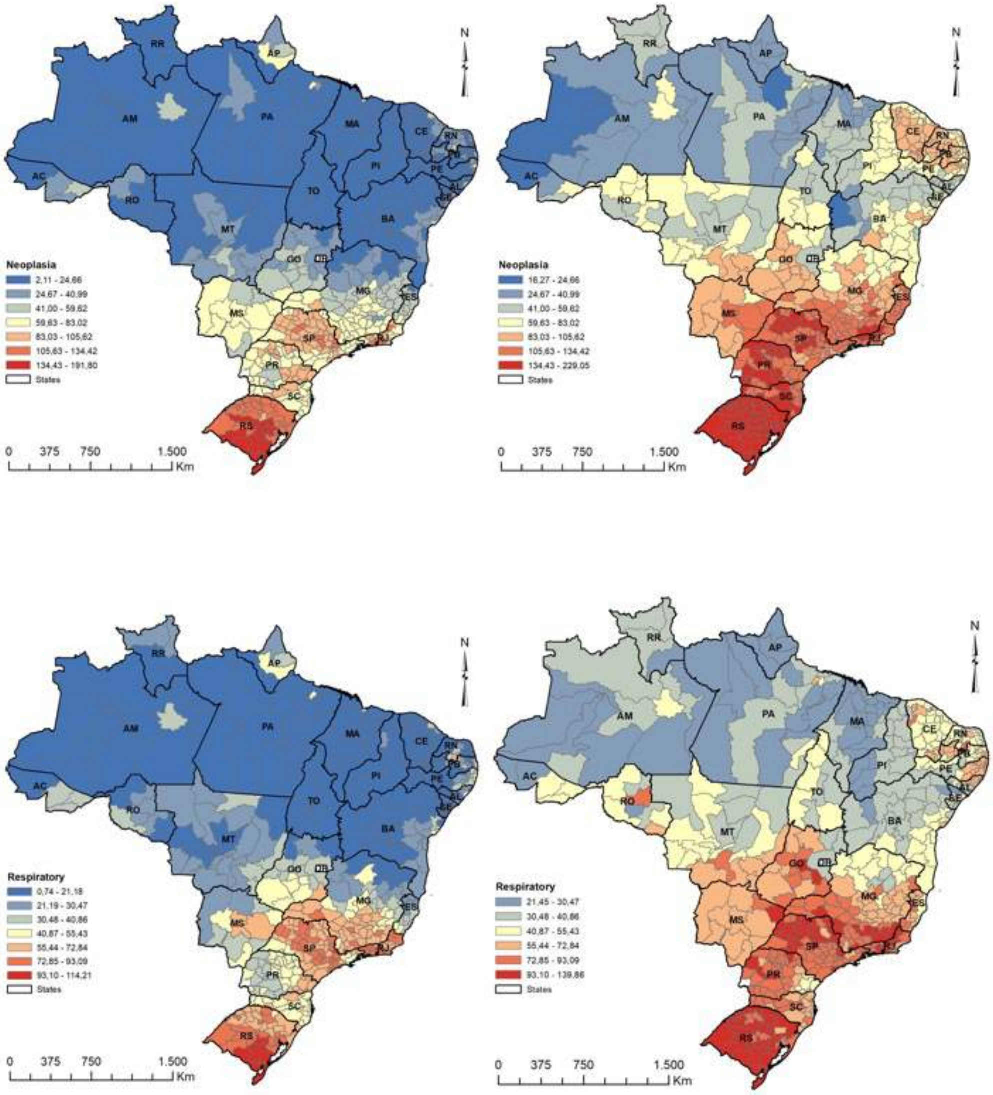


Figure 5 – Maximum likelihood TOPALS fit of log mortality rates by age, males, selected mesoregions, Brazil (2010)
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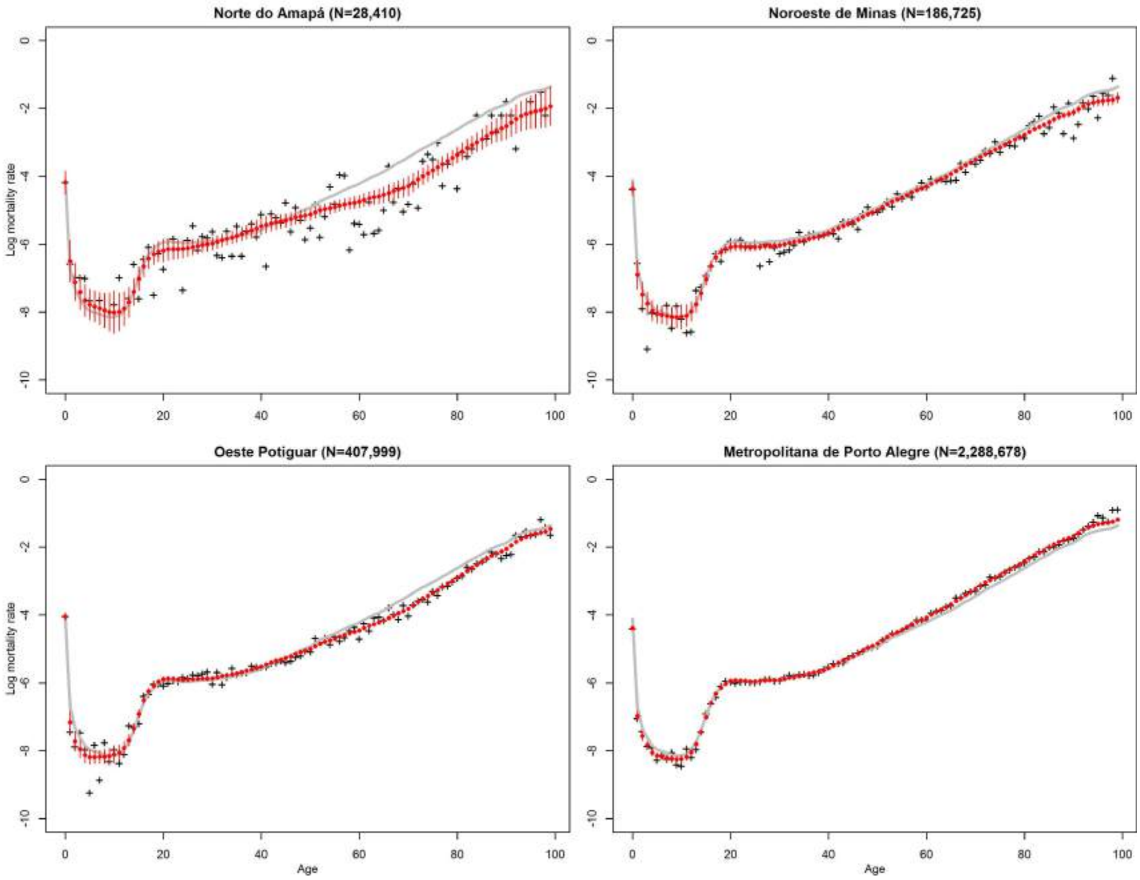
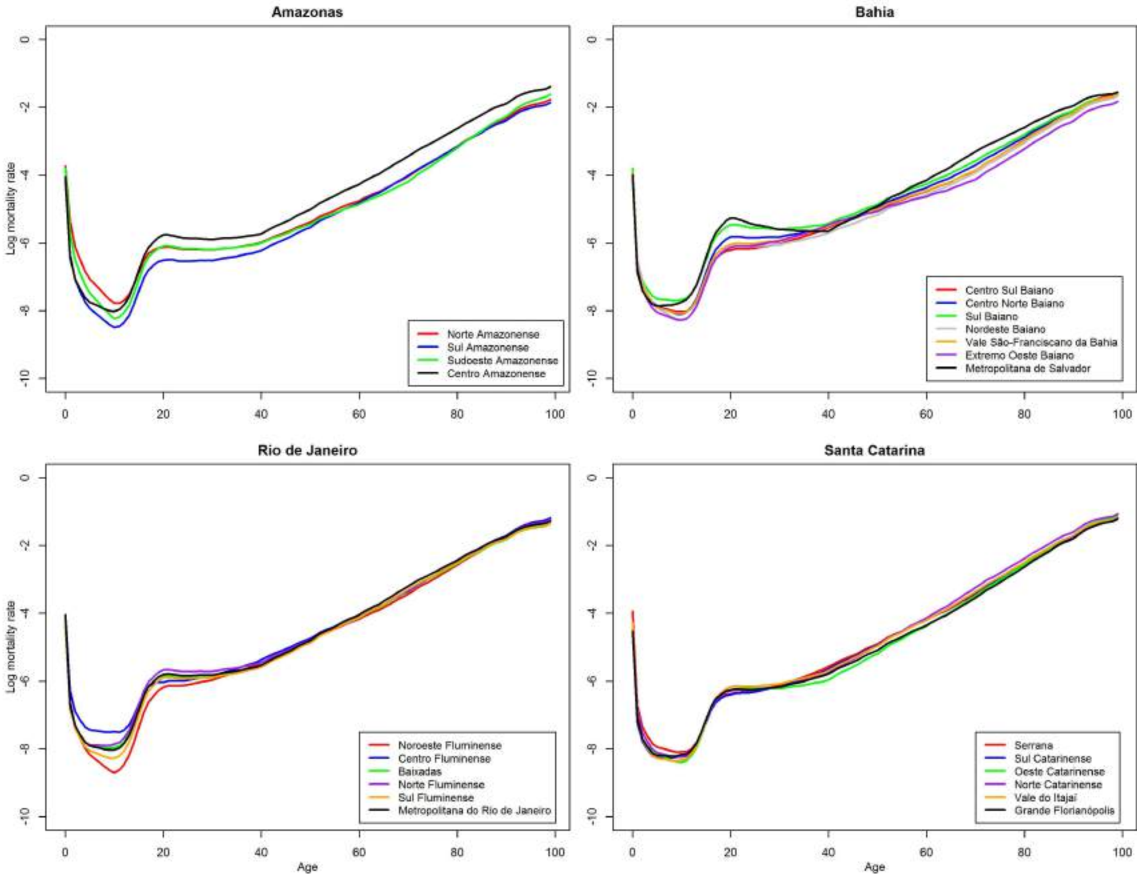


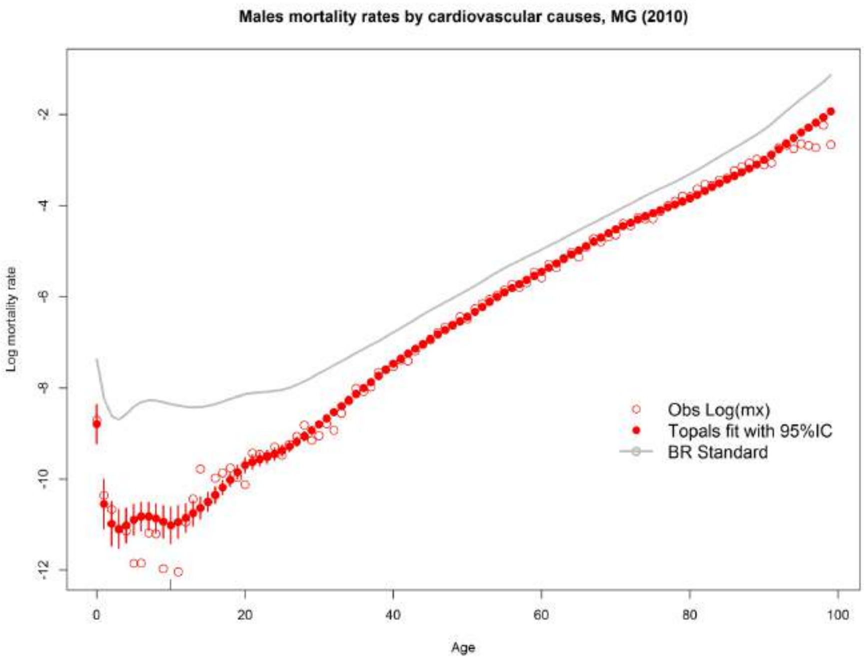
Source: Population Censuses (2000, 2010), Ministry of Health (http://www.datasus.gov.br)..
Note: The symbols “+” represent observed ln(deaths/pop) for each single year of age for three years period around the 2010 Brazilian Census. Red points represent the fitted ln(deaths/pop) by TOPALS method with a 95% Confidence Interval (vertical red segments). The grey solid curve represent the standard schedule for males log mortality rates by age (standard = Brazilian males age-specific log mortality rates in 2010).

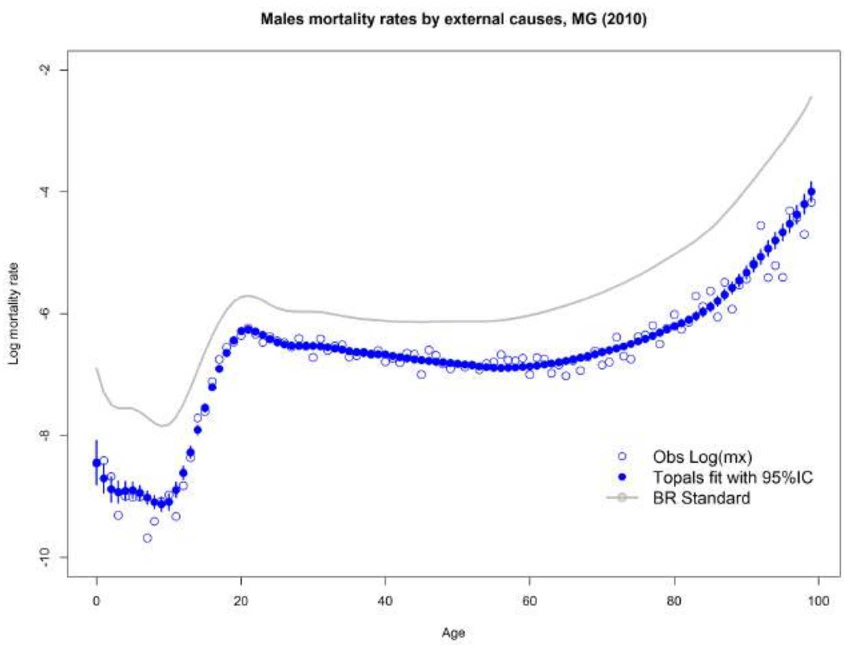
Figure 6 –TOPALS fit of males log mortality rates by age for all mesoregions in selected states, Brazil (2010)



Source: Population Censuses (2000, 2010) and Ministry of Health (http://www.datasus.gov.br)and Ministry of Health (http://www.datasus.gov.br).

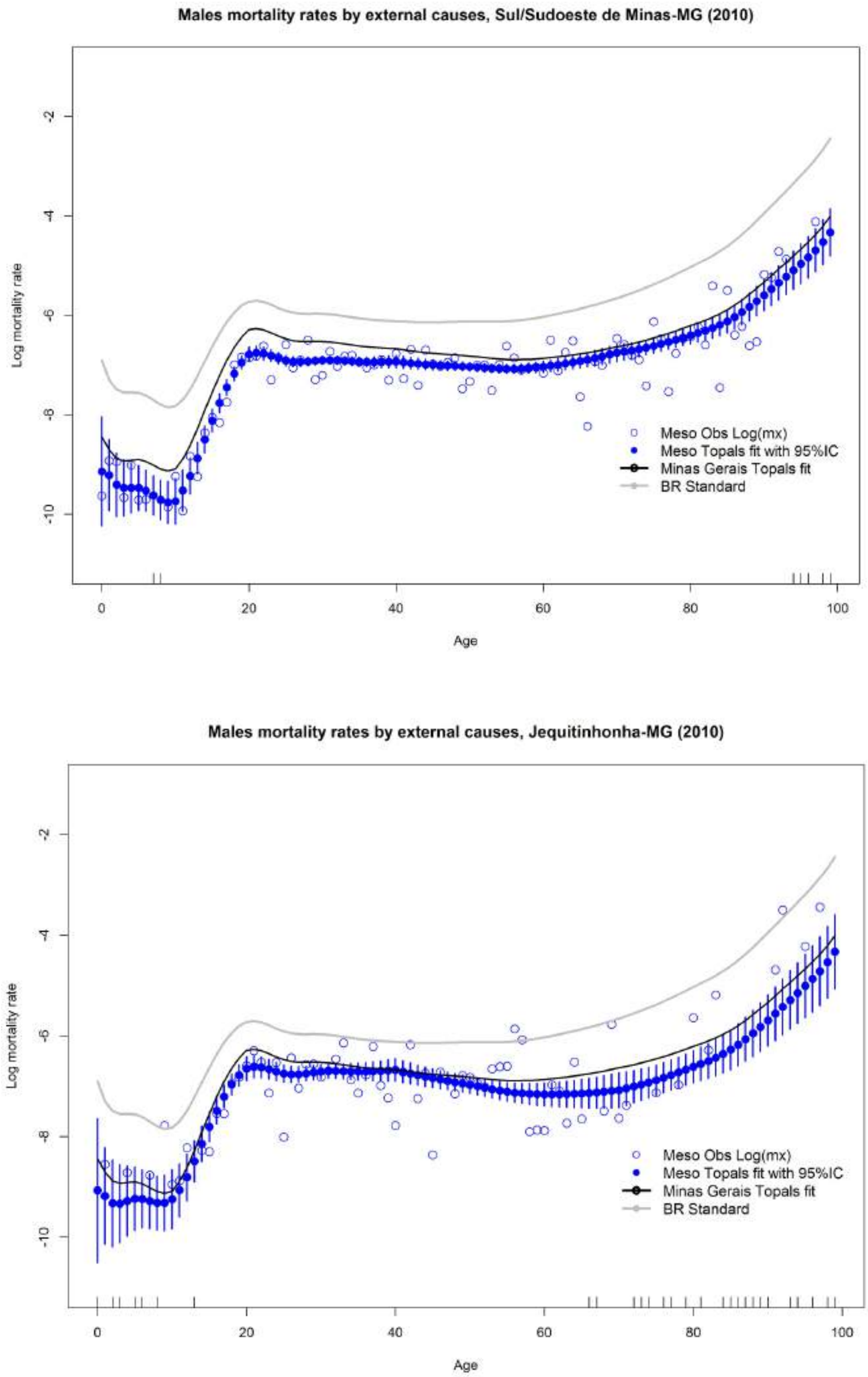
Figure 7 –TOPALS fit of males log mortality rates by age, males, Minas Gerais, External Causes of Deaths and Cardiovascular Diseases





Source: Population Censuses (2000, 2010) and Ministry of Health (http://www.datasus.gov.br)and Ministry of Health (http://www.datasus.gov.br).

Figure 8 –TOPALS fit of log mortality rates by age, Cardiovascular Diseases and External Causes of Deaths, males, Sul/Sudoeste de Minas and Vale do Jequitinhonha (small area in Minas Gerais), 2010



Source: Population Censuses (2000, 2010) and Ministry of Health (http://www.datasus.gov.br)and Ministry of Health (http://www.datasus.gov.br).