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Rural-Urban health and mortality differentials in Brazil, 2010-2013

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Résumé

L'urbanisation et le développement économique dans les pays à revenu élevé ont conduit au débat sur les différences entre la santé et la mortalité dans les zones rurales et urbaines. Les pays à revenu faible et intermédiaire connaissent des processus d'urbanisation inégaux qui se traduisent par une pénalité de mortalité urbaine. Le Brésil est un exemple de scénario de mortalité à l'avantage du rural, malgré l'accès limité aux services de santé en zones rurales. Cet article évalue les écarts de santé et de mortalité dans les zones rurales et urbaines à l'aide des données sur la prévalence de la morbidité tirées de l'Enquête nationale sur la santé de 2013 et des informations sur la mortalité du recensement national de 2010. Les résultats montrent que les résidents urbains ont des taux de prévalence de diabète et de maladie cardiaque plus élevés, tandis que les résidents ruraux ont une prévalence plus élevée de maladies ostéoarticulaires et d'incapacités physiques. Au total, les adultes des zones rurales avaient de meilleurs indicateurs de mortalité que ceux des zones urbaines. Cependant, nous avons constaté qu'une partie importante de la vie d'un individu rural est affectée par des morbidités physiques et musculo-squelettiques. Ces différences entre les espaces urbains et ruraux doivent être prises en compte lors de la prise de décisions en matière de politique de santé.

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Mots-clés
Mortalité, santé, différentiels rural-urbain, espérance de vie, Brésil.

Abstract
Urbanization and economic development in developed countries fostered the debate of rural vs. urban health and mortality differentials. Low and middle-income countries experience uneven urbanization processes that result in an urban mortality penalty. Brazil is an example of this scenario of rural mortality advantage, despite the limited access to health services by rural residents. This paper assesses health and mortality differentials of rural and urban areas using morbidity prevalence data from the Brazilian National Health Survey of 2013 and the mortality information from the Brazilian National Census of 2010. The results show that urban residents display higher prevalence rates of diabetes and heart diseases, whereas rural residents display higher prevalence rates of osteoarticular diseases and functional disabilities. Indeed, adult individuals of rural areas presented better mortality indicators than those from urban areas. However, we found that a significant part of a rural individual's life is affected by physical and musculoskeletal morbidities. These differences between urban and rural spaces need to be considered when making health policy decisions.

Keywords
Mortality, health, rural-urban differentials, life expectancy, Brazil.

Introduction

At the beginning of urbanization and industrialization processes in Western countries, residents of urban areas used to exhibit higher mortality rates than their rural counterparts (Woods, 2003). Living conditions improved in Western cities through socio-economic development and economic growth (Deaton, 2003), however, unequal regional socio-economic development led to health and mortality differentials within countries (Allan *et al*., 2017). In the United States, for example, rural and non-metropolitan residents are more likely to experience lack of access to health equipment, health illiteracy and other kinds of socio-economic deprivation which result in life expectancy and health disadvantages (Chen *et al*., 2019; Henning-Smith *et al*., 2019).

The debate over urban and rural mortality differentials in developing countries is usually divided in two components: infant/child mortality and adult mortality (Garcia, 2020; Menashe-Oren, Stecklov, 2018). Infant and child mortality are more impacted by community-level characteristics and socio-economic situations (Garcia, 2020). In Brazil, for example, urban areas exhibit an under-five mortality advantage in comparison to the country's rural areas, as a result of higher schooling levels and higher access to sanitation and public health facilities (Sastry, 1997).

Despite the urban advantage observed in child and infant mortality levels, most studies documented lower adult mortality rates in rural areas of low-income countries (Menashe-Oren, Stecklov, 2018). Metropolitan regions in developing countries present high within-urban mortality gaps among social groups due to unequal allocation of essential public services and infrastructure, a consequence of rapid urbanization processes that took place over the last 50-70 years. Living conditions in these developing urbanized centers deteriorate individuals' health and expose them to higher mortality risks compared to their rural counterparts, characterizing an urban death penalty (Fink *et al.*, 2016).

These elements of urban-rural mortality debate are documented in several studies of Brazilian mortality differentials. For instance, the advantage of urban environments regarding mortality in Brazil prevails in some specific conditions. Carvalho and Wood (1978) showed that urban-rural life expectancy differentials favored the urban areas of wealthier social strata. In contrast, we observe the opposite in impoverished regions of the country in the 1960-70 period. Using the 2010 National Census mortality data, Albuquerque (2019) verified a mortality advantage for rural areas, especially for men. He estimated 73.6 and 69.3 life expectancy at birth for the rural and urban male population, respectively, and 77.8 and 77.1 years for females. Pereira (2020) disentangled these findings by comparing Brazilian mortality levels of urban residents from slums and from out of slums with rural resident's mortality levels and verified an urban death penalty for those living in these marginalized urban environments. Indeed, residents of the Brazilian periphery of urban metropolitan areas have to deal with damaged social conditions, limited access to basic urban infrastructure and services such as schools, health facilities and public sanitation, as well as high violence and crime rates (Rodella, 2015). Therefore, the adult population from these deprived urban pheripherical areas are more likely to experience worsened health conditions and higher mortality rates (Pereira, 2018; Pereira, Queiroz, 2016).

Regarding health and morbidity profiles, urban residents report higher prevalence rates of good health status than rural residents (Arruda *et al.*, 2018). These differences, however, are influenced by socioeconomic status and when controlling for these variables, rural residents from lower socioeconomic strata are more likely to report being in good health than their urban counterparts (Maia, Rodrigues, 2010). Additionally, male urban residents exhibit higher prevalence of abdominal obesity than males in rural areas (Martins-Silva *et al*., 2019). On the other hand, rural residents have poorer access to health services (Arruda *et al*., 2018) and rural workers are more exposed to physical and chemical risk factors such as physically harming and intense activities or pesticides (Moreira *et al*., 2015).

Despite the debate over mortality and health differentials across and within urban and rural areas, there are no studies in Brazil that address both topics simultaneously. Recent studies brought up the discussion regarding urban-rural mortality disparities (Albuquerque, 2019; Pereira, 2020) and differentials in access to health facilities (Arruda *et al*., 2018). However, these studies did not consider health life expectancy nor looked into the age-specific contributions of mortality and health for the observed differences between areas. In this sense, the rural life expectancy advantage observed in the Brazilian National Census of 2010 (Albuquerque, 2019) may not be followed by a healthy life expectancy advantage, e. g., people from rural areas might live for longer periods, but they would experience a larger share of life with disabilities that can mitigate their capacity to develop daily activities.

This paper aims to provide further evidence to the urban-rural health and mortality debates by applying a joint health-mortality methodological assessment in Brazil and decomposing observed differences among estimated health expectancy across these areas. We use mortality data collected from the 2010 National Census and prevalence data of four specific health conditions collected from the National Health Survey of 2013 and compute estimates for life expectancy and health expectancy for the adult population. Further, we decompose health expectancy differences between rural and urban populations to uncover the health and mortality age profiles of these differences. Our results show that rural residents experience health expectancy and life expectancy advantage. However, for some specific conditions such as musculoskeletal disorders the mortality advantage of rural areas compensates the health condition disadvantages, while for chronic diseases (cardiovascular diseases and diabetes) the health life expectancy differences are the joint result of urban health and mortality disadvantages.

Materials and Methods

Data source

We use data from 2010's Brazilian national census of 2010 and 2013's Brazilian national health survey (PNS) to estimate mortality age profiles and implement further extensions on these functions to estimate life expectancy and health expectancy indicators. Both household inquiries are conducted by the Brazilian Bureau of National Statistics (IBGE).

PNS collects information on access and use of health services, preventive health behavior, and socio-demographic characteristics in order to provide regular monitoring of health indicators, such as chronic diseases prevalence (IBGE, 2013; Szwarcwald *et al*., 2014). The survey's questionnaire consists of three parts: the first part is related to household characteristics, the second part includes questions on socioeconomic conditions and health status of residents, and the third is answered by an adult aged 18 or more from the household and includes questions about lifestyle and morbidity (Szwarcwald *et al*., 2014). The sample of PNS consists of 79875 households selected through a three-stage cluster sampling and is representative at state, capital cities and rural levels (Szwarcwald *et al*., 2014).

The addition of a mortality inquiry in the 2010 Population Census – including questions about age and sex of household deaths over a defined period – expanded the data alternatives to study mortality differentials in the country (FBGE, 2010). Over the last 40 years, Brazil experienced notable progress in death registration completeness levels and data quality, results of improvement of the civil registration and mortality information system (SIM, from portuguese Sistema de Informações de Mortalidade) (Queiroz *et al*., 2020; Queiroz *et al*., 2017). However, the mortality information system managed by the Ministry of Health does not provide detailed information about socioeconomic characteristics of the deceased, thus the mortality enquiry in the census questionnaire is an alternative to the mortality evaluation of different social groups (Ribeiro *et al*., 2017; Silva *et al*., 2016; Pereira, Queiroz, 2016; Queiroz, Sawyer, 2012). In other countries, such as China (Banister, Hill, 2004) and South Africa (Dorrington *et al.*, 2004), the census mortality inquiry has proven to be a useful and reliable source to estimate adult mortality, especially in places where civil registration and vital statistics systems are poorly developed.

It is important to highlight that the delimitation of rural and urban environments in Brazil do not follow concrete rules such as population counts or population density as in other countries (IBGE, 2017; Pera, Mello

Bueno, 2016). In Brazil, municipalities have autonomy for defining which areas are classified as urban and this classification is key to defining property tax payments (Brazil, 1966). Therefore, some authors mention that the «real» rural population in the country is higher than expressed by the local authorities' definitions and captured by National Censuses (Veiga, 2003). Despite this unclear criterion of delimitation of rural environments, we use this definition since the PNS survey is not representative at the level of municipalities and hence, does not allow for the construction of different classification criteria of rural and urban areas comparable to census information.

Data analysis

Our methodological strategy consists of four steps: 1) estimation of essential life table functions for each population group (urban and rural residents) using 2010 National Census mortality data, which involves the adjustment for under-reporting of death counts (Queiroz, Sawyer, 2012); 2) estimation and analysis of disease and functional disability age-specific prevalence data from PNS survey and the 2010 National Census data on disease and disability prevalence; 3) construction of disease/disability-free life expectancy indicators (also known as health expectancy) for each population group; and 4) decomposition of health expectancy differentials among rural and urban populations in terms of overall mortality profiles contribution and specific morbidity profiles contribution.

Correction of mortality levels

Brazilian 2010 national census mortality information has completeness of death enumeration rates ranging from 80-85% (Queiroz, Sawyer, 2012). Since death registry coverage is sensitive to regional inequalities (Queiroz *et al.*, 2017), census mortality data might also exhibit this pattern and is likely to present differences between rural and urban households. However, as mentioned previously, these boundaries are defined by each municipality without concrete classification criteria and significant urban expansion has been observed from 2000[6] to 2010 (Pera, Mello Bueno, 2016). As rural and urban areas do not share the same boundaries

6. The population data of 2000 is required for the estimation of death enumeration completeness because the most robust death distribution methods are the two-census methods, since they do not rely on the assumption of population stability (Moultrie et al., 2013).

between these two censuses and death distribution methods (DDM) assume closed populations (Moultrie *et al*., 2013), death enumeration completeness estimates are affected by increases in migration effects (Hill *et al*., 2009). Therefore, we assume that death reporting coverage is the same across urban and rural areas, although they differ across Brazilian 26 states and the Federal District.

Before turning to the evaluation of the level of completeness of death counts enumeration, we perform a series of data analysis for data on population and death counts. First, we evaluate the differences in digit preference for rural and urban population using traditional demographic indexes. We used Myers and Whipple indexes (Shyrock *et al*., 1980), using the package DemoTools[7]. The results for both urban and rural populations do not indicate digit preferences for neither groups in the 2010 census, Whipple Index for urban males is 1'046 and for the rural males is 1'052, for females these values are 1'031 and 1'044, respectively.

Second, in order to verify a trend of exaggeration in the age reported in the death counts enumeration, we compared the number of deaths observed in advanced ages (above 80) will be high in relation to the total number of deaths of the elderly (60 years or more), following the procedure proposed in Jdanov *et al*. (2008). As a control check, we assume that it would not be reasonable to find values for the ratios that were much higher than for Sweden'. In Brazil, we calculate the ration as 0.38 for males in rural areas and 0.47 for females in rural areas. For the urban areas we find 0.47 for females and 0.35 for males. In Sweden, around 2010, the values are 0.57 for males and 0.73 for females (Human Mortality Database, 2021).

We estimated completeness of death counts enumeration for each of the Brazilian states and Federal District[8] by applying synthetic extinct generations (SEG) (Bennett, Horiuchi, 1984), generalized growth balance (GGB) (Hill, 1987) and adjusted synthetic extinct generations (adjusted SEG) (Dorrington *et al*., 2008; Hill *et al*., 2009), two-census methods built in the R package DDM (Death Registration Coverage Estimation) (Riffe *et al*., 2017)[9]. We decided to use the adjusted SEG method due to its robust-

7. Demotools in available at: https://timriffe.github.io/DemoTools/.

8. We have also tested other alternatives of gegraphical division in the application of the DDM, such as Brazilian macrorregions, and all of them presented similar results that point to the same direction of our conclusions.

9. Package is available at: https://cran.r-project.org/web/packages/DDM/index.html.

ness to migration and intercensal relative enumeration coverage differences (Hill *et al*., 2009). The results and methodological procedure for the mortality completeness adjustment are presented in Appendix A. Census death counts for the adult population (20+) were then corrected for each state by dividing the observed death counts by its respective death enumeration completeness estimates. The aggregated adjusted death counts by age and sex for urban and rural areas were then used to estimate standard life-table functions.

Health expectancy estimation by Sullivan method

The second step was to estimate health expectancy. We use the Sullivan method to use data from disease and functional disability prevalence to construct a single index of mortality and morbidity (Sullivan, 1971). The index provides an estimate of years of life free of disability that a member of the cohort would experience if the current age-specific rates of mortality and disease/disability prevalence prevailed throughout the cohort's lifetime (Sullivan, 1971).

The primary inputs of the method are the age-specific mortality rates for life table functions estimation and age-specific disease or disability (morbidity) prevalence, $_nP_x$. After the estimation of life table functions using mortality rates as inputs, the complement of the morbidity prevalence (morbidity-free prevalence) are multiplied by the person-years lived, $_nL_x$ for each age group (Equation 1). Therefore, the life expectancy computed by the Sullivan method (e_x^{SUL} or h_x) is an estimate of the morbidity-free life expectancy or health expectancy of the respective age-group

$$(1) \quad {}_nL_x^{SUL} = {}_nL_x * (1 - {}_nP_x)$$

We evaluate the morbidity prevalence and compute morbidity-free life expectancy for some specific sets of morbidities grouped in 4 categories: 1) cardiovascular diseases; 2) diabetes; 3) osteoarticular diseases (e.g., arthritis, rheumatism and back pain) – these first three inquired by the PNS survey - 4) and severe or total functional disabilities to walk, see or listen – inquired by the 2010 National Census. Cardiovascular diseases and diabetes were selected because of their recent burden increasing trend in the country (Fatima Marinho Souza *et al*., 2017) and osteoarticular diseases and functional disabilities were selected due to its acknowledged impact on rural workers (Moreira *et al*., 2015).

Since differences in urban-rural mortality are expected to favor rural residents (Albuquerque, 2019), we compare both populations also by a relative measure of morbidity-free life expectancy. That is, we compute the fraction of life expectancy that the synthetic cohort is expected to live without each related morbidity ($\frac{h_x}{e_x}$ ratio). This ratio can be interpreted as a proxy of the proportion of life expected to be lived free from morbidity for a synthetic cohort with a set of age-specific morbidity prevalence rates and age-specific mortality rates. We adopt this strategy to compare relative measures and avoid distortions that might come from absolute values. We focus our attention on adult mortality differentials (20-69 age-groups) because PNS had disease prevalence data available only for the adult population (18+)[10].

Decomposition of rural-urban DFLE differentials

In the final methodological step, we apply the stepwise-replacement decomposition method (Andreev *et al.*, 2002). The estimation of person-years lived in good health, in Equation 1, requires two-variable vectors: person-years lived by age group, ${}_nL_x$, derived from age-specific mortality rates vector (M_x), and age-specific health condition or morbidity-free prevalence vectors (Π_x). Then, the health expectancy (h_x) at age x can be stated as a function of age-specific mortality rates and age-specific health prevalence (Equation 2).

$$(2)\ h_x = h_x(M_x, \Pi_x)$$

The rural-urban differences for health expectancy can be decomposed into two components computed by applying the proposed stepwise replacement algorithm. The algorithm's rationale is based on the transformation of one population group vector of health expectancy (h_x^{rur}, for example) into the other population group vector of health expectancy (h_x^{urb} in our case). Considering the components of h_x function (Equation 2),we can obtain rural health expectancy vector estimates out of urban health expectancy vector by transforming each of its elements M_x^{rur} and Π_x^{rur} into M_x^{urb} and Π_x^{urb} which is performed in an age-by-age replacement strategy: M^x and Π^x are the mortality and morbidity-free prevalence rates vectors composed by rates m_y^{rur} and π_y^{rur} at ages $x < y$ and m_y^{urb} and π_y^{urb} at ages $x \geq y$, respectively (Andreev *et al.*, 2002).

10. Even though PNS had prevalence data available only for adults aged over 18 years old, we considered the prevalence distribution of diseases for age group 15-19 equal to the rates observed for the age group 18-19.

Therefore, the difference $h_x^{rur} - h_x^{urb}$ is the sum of two components: 1) $\gamma_x^{rur-urb}$ (Equation 3), component of h_x difference due to difference in mortality rates at age x, and 2) $\lambda_x^{rur-urb}$ (Equation 4), component of h_x difference due to difference in morbidity-free prevalence at age x.

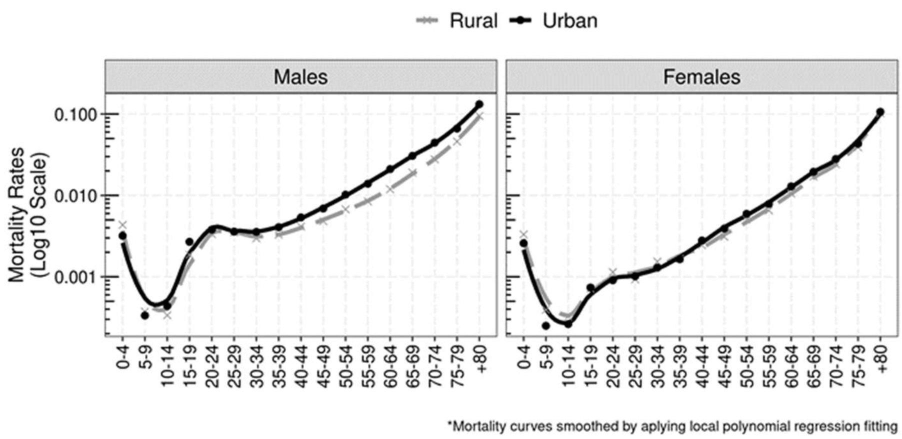
$$(3)\ \gamma_x^{rur-u} = \frac{1}{2}\Big[[h_x(M^{x+1}, \Pi^x) - h_x(M^x, \Pi^x)] + [h_x(M^{x+1}, \Pi^{x+1}) - h_x(M^x, \Pi^{x+1})]\Big]$$

$$(4)\ \lambda_x^{rur-urb} = \frac{1}{2}\Big[[h_x(M^x, \Pi^{x+1}) - h_x(M^x, \Pi^x)] + [h_x(M^{x+1}, \Pi^{x+1}) - h_x(M^{x+1}, \Pi^x)]\Big]$$

Results

Figure 1 presents age-specific mortality rates by place of residence. We observe that infant and child mortality rates are higher in rural areas than in urban areas, and rural adult mortality rates are lower than urban adult mortality rates. This compensatory effect of rural adult mortality advantage concerning lower under-five mortality indicators results in higher life expectancy estimates for rural populations (Table 1). The estimated rural life expectancy advantage is more pronounced in males than in females, and it gets higher for older ages. Further, we verify higher life expectancy sex gaps in urban areas than in rural areas.

FIGURE 1 Rural and urban age-specific mortality rates by sex – Brazil, 2010



Source: 2010 Brazilian National Census.

TABLE 1 Rural and urban life expectancy estimates by sex and age – Brazil, 2010

Age	Males			Females			Sex differentials (Females-Males)	
	Rural	Urban	Difference (Rural-Urban)	Rural	Urban	Difference (Rural-Urban)	Rural	Urban
20	55.2	50.7	4.5	59.4	58.1	1.3	4.2	7.4
40	38.3	33.9	4.4	40.7	39.3	1.4	2.4	5.4
60	21.7	18.4	3.3	23.3	22.2	1.1	1.6	3.8

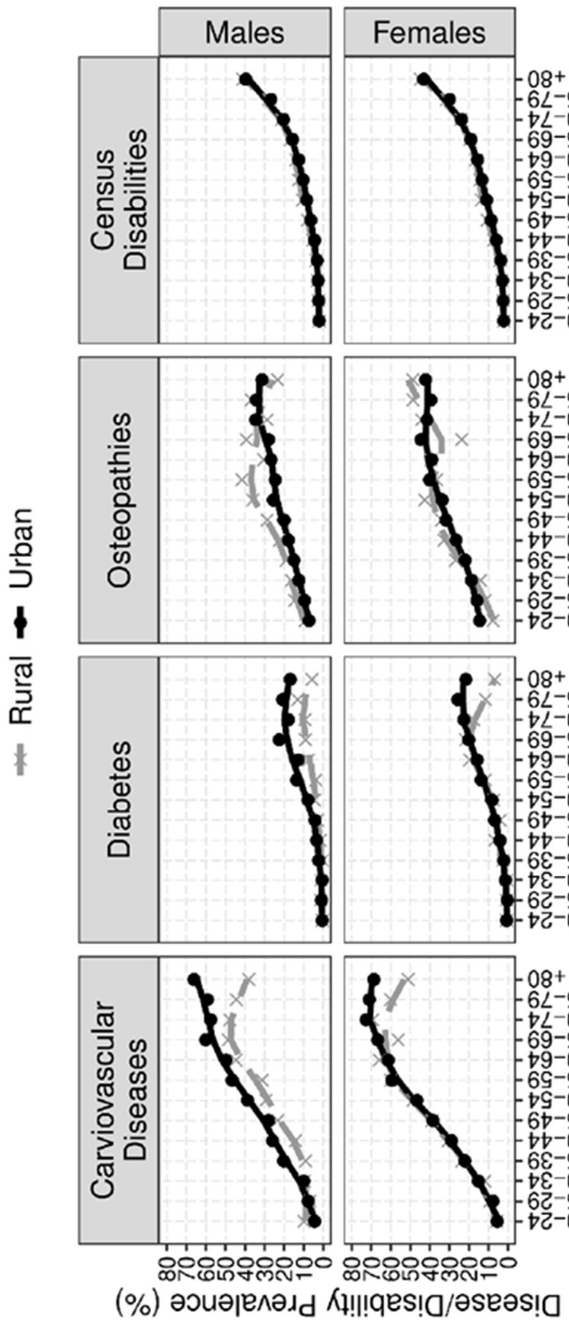
Source: 2010 Brazilian National Census.

Concerning estimates of disease and disability prevalence, Figure 2 presents results by age and residence areas. We present the prevalence rates estimated from data of the PNS survey of 2013 for cardiovascular diseases, diabetes, and osteoarticular diseases and from the 2010 National Census data for functional disabilities and their respective smoothed estimates[11]. The smoothing methods were used to minimize the high variability of prevalence rates, especially for PNS lower counts of rural residents. Smoothing of functional disability prevalence for census information is presented, but the original prevalence rates were used for Sullivan method estimation of the next section since they showed very low variability.

For the adult population, there are rural penalties (higher rural-urban prevalence ratios) in the prevalence of osteoarticular diseases and functional disabilities for males and of cardiovascular diseases and functional disabilities for females. Rural men are in a better off situation regarding diabetes prevalence rates, which exhibited wide gaps for advanced ages. Female prevalence curves for diabetes did not present any significant gap. Significant decreases observed in PNS morbidity prevalence for the elderly may be related to poor disease diagnosis of this age-group in rural populations.

11. Prevalence rates of diseases and disabilities were smoothed by applying the locally estimated scatterplot smoothing method (LOESS).

FIGURE 2 Rural and urban disease and disability prevalence by sex and age – Brazil, 2010-2013



Source: 2010 Brazilian National Census 2010 and 2013 National Health Survey.

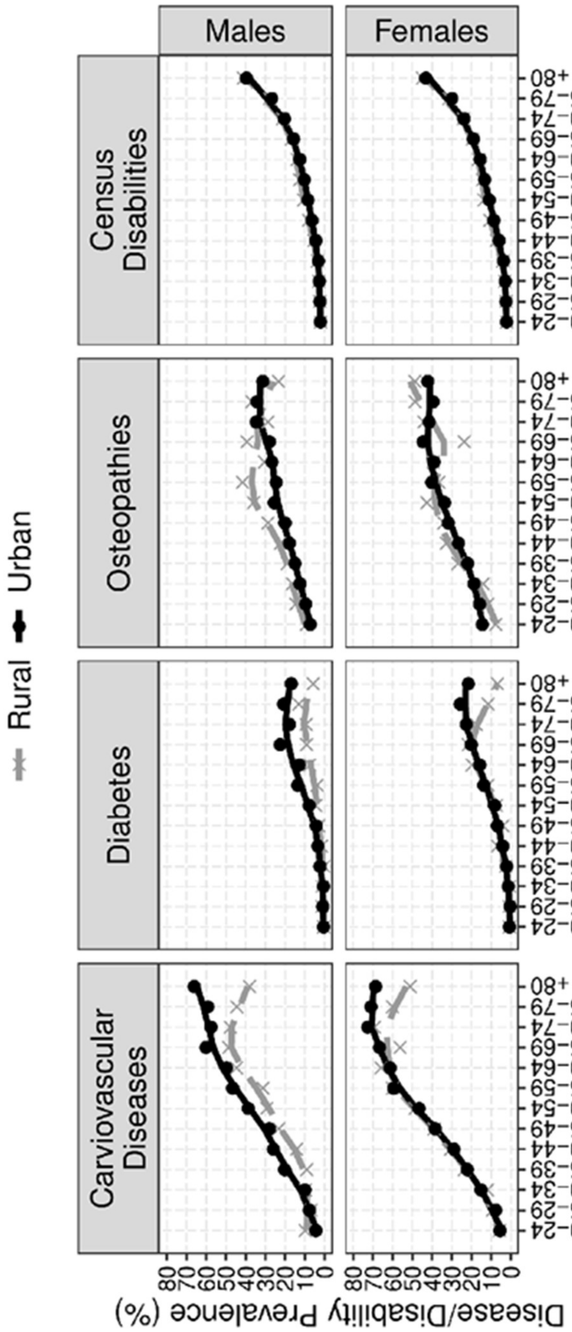
Table 2 presents the results of morbidity-free life expectancy or health expectancy (h_x) estimates for males and females of rural and urban areas at birth, at 20 years old, at 40 years old, and at 60 years old. The absolute differences in morbidity and mortality highlight rural advantages in health expectancy and life expectancy, however, when examining relative measures of health expectancy ($\frac{h_x}{e_x}$ ratio), the rural advantage prevails only for cardiovascular diseases and diabetes, whereas a relative urban advantage is observed for osteoarticular diseases and functional disabilities.

TABLE 2 Rural and urban health expectancy estimates (h_x) and health expectancy to life expectancy ratios (h_x / e_x) by sex and age - Brazil, 2010-2013

	Males		Females	
	Rural	Urban	Rural	Urban
Cardiovascular diseases				
Age	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)
20	41.1 (0.74)	34.6 (0.68)	36.2 (0.61)	34.3 (0.59)
40	25.1 (0.66)	18.7 (0.55)	19.4 (0.48)	17.4 (0.44)
60	12.1 (0.56)	7.7 (0.42)	9.4 (0.40)	7.2 (0.32)
Diabetes				
Age	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)
20	52.9 (0.96)	46.8 (0.92)	54.7 (0.92)	52.3 (0.90)
40	36.0 (0.94)	29.9 (0.88)	36.1 (0.89)	33.5 (0.85)
60	19.8 (0.91)	15.1 (0.82)	19.8 (0.85)	17.6 (0.79)
Osteoarticular diseases				
Age	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)
20	41.0 (0.74)	40.5 (0.80)	41.0 (0.69)	40.3 (0.69)
40	26.2 (0.68)	25.2 (0.74)	24.9 (0.61)	24.7 (0.63)
60	14.9 (0.69)	12.8 (0.70)	13.7 (0.59)	13.0 (0.59)
Census disabilities				
Age	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)	h_x (h_x / e_x)
20	48.7 (0.88)	45.9 (0.91)	50.8 (0.86)	50.5 (0.87)
40	31.9 (0.83)	29.2 (0.86)	32.5 (0.80)	32.0 (0.81)
60	16.4 (0.76)	14.4 (0.78)	16.7 (0.72)	16.3 (0.73)

Source: Brazilian National Census 2010 and National Health Survey 2013.

FIGURE 2 Rural and urban disease and disability prevalence by sex and age – Brazil, 2010-2013



Source: 2010 Brazilian National Census 2010 and 2013 National Health Survey.

Discussion

The purpose of this paper was to analyze mortality and health differentials among Brazilian rural and urban areas using data from 2010 National Census and 2013 National Health Survey. We combine these data sources to construct estimates for health expectancy and decompose its differences across rural and urban areas. Therefore, we investigate the differentials in health expectancy related to the prevalence of four types of diseases or disabilities: cardiovascular diseases, diabetes, osteoarticular diseases and functional disabilities.

The inclusion of household mortality inquiry in the 2010 National Census represented an opportunity for the analysis of mortality differentials in Brazil (Queiroz, Sawyer, 2012). In the past, the mortality differentials assessment between rural and urban areas was performed using indirect demographic methods, usually for estimating under-five and infant mortality (Carvalho, Wood, 1978; Sastry, 1997). Both past and recent studies have documented a rural advantage in life expectancy at birth, particularly for males (Albuquerque, 2019; Carvalho, Wood, 1978; Pereira, 2020). Our results reflect those earlier findings. Life expectancy at age 20 was 55.2 in rural areas and 50.7 in urban areas, resulting in 4.5 years of rural advantage in life expectancy. For females, these life expectancy were 59.4 in rural areas and 58.1 in urban areas. Therefore, the female life expectancy advantage is considerably higher in urban areas (7.4 years of female advantage) than in rural areas (4.2 years of female advantage), which may refer to differences in lifestyles (Smith *et al.*, 2012) and to the higher exposition of young males to violence in disadvantaged metropolitan areas (Malta *et al.*, 2017; Pereira, 2018; Pereira, Queiroz, 2016). A detailed investigation of the causes of these sex differentials across rural and urban areas would require the assessment of related causes of deaths in each area, which is not available in the Brazilian mortality information system.

The rural advantage in mortality, however, has not been observed in health and socioeconomic status and access to health equipment (Arruda *et al.*, 2018). The rural areas of the country experience higher levels of socioeconomic vulnerability and lower economic integration (Camarano, 2002; Soares *et al.*, 2016; Viacava *et al.*, 2019). The distance of health equipment, lack of resources to pay for transportation, the lack of health professionals, or unavailability of higher complexity health services are elements that illustrate the hindrances to the access of public health systems by the rural population (Viacava *et al.*, 2019). The difficulties of accessing health equipment due to distance or lack of resources were mentioned by 56% of rural residents who did not access health services and needed to against 17% of urban residents in the PNS survey of 2013. Urban residents mostly did not access health services when they needed to because of the long waiting time (28% against 8% of rural population). Thus, these differentials in access to health services may incur lower disease diagnosis. Indeed, PNS data shows that the rural population had a higher percentage of people that never had measured their glycemic levels (21% against 10% for urban residents) or blood pressure (6% against 3% for urban residents). This situation is worsened for the elderly, population group with higher demand for such services (Viacava *et al*., 2019).

The social and economic barriers to services and health facilities also shape how a population group feels regarding its health state (Viacava *et al*., 2019). Therefore, rural residents are more likely to report worsened health status than urban residents (Arruda *et al*., 2018; Camarano, 2002; Maia, Rodrigues, 2010). Nevertheless, when we disentangle the self-perception of health state by social groups, rural residents from lower social strata have higher probability of referring to a good state of health than their counterparts from urban areas (Maia, Rodrigues, 2010).

Over the last 30 years, Brazil has experienced substantial changes in its public health policy induced by the implementation and consolidation of the country's unified health system (SUS, from Portuguese *Sistema Único de Saúde*) (Castro *et al*., 2019). SUS guaranteed a massive expansion of health care assistance for the most vulnerable social groups through a universal and free of charge health services. This scenario of health vulnerability observed in the rural populations could have been worse if the Family Health Strategy (ESF, from Portuguese *Estratégia de Saúde da Família*) of the Brazilian Ministry of Health was not successful in reaching remote communities of the countryside of Brazil (Bhalotra *et al*., 2020; Lima *et al*., 2019; Malta, 2016). The family health strategy is a public health policy approach focused on primary care at the community level which brought several positive outcomes for the population such as the reduction of infant mortality rates (Macinko *et al*., 2006), reduction of maternal mortality rates (Bhalotra *et al*., 2020) and decrease in hospitalizations due to causes sensitive to primary care (Pimenta *et al*., 2018). ESF policy approach is oriented towards the needs of the poorest regions and most vulnerable social groups.

The ESF program expansion provides diagnosis and follow-up of chronic diseases in rural populations and provides an enhancement of its health literacy, which might also have contributed to further mortality improvements of these groups (Bhalotra *et al*., 2020; Rocha, Soares, 2010). Also, lower exposition to urban-related mortality causes such as violence and accidents seems likely to play a key role in lower mortality observed in rural areas (Pereira, 2020). Moreover, the results of this work support the efforts of family health strategy towards health coverage of most vulnerable and remote areas of the country (Guimarães, 2018).

In 2013, 54.4% of Brazilian households were registered in the local family health unit, which represented 74.9% of rural households, and 50.6% of urban households (Malta, 2016). This higher ESF coverage and primary care assistance in rural areas might account for the favorable results of rural residents concerning mortality and cardiovascular diseases and diabetes morbidity differentials, since ESF professionals provide not only health care support, but also health information and the promotion of health literacy in local communities.

Despite the efforts of SUS and ESF in reducing health inequalities between rural and urban areas, lifestyles and other characteristics of each of this environments also shape the observed differences life expectancy and health. For instance, rural populations observe higher prevalence of specific disabilities, and diseases such as chronic pains, back pains, arthritis, and urban populations are usually more susceptible to diabetes, high blood pressure, heart diseases, and depression (Camarano, 2002). Moreira *et al*. (2015) found that back pain, rheumatism, arthritis and high blood pressure were associated with agricultural activities and results from intense physical effort in work. Our results confirmed that rural residents are more susceptible to suffer from functional disabilities and and musculoskeletal pain due to the physically demanding labor required in agriculture (Maia, Rodrigues, 2010; Moreira *et al*., 2015).

The decomposition exercise highlights that health expectancy differences observed between rural and urban populations are not only due to overall mortality difference but also related to differences in age-specific morbidity prevalence. The results are aligned to the literature, which shows that cardiovascular diseases and diabetes are urban-related morbidities, whereas physical disabilities and osteoarticular diseases are rural related morbidities which reflect the physically harming work performed in rural areas (Camarano, 2002; Moreira *et al*., 2015). Hence, rural residents exhibit a double advantage (in mortality and morbidity) when we compare health expectancy for cardiovascular diseases and diabetes. On the other hand, this advantage is restricted to the mortality profile advantage when we decompose differences for osteoarticular diseases and functional disabilities.

This paper's results have some limitations. As mentioned, the rural population's lower access to health services results in lower diagnostic rates of health indicators such as glycemic level and blood pressure. Then, prevalence rates for rural groups might be underestimated due to a lack of diagnosis. Also, the methods used to estimate completeness have some limitations. They assume that: 1) population is closed to migration; 2) completeness (of mortality and census counts) is constant in all age groups; and 3) age misreporting is minimal or non-existent. Also, Murray *et al*. (2010) suggest that there are some uncertainty in the estimates produced by the methods. To overcome this limitations we applied and tested a variation of combination of methods and age segments as suggested by Hill (2017). Despite these important details, the data sources are robust and the results are in tandem with findings of previous studies on rural and urban health and mortality differentials. We verified the existence of an urban adult mortality penalty and also an urban adult morbidity penalty for cardiovascular diseases and diabetes. Finally, we verified a rural morbidity penalty related to functional disabilities (to walk, see, and listen) and osteoarticular diseases. This penalty contributes to lower health expectancy differences related to these two morbidities, but the overall rural mortality advantage produced a compensatory effect. Therefore, rural residents exhibit higher life expectancy, but a significant share of this life expectancy co-occur with physical and musculoskeletal related morbidities.

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Appendix A

In this appendix we present the methodological procedure adopted for the estimation of death coverage rates for each of Brazilian 26 states and the Federal District. We used the extended version of the synthetic extinct generations (SEG) method for two censuses which uses the results of the generalized growth balance (GGB) method to adjust for intercensal population coverage ratio (delta) (Dorrington *et al*., 2008; Hill *et al*.,2009, Hill, 2017).

The delta estimates were computed by selecting age groups within the range 15-69 using the GGB method and the relative death enumeration completeness was computed using the delta-adjusted vesion of the SEG method selecting age groups from 30 to 69. We selected older age groups for the estimation of death enumeration completeness to minimize biases from migration, which are responsible for significant errors when applying the DDM (Dorrington *et al*., 2008; Murray *et al*., 2010; Hill, 2017). We used the R package DDM (Riffe *et al*., 2017) to construct our estimates.

Since we are using two-census methods to allow the relaxation of population stability assumption of pioneer one-census methods, we use age-specific mortality rates computed for national census of 2010 and estimate average deaths in the 2000-2010 period using the population geometric average between the two census periods, as stated in Equation A1.

$$(A1)\ deaths = \frac{deaths_{2010}}{population_{2010} + 0.5 * deaths_{2010}} \sqrt{population_{2010} * population_{2000}}$$

Table A1 shows the results of estimated death coverage rates for the adult population fitted values for the selected age ranges for GGB and Adjusted SEG and the intercensal relative population coverage – delta.

TABLE A1 Death enumeration completeness and intercensal relative population coverage – Brazil, 2010

	Males		Females	
	Adjusted SEG	Delta	Adjusted SEG	Delta
Brazil	0.786	0.995	0.750	0.990
North				
Rondônia	0.829	1.011	1.043	1.038
Acre	0.595	0.908	0.804	0.949
Amazonas	0.872	0.988	0.895	1.014
Roraima	0.797	0.908	0.891	0.911
Pará	0.729	0.965	0.802	0.987
Amapá	0.886	0.884	1.270	0.905
Tocantins	0.785	0.962	0.801	0.965
Northeast				
Maranhão	0.812	1.005	0.792	1.000
Piauí	0.743	1.002	0.681	1.012
Ceará	0.689	0.964	0.676	0.979
Rio Grande do Norte	0.887	0.989	0.738	0.975
Paraíba	0.744	0.991	0.731	1.000
Pernambuco	0.823	1.009	0.756	1.003
Alagoas	0.877	1.039	0.833	1.022
Sergipe	0.990	1.009	0.730	0.969
Bahia	0.783	1.036	0.771	1.030
Southeast				
Minas Gerais	0.765	0.996	0.734	0.994
Espírito Santo	0.810	0.983	0.749	0.983
Rio de Janeiro	0.779	0.981	0.697	0.962
São Paulo	0.794	1.002	0.740	0.990
South				
Paraná	0.840	1.007	0.804	1.006
Santa Catarina	0.762	0.937	0.764	0.941
Rio Grande do Sul	0.810	1.023	0.791	1.014
Midwest				
Mato Grosso do Sul	0.835	0.955	0.825	0.966
Mato Grosso	0.599	0.930	0.885	0.955
Goiás	0.770	0.937	0.735	0.951
Federal District	0.812	0.950	0.941	0.959

Source: 2010 Brazilian National Census.