Public Health 180 (2020) 102–108

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Narrowing geographic inequality in life expectancy in Brazil: a multilevel analysis between 1991 and 2010

A.F. Boing [a, b, *], A.C. Boing [a, b], K.J.P. Wagner [c], S.V. Subramanian [a]

[a] Department of Social and Behavioral Sciences, Harvard T H Chan School of Public Health, Boston, USA
[b] Post-Graduate Program in Public Health, Federal University of Santa Catarina, Florianópolis, Brazil
[c] Center for Rural Sciences, Federal University of Santa Catarina, Curitibanos, Santa Catarina, Brazil

ARTICLE INFO

Article history:
Received 12 July 2019
Received in revised form
19 September 2019
Accepted 12 November 2019

Keywords:
Life expectancy
Socio-economic factors
Geographic factors
Multilevel analysis

ABSTRACT

Objectives: To analyze the geographic inequalities in life expectancy (LE) and the probability of survival up to 40 and 60 years in Brazil between 1991 and 2010, to partition the variance of these indicators by including municipalities, states, and macroregions in the analysis, and to test the association between municipal socio-economic and health services indicators with life expectancy.
Study design: Multilevel analysis.
Methods: Census data from 1991, 2000, and 2010 were used to calculate the outcomes and the socio-economic variables. Municipalities were separated into centiles according to their values in each outcome. Absolute and relative differences were calculated for each year. Multilevel linear regression models were performed, taking into account three levels: regions, states, and municipalities. Municipal socio-economic and health services variables were included in the model with the 2010 data.
Results: All 5545 Brazilian counties showed improvement in the three indicators, but the magnitude varied significantly across the country. The highest gains in LE were observed in the North and Northeast regions. The gap in LE between the 1st and 99th percentile decreased from 19.6 years to 12.2 years. The relative difference also fell, from 1.37 to 1.18. Most counties' socio-economic and health services indicators were associated with the outcomes and explained 86.7%, 31.2%, and 32.4% of the variation in LE attributable to regions, states, and counties, respectively.
Conclusions: The average life expectancy increased between 1991 and 2010. Concomitantly, a reduction in geographic disparities was observed. The counties' socio-economic and health services variables explained much of the variation of the outcomes in 2010.

Introduction

Globally, life expectancy (LE) has increased substantially throughout the twentieth century and the first decades of the twenty-first century. Between 1950 and 2017, the LE went from 48.1 to 70.5 years among men and from 52.9 to 75.6 years among women.[1] Brazil follows the same pattern in LE, increasing from 36.5 to 75.4 years between 1930 and 2015.[2,3] This indicator reflects changes in the living conditions of the population, including increases in income, improvements in educational level and sanitary conditions, and advances in medicine.[1]

However, at the same time that LE is increasing, and humanity is expanding its knowledge of how to live longer, the literature has shown an increase in the geographic and socio-economic inequality of LE within many countries. In Belgium, the educational difference in LE (and LE without disabilities) increased between the 1990s and 2000s.[4] The widening of social inequality in LE and/or quality-adjusted life expectancy (QALE) was also observed in Denmark (1980s–2010s),[5] United States (1980s–2010s),[6] England (1980s–2010s),[7] Netherlands (2000s–2010s),[8] Estonia (1980s–2000s),[9] New Zealand (1980s–2000s)[10] and Russia (1980s–2000s),[11] whether between regions or populational groups.

Brazil has been one of the most unequal countries in the world for decades. The country has always been marked by deep socio-

* Corresponding author. Federal University of Santa Catarina, Department of Public Health, Florianópolis, SC, Brazil, Zip Code: 88040-900. Tel.: +55 48 99112 5624.
E-mail address: antonio.boing@ufsc.br (A.F. Boing).

https://doi.org/10.1016/j.puhe.2019.11.015
0033-3506/

economic and geographic inequalities. However, between the 1990s and early 2010s, the country managed to control inflation, develop, and expand its social programs, increase investment in effective public policies (i.e., education, health), and develop a well-succeeded cash-transfer program.[12] Given the implementation of such policies, it is important to know whether regional differences in life expectancy followed the pattern observed in the aforementioned countries, or if a different scenario, with decreasing inequalities, was achieved.

Moreover, when exploring geographic disparities in LE, studies have relied on single-level analysis, taking into account either municipalities or states. However, health services are administered at both levels, and public policies may focus on specific municipalities, states, or macroregions. The importance of a given level can only be properly assessed when all the spatial dimensions that may explain the variances are considered in the analysis.[13] Policymakers and researchers could benefit from analyses showing which geographic unit (municipalities, states, regions) is responsible for most of the variance in the health indicator. Furthermore, little is known about the potential influence of municipal socio-economic and demographic characteristics on the variation of life expectancy in recent decades in Brazil. Such studies are usually carried out in rich countries. For example, Dwyer-Lindgren et al.[6] reported that in the United States, socio-economic status, race/ethnicity, behavioral/metabolic risk factors, and health care factors explained 74% of the county-level variation in life expectancy.

A better understanding of the variation in LE during the 1990s and 2000s and the factors that explain the fluctuation of this indicator between geographic units can be useful for the formulation of more equitable actions, especially in Brazil, a country marked by a deep inequality. The aim of this study was to analyze the geographic inequalities in LE and the probability of survival to 40 and 60 years of age in Brazil between 1991 and 2010, to partition the variance of these indicators by including municipalities, states and macroregions in the analysis, and to test the association between municipal socio-economic and health indicators with life expectancy.

Methods

Brazil is a federative republic formed by the union of 26 states, a Federal District, and 5570 municipalities. The municipalities are the smallest autonomous units of the Federation; they have political autonomy, and within the limits established by the Constitution, self-administration, and self-organization. The 26 states are divided into five major regions: North, Northeast, Midwest, Southeast, and South. The latter two account for 70% of the country's Gross Domestic Product (GDP) and have the best social indicators.

The health indicators analyzed in the present study were (i) life expectancy, (ii) probability of surviving to 40 years of age, and (iii) probability of surviving to 60 years of age. All data are from the years 1991, 2000, and 2010 and were obtained from the Atlas of Human Development, published by the United Nations Development Program (UNDP).[14] For the calculations, UNDP used demographic census data from the country in the respective years. The methodology proposed by Brass[15] was used to perform the life expectancy estimation. In the case of municipalities where the mortality pattern was not known, the tables generated for their respective states were used as the standard. The procedure was supported by the Center for Regional Development and Planning (Cedeplar) of the Federal University of Minas Gerais (UFMG). For 1991 and 2000, the mortality tables were based on the 1991 Demographic Census and the National Household Sample Surveys (PNAD) of the 1990s. For the year 2010, the calculations already included data from the 2010 Demographic Census. Further methodological details can be obtained at the Atlas website[39].

The municipal independent variables used in multilevel models were (i) proportion of illiteracy among persons over 14 years of age, (ii) household income per capita, (iii) proportion of formal employment among persons over 17 years of age, (iv) proportion of households with running water and bathrooms, (v) proportion of population covered by the Family Health Strategy, and (vi) ratio of physicians in the public health sector to inhabitants. Variables (i), (ii), (iii) and (iv) were obtained from the Human Development Atlas of Brazil and use data from the 2010 national Census. The variable (v) was calculated by the Primary Care Department of the Ministry of Health of Brazil, and variable (vi) was obtained from CNES, the National Registry of Health Establishments. Both variables are referent to July 2010.

Initially, for each municipality, we calculated the variations of life expectancy between 1991 and 2010, SU40 and SU60. The values were plotted on maps to allow the spatial visualization of the municipalities that presented the greatest gains in the two decades analyzed. We also plotted the municipal values of the three outcomes in 2010, the most recent period with the available data. Then, the municipalities were separated into centiles according to their values in each outcome, with centile 1 being the lowest value. Compared with this centile, the absolute and relative differences of the 25th, 50th, 75th, and 99th centiles were calculated for 1991, 2000, and 2010. In all cases, the respective confidence intervals (95%) were also reported.

Finally, multilevel linear regression models were calculated. We considered three levels of analysis: regions, states, and municipalities. First, for each municipality and health indicator, we calculated the difference in the values between 1991 and 2010. In empty models, we calculated the variances with their respective standard errors. The same procedure was followed for the 2010 figures, the most recent year with available data in the country. In all models, we calculated the Variance Partition Coefficient (VPC) of each level of analysis. By partitioning the variance between different levels, the VPC provided us information on the proportion of total variance in the outcome that is attributable to each area level. As the last step of the data analysis, we included the municipal socio-economic and health services variables in the model with the 2010 data. Regression coefficients with respective confidence intervals (95%) were reported.

The maps were plotted in QGIS 3, and data analysis was performed in Stata 15. All data used in the present study are in the public domain.

Results

The average life expectancy (LE) in Brazil increased by 9.2 years between 1991 and 2010, reaching 73.9 years in 2010. The gain was higher in the 2000s (+5.3 years) than in the 1990s (+3.9 years). A substantial increase was also observed in the probability of surviving up to 40 (p40) and 60 (p60) years of age. Between 1990 and 2010, p40 increased 7.5 percentage points (pp) and p60 13.1 pp, reaching 94.4% and 84.0%, respectively.

All 5545 Brazilian counties showed improvement in the three indicators, but the magnitude varied significantly across the country. Fig. 1 shows that the highest gains were observed in the North and Northeast regions (Fig. 1), which had the worst indicators in 1991. These regions concentrate the 685 municipalities with the highest increase in life expectancy between 1991 and 2010, 1654 with the highest increase in p40 and 1404 with the highest increase in p60.

Thereby, there was a reduction in relative and absolute inequality in life expectancy, p40, and p60 in Brazil. Between 1990

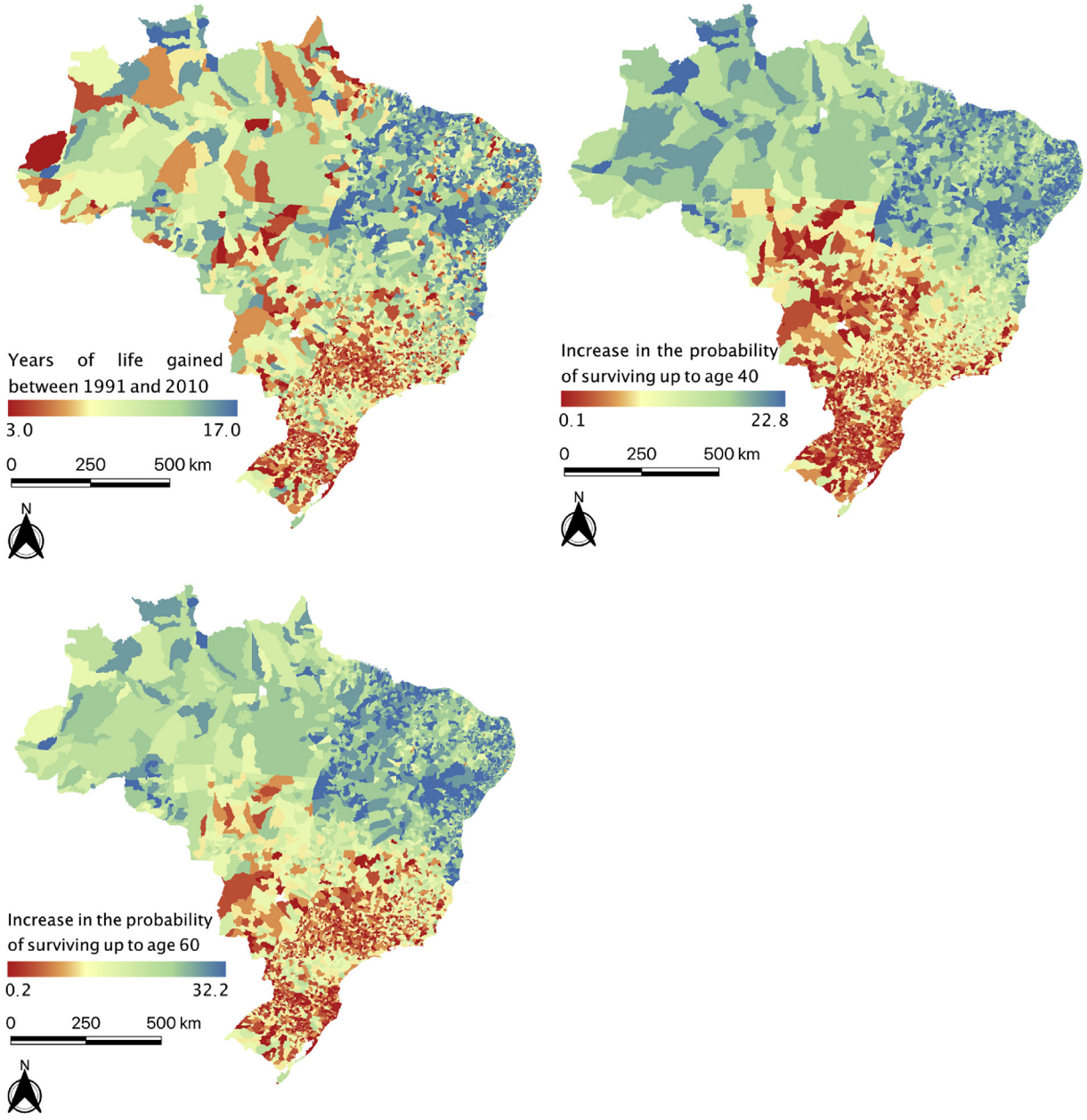

Fig. 1. Change in life expectancy at birth, probability of surviving up to ages 40 and 60 by county. Brazil, 1991 to 2010.

and 2010, the gap in life expectancy between the 1st and 99th percentile decreased from 19.6 years to 12.2 years (Table 1). The relative difference also fell, from 1.37 to 1.18. The reduction of inequalities was even more pronounced in the probability of surviving to 40 years of age. The difference of 21.2pp in 1991 reached 6.5pp in 2010. Finally, in 1991, the proportion of people living up to 60 years of age was 64% higher in the 1st percentile; in 2010, the figure was reduced to 20%.

Despite this reduction in inequalities, in 2010, Brazil was still marked by deep differences in the three indicators. Fig. 2 shows that there is strong regional inequality in life expectancy and the probability of surviving up to ages 40 and 60 years. The worst indicators are still concentrated in the North and Northeast, especially life expectancy. None of the 880 municipalities with the highest life expectancy in the country are from the North or Northeast, while all 304 municipalities with the lowest life expectancy are located in these regions.

The multilevel regression models showed that counties and regions accounted for the major part of the total variability of the outcomes (Table 2). When analyzing the difference in life expectancy between 1991 and 2010, we observed that the proportion of variation attributable to regions reached almost 30%. This figure exceeded 75% and 62% when analyzing p40 and p60, respectively. Between-counties variation ranged from 18.7% (p40) to 56.3% (life expectancy) of the total variation. When analyzing data from 2010 only, we observed that regions accounted for 55.5% of the total variability in life expectancy, while counties explained 49.2% in p40 and 73.9% in p60.

Table 3 shows the regression coefficients for the 2010 data. Higher illiteracy was negatively associated with LE, p40, and p60;

Table 1
Absolute and relative inequality in life expectancy at birth, probability of surviving up to ages 40 and 60 years. Brazilian counties, 1991, 2000, and 2010.

	Mean			Absolute difference (95% CI)			Ratio (95% CI)		
	1991	2000	2010	1991	2000	2010	1991	2000	2010
Life expectancy (years)									
Percentile 1	52.6	58.8	66.1	0.0	0.0	0.0	1.00	1.00	1.00
Percentile 25	60.1	65.2	71.1	7.5 (7.5–7.6)	6.4 (6.4–6.4)	5.0 (5.0–5.0)	1.14 (1.09–1.20)	1.11 (1.06–1.16)	1.08 (1.03–1.12)
Percentile 50	64.4	69.0	73.4	11.8 (11.7–11.8)	10.2 (10.1–10.2)	7.4 (7.3–7.4)	1.22 (1.17–1.28)	1.17 (1.12–1.23)	1.11 (1.06–1.16)
Percentile 75	67.6	71.5	75.1	15.0 (14.9–15.0)	12.7 (12.6–12.7)	9.0 (9.0–9.1)	1.28 (1.22–1.35)	1.22 (1.16–1.27)	1.14 (1.09–1.19)
Percentile 99	72.2	76.2	78.2	19.6 (19.5–19.6)	17.4 (17.3–17.4)	12.2 (12.1–12.2)	1.37 (1.31–1.44)	1.30 (1.24–1.36)	1.18 (1.13–1.24)
Probability of surviving up to age 40 years (%)									
Percentile 1	72.9	79.6	90.1	0.0	0.0	0.0	1.00	1.00	1.00
Percentile 25	82.0	86.7	92.9	9.1 (9.0–9.1)	7.1 (7.0–7.1)	2.8 (2.8–2.9)	1.12 (1.08–1.17)	1.09 (1.04–1.13)	1.03 (0.99–1.07)
Percentile 50	87.3	90.7	93.9	14.4 (14.3–14.4)	11.0 (11.0–11.0)	3.8 (3.8–3.8)	1.20 (1.15–1.25)	1.14 (1.09–1.18)	1.04 (1.00–1.08)
Percentile 75	90.2	92.3	94.7	17.3 (17.3–17.4)	12.7 (12.6–12.7)	4.6 (4.6–4.6)	1.24 (1.19–1.29)	1.16 (1.11–1.20)	1.05 (1.01–1.09)
Percentile 99	94.1	95.0	96.6	21.2 (21.1–21.2)	15.4 (15.4–15.4)	6.5 (6.5–6.5)	1.29 (1.24–1.34)	1.19 (1.15–1.24)	1.07 (1.03–1.11)
Probability of surviving up to age 60 years (%)									
Percentile 1	50.8	60.7	74.4	0.0	0.0	0.0	1.00	1.00	1.00
Percentile 25	63.9	71.9	81.0	13.1 (13.0–13.1)	11.1 (11.1–11.2)	6.5 (6.5–6.6)	1.26 (1.20–1.32)	1.18 (1.13–1.24)	1.09 (1.04–1.13)
Percentile 50	70.1	76.7	82.9	19.3 (19.2–19.4)	16.0 (15.9–16.0)	8.4 (8.4–8.5)	1.38 (1.32–1.45)	1.26 (1.21–1.32)	1.11 (1.07–1.16)
Percentile 75	75.4	79.7	84.6	24.6 (24.6–24.7)	19.0 (18.9–19.0)	10.1 (10.1–10.2)	1.48 (1.41–1.56)	1.31 (1.25–1.37)	1.14 (1.09–1.19)
Percentile 99	83.5	85.8	89.3	32.6 (32.6–32.7)	25.1 (25.0–25.1)	14.8 (14.8–14.9)	1.64 (1.57–1.72)	1.41 (1.35–1.48)	1.20 (1.15–1.25)

CI: confidence interval.

there was a positive association between the three outcomes and per capita income, i.e., the proportion of people in formal employment, the proportion of households with water and bathroom, and the ratio of doctors per inhabitant. These counties' socio-economic and health services indicators explained 86.7%, 31.2%, and 32.4% of the variation in LE attributable to regions, states, and counties, respectively.

Discussion

This study has five major findings: (i) all Brazilian municipalities showed increased LE, p40, and p60 between 1990 and 2010; (ii) higher increases were observed in the North and Northeast regions; (iii) there was a remarkable reduction in geographic inequality in all indicators, but in 2010, the lowest values were still observed in the North and Northeast regions; (iv) counties and regions accounted for the major part of the total variability of the outcomes; (v) each counties' socio-economic and health services indicators explained an expressive proportion of the LE variation attributable to regions, states and counties.

To the best of our knowledge, this is the first study analyzing the evolution of geographic disparities in life expectancy in Brazil according to municipalities, partitioning the variance, and testing the association of the outcome with municipal socio-economic and health variables. One previous study analyzed the evolution of life expectancy in Brazilian macroregions and reported that the differences between the Northeast and Southeast regions increased between 1940 and 1960.[16] A convergence of values began to be observed from the 1970s onward. The present study, when analyzing the municipality data, shows that the differences between the poorer regions (North and Northeast), compared to the richer ones (South and Southeast), decreased over the 20-year period analyzed and were seen for all indicators analyzed (LE and the probability of surviving up to ages 40 and 60 years).

Globally, reductions in geographic disparities in LE were also reported in Korea and Mexico. Jo et al.[17] analyzed data from 2005 to 2013 and found out that life expectancy increased in all 16 subnational Korean regions, and that the minimum and maximum ranges of LE decreased from 5.93 years in 2005 to 2.54 years in 2011. In Mexico, Gomez-Dantés et al.[18] and Pelaez et al.[19] also described a process of internal convergence of life expectancy among federal entities. Pelaez et al.[19] described limited life expectancy growth in more advanced regions. Gomez-Dantés et al.[18] reported that states with high or very high marginalization presented the largest increases in life expectancy (the gap narrowed from 6.2 years in 1990 to 5.5 years in 2013). In China, discrepancies in life expectancy at birth between all provinces presented a slight decrease between 1990 and 2008, but within-region inequalities remained stable, and the overall increase in the indicator was very modest.[20]

In many countries, however, studies have reported widening disparities in life expectancy among subnational regions.[6,21] In trying to explain this trend, some authors have pointed to economic crises, austerity policies, cuts in public investment, and growing national income inequalities.[5,8,10] That may help to explain why countries have failed in reducing health inequalities. In addition, Turner et al.[22] outline the (i) lack of attention to social/economic inequality, (ii) failure to prioritize prevention, early diagnosis, and treatment in primary care, (iii) lack of performance management and (iv) insufficient scientific base to sustain public policies. In order to tackle inequalities in LE, Mackenbach[23] highlights the necessity of targeting income inequalities and working conditions and emphasizes that the use of effective policies delivered at a large scale is decisive.

What is remarkable in the Brazilian case is that, besides the narrowing geographic gap trend, LE increased in all municipalities, and the national increase of LE, SU40, and SU60 was very expressive. These results are strongly associated with the striking decline in infant mortality rate (IMR) observed in Brazil in the second half of the 20th century. For instance, the IMR was 80 deaths per 1000 live births in 1980, 48 in 1990, 29 in 2000, and 17.2 in 2010.[24] The decline in the disparities of IMR among Brazilian regions also helps to explain the reduction in regional inequalities in LE, SU40, and SU60. In 1990, the absolute difference in IMR between the Northeast and the South was 47.5; in 2010, the value reached 11.5.[24] Over the last few decades, Brazil has experienced a mortality decline among adults, including older adults, which has had an impact on overall life expectancy variations.

During this period, Brazil made important improvements in increasing the population's education level and expanding the coverage of sanitation services. In the early 1990s, the new public health system (SUS) began to dramatically expand and decentralize health services, strengthening primary health care, increasing immunization rates, and offering comprehensive care.[25] Many studies have provided evidence of the positive impact of the Brazilian

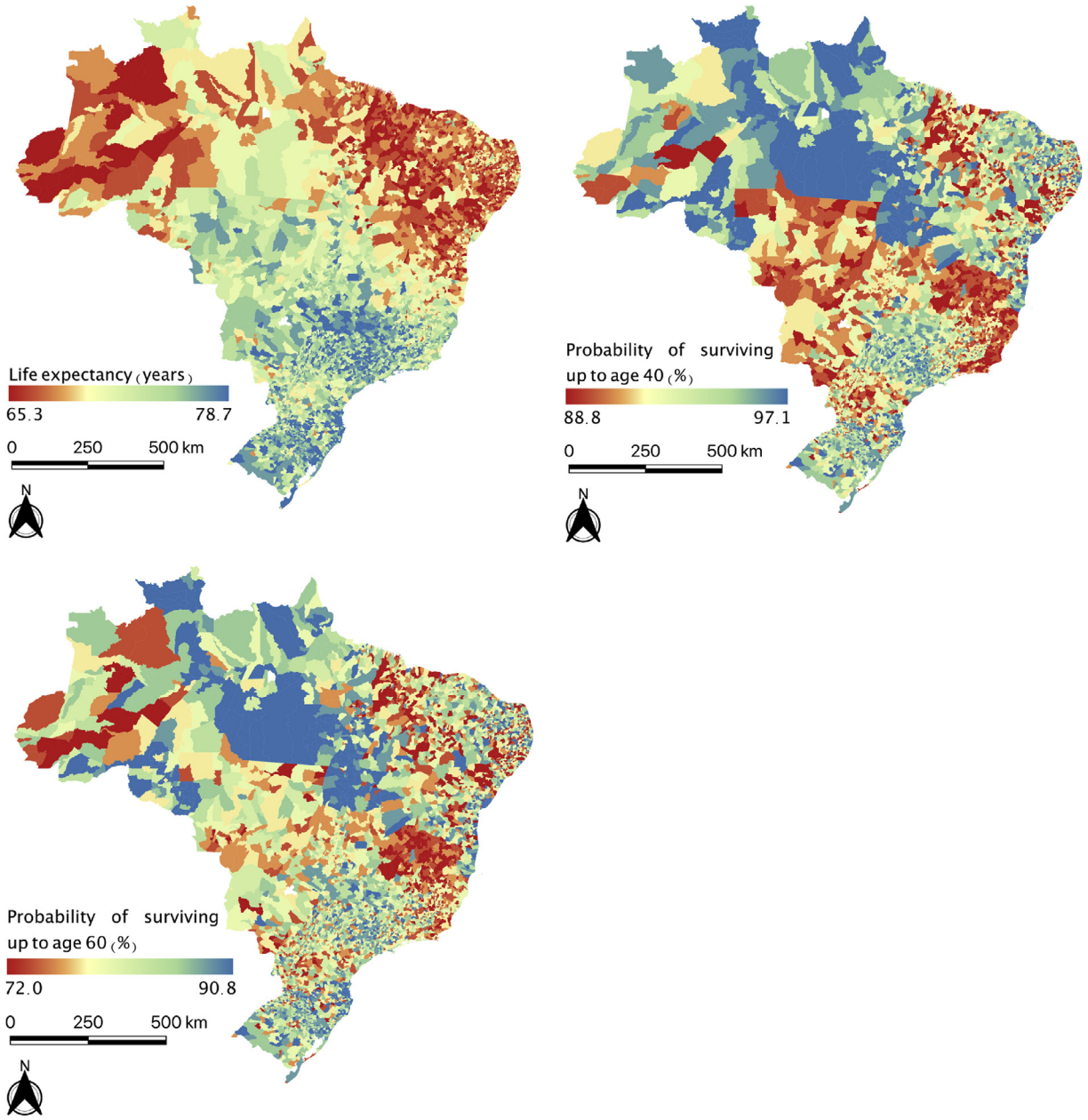

Fig. 2. Life expectancy at birth, probability of surviving up to ages 40 and 60 years by county. Brazil, 2010.

public health system.[26,27] Moreover, in the 1990s, despite problems with high-interest rates, low public budget allocation for social policies, and difficulties in tackling inequalities, Brazil was successful in controlling inflation.[12] In the first decade of the 2000s, there was an important expansion of the public health sector budget and many strong social policies, such as Programa Bolsa Família, the Brazilian cash transfer program, were developed and have had an important impact on health indicators.[28,29]

During the same period, the gross domestic product of the Northeast region increased more than the national average and 30% more than that of the South. Social programs targeting poverty also had major impacts in the North and Northeast.[30] Between 1991 and 2010, these two regions experienced the highest increase in expected years of study and employment rate and the highest decrease in poverty. Nonetheless, in 2010, in general, they still had the worst social and economic indicators compared to the South and Southeast.[14] That helps to explain why, in spite having narrowed, the regional gap is still significant.

The outcomes of the present study were associated with the municipal socio-economic variables analyzed. In the United States, the socio-economic and race/ethnicity factors explained 60% of the county-level variation in life expectancy. The literature corroborates this finding, indicating that unemployment is associated with increased risk of all-cause mortality[31] and has an important influence on LE.[32] Regarding income, other studies also corroborate its effect on LE. In the United States, between 1980 and 2015, its association with LE became stronger over time.[33] When analyzing income data at the county level in the United States, Allen et al.[34] observed a positive correlation with LE ($r = 0.68$). The same association was reported in China by Wang and Ren.[35]

In China, an upper-middle-income country like Brazil, Jiang et al.[36] reported that different dimensions of social development

Table 2
Variance estimates, standard errors, and variance partition coefficient (VPC) in life expectancy at birth, probability of surviving up to ages 40 and 60 years. Brazil, 1991, 2000, and 2010.

	Life expectancy	Probability of surviving up to age 40 years	Probability of surviving up to age 60 years
Difference between 2010 and 1991			
Region			
VE (SE)	2.19	18.56	26.88
% VPC	29.6%	75.3%	62.8%
State			
VE (SE)	1.04	1.49	3.21
% VPC	14.1%	6.0%	7.5%
County			
VE (SE)	4.15	4.60	12.69
% VPC	56.3%	18.7%	29.7%
2010			
Region			
VE (SE)	3.47	0.56	1.22
% VPC	55.5%	27.1%	14.4%
State			
VE (SE)	0.32	0.49	0.95
% VPC	5.0%	23.7%	11.4%
County			
VE (SE)	2.47	1.02	6.15
% VPC	39.5%	49.2%	73.9%

VE: variance; SE: standard error; VPC: variance partitioning coefficient.

Table 3
Association between county's socio-economic and health services variables with life expectancy at birth, probability of surviving up to ages 40 and 60 years according to multilevel regression models, Brazil, 2010.

	Crude model			Adjusted model		
	LE β (95% CI)	P40 β (95% CI)	P60 β (95% CI)	LE β (95% CI)	P40 β (95% CI)	P60 β (95% CI)
% of illiteracy						
2nd quartile	−1.12 (−1.23;-1.29)	−0.64 (−0.71;-0.57)	−1.63 (−1.80;-1.45)	−0.56 (−0.68;-0.44)	−0.31 (−0.39;-0.24)	−0.81 (−1.00;-0.62)
3rd quartile	−2.23 (−2.37;-2.10)	−1.35 (−1.44;-1.27)	−3.31 (−3.52;-3.10)	−0.92 (−1.08;-0.75)	−0.55 (−0.66;-0.44)	−1.34 (−1.61;-1.08)
4th quartile	−3.43 (−3.61;-3.26)	−2.15 (−2.26;-2.04)	−5.29 (−5.56;-5.02)	−1.49 (−1.70;-1.28)	−0.94 (−1.08;-0.81)	−2.31 (−2.65;-1.98)
Per capita income						
2nd quartile	1.24 (1.13; 1.36)	0.81 (0.74; 0.89)	2.05 (1.86; 2.23)	0.73 (0.60; 0.86)	0.48 (0.39; 0.56)	1.20 (0.99; 1.41)
3rd quartile	2.66 (2.50; 2.81)	1.71 (1.61; 1.81)	4.18 (3.94; 4.42)	1.57 (1.38; 1.75)	1.01 (0.89; 1.14)	2.48 (2.18; 2.78)
4th quartile	3.70 (3.54; 3.86)	2.31 (2.20; 2.41)	5.69 (5.43; 5.95)	2.12 (1.90; 2.34)	1.32 (1.18; 1.46)	3.28 (2.93; 3.63)
% formal employment						
2nd quartile	0.65 (0.53; 0.76)	0.42 (0.34; 0.49)	1.03 (0.85; 1.21)	0.18 (0.07; 0.28)	0.11 (0.04; 0.18)	0.27 (0.10; 0.44)
3rd quartile	1.33 (1.21; 1.45)	0.85 (0.77; 0.93)	2.08 (1.89; 2.28)	0.24 (0.12; 0.37)	0.16 (0.08; 0.24)	0.38 (0.18; 0.58)
4th quartile	2.08 (1.94; 2.22)	1.30 (1.20; 1.38)	3.18 (2.96; 3.40)	0.41 (0.26; 0.56)	0.26 (0.16; 0.36)	0.63 (0.39; 0.88)
% households with water and bathroom						
2nd quartile	1.01 (0.88; 1.14)	0.65 (0.57; 0.74)	1.65 (1.44; 1.85)	0.27 (0.14; 0.39)	0.17 (0.08; 0.25)	0.44 (0.24; 0.64)
3rd quartile	2.01 (1.84; 2.18)	1.27 (1.16; 1.38)	3.12 (2.85; 3.40)	0.37 (0.20; 0.55)	0.23 (0.12; 0.34)	0.56 (0.29; 0.84)
4th quartile	2.40 (2.22; 2.57)	1.50 (1.39; 1.62)	3.69 (3.40; 3.97)	0.49 (0.30; 0.67)	0.30 (0.18; 0.42)	0.73 (0.43; 1.02)
% FHP coverage						
2nd tertile	−0.14 (−0.29; 0.01)	−0.07 (−0.17; 0.02)	−0.19 (−0.43; 0.06)	−0.03 (−0.16; 0.09)	−0.02 (−0.10; 0.07)	−0.04 (−0.25; 0.16)
3rd tertile	−0.71 (−0.84;-0.58)	−0.44 (−0.52;-0.35)	−1.06 (−1.26;-0.86)	−0.08 (−0.20; 0.03)	−0.06 (−0.14; 0.01)	−0.13 (−0.31; 0.05)
Physician/inhabitant						
2nd quartile	0.24 (0.12; 0.35)	0.16 (0.08; 0.23)	0.39 (0.21; 0.57)	0.08 (−0.02; 0.18)	0.06 (−0.01; 0.12)	0.14 (−0.02; 0.30)
3rd quartile	0.60 (0.49; 0.72)	0.38 (0.31; 0.46)	0.96 (0.78; 1.14)	0.20 (0.10; 0.30)	0.13 (0.06; 0.19)	0.32 (0.16; 0.49)
4th quartile	1.27 (1.15; 1.39)	0.77 (0.70; 0.85)	1.94 (1.75; 2.13)	0.37 (0.26; 0.48)	0.21 (0.14; 0.28)	0.57 (0.39; 0.74)

LE: life expectancy; P40: probability of surviving up to age 40 years; P60: probability of surviving up to age 60 years; CI: confidence interval; FHP: family health program.

influence LE in the regions of the country, in addition to economic factors. The authors found out that education and health-services indicators play an important role in explaining temporal and geographic variation in life expectancy.[36] When we analyzed the number of physicians per capita in the present study, we found a direct association. The literature has shown a positive association between living in areas with more physicians (especially primary care doctors) and LE, independent of the country's income.[37,38] Brazil had an increase in the density of physicians between 1990 (1.48 doctors per 1000 inhabitants) and 2010 (1.91 doctors per 1000 inhabitants). This increase can be explained by the opening of new medical schools and the authorization of more undergraduate vacancies throughout the country.

Over two decades of economic and social advances, Brazil was capable of reducing geographic inequalities in life expectancy and increasing the probability of surviving up to 40 and 60 years of age. The importance of economic stability and GDP growth associated with redistributive and pro-poor policies is well known and should be part of the national agenda for the years ahead. Nonetheless, since 2015, Brazil has been experiencing low economic growth and implemented austerity measures that have cut public investment in social policies. It will be important to monitor the evolution of

health indicators and socio-economic inequalities in the following years.

Author statements

Ethical approval

For this type of study, ethical approval is not required. We used Census data aggregated by municipalities and with no identification of the individuals.

Funding

National Council of Scientific Development - CNPq - for granting financial resources (205120/2018-0).

Competing interests

The authors declare no conflict of interests.

References

1. Collaborators GM. Global, regional, and national age-sex-specific mortality and life expectancy, 1950-2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;**392**(10159):1684–735.
2. Brasil. *Instituto Brasileiro de Geografia e Estatística (IBGE). Síntese de indicadores sociais: uma análise das condições de vida da população brasileira: 2016*. Rio de Janeiro: IBGE; 2016.
3. Brasil. *Instituto Brasileiro de Geografia e Estatística (IBGE). Tendências demográficas: uma análise dos resultados da amostra do censo demográfico 2000*. Rio de Janeiro: IBGE; 2004.
4. Van Oyen H, Charafeddine R, Deboosere P, Cox B, Lorant V, Nusselder W, Demarest S. Contribution of mortality and disability to the secular trend in health inequality at the turn of century in Belgium. *Eur J Public Health* 2011 Dec;**21**(6):781–7.
5. Brønnum-Hansen H, Baadsgaard M. Widening social inequality in life expectancy in Denmark. A register-based study on social composition and mortality trends for the Danish population. *BMC Public Health* 2012;**12**:994.
6. Dwyer-Lindgren L, Bertozzi-Villa A, Stubbs RW, Morozoff C, Mackenbach JP, van Lenthe FJ, Mokdad AH, Murray CJL. Inequalities in life expectancy among US counties, 1980 to 2014: temporal trends and keydrivers. *JAMA Intern Med* 2017;**177**(7):1003–11.
7. Newton JN, Briggs AD, Murray CJ, Dicker D, Foreman KJ, Wang H, et al. Changes in health in England, with analysis by English regions and areas of deprivation, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015;**386**(10010):2257–74.
8. Gheorghe M, Wubulihasimu P, Peters F, Nusselder W, Van Baal PH. Health inequalities in The Netherlands: trends in quality-adjusted life expectancy (QALE) by educational level. *Eur J Public Health* 2016;**26**(5):794–9.
9. Leinsalu M, Vågerö D, Kunst AE. Estonia 1989-2000: enormous increase in mortality differences by education. *Int J Epidemiol* 2003;**32**(6):1081–7.
10. Pearce J, Dorling D. Increasing geographical inequalities in health in New Zealand, 1980-2001. *Int J Epidemiol* 2006;**35**(3):597–603.
11. Murphy M, Bobak M, Nicholson A, Rose R, Marmot M. The widening gap in mortality by educational level in the Russian Federation, 1980-2001. *Am J Public Health* 2006;**96**(7):1293–9.
12. Neri MC. Pobreza e políticas sociais na década da redução da desigualdade. *Nueva Soc* 2007;**3**:53–73.
13. Kim R, Subramanian SV. What's wrong with understanding variation using a single-geographic scale? A multilevel geographic assessment of life expectancy in the United States. *Proc Environ Sci* 2016;**36**:4–11.
14. *Programa das Nações Unidas para o Desenvolvimento (PNUD), Instituto de Pesquisa Econòmica Aplicada (Ipea), Fundação João Pinheiro (FJP)*. Atlas de Desenvolvimento Humano: PNUD, Ipea, FJP; 2013.
15. Brass W. Perspectives in population prediction: illustrated by the statistics of England and Wales. *J R Stat Soc* 1974;**137**:532–70.
16. Borges GM. Health transition in Brazil: regional variations and divergence/convergence in mortality. *Cad Saúde Pública* 2017;**33**(8):e00080316.
17. Jo MW, Seo W, Lim SY, Ock M. The trends in health life expectancy in Korea according to age, gender, education level, and subregion: using quality-adjusted life expectancy method. *J Korean Med Sci* 2019;**34**(Suppl 1):e88.
18. Gómez-Dantés H, Fullman N, Lamadrid-Figueroa H, Cahuana-Hurtado L, Darney B, Avila-Burgos L, et al. Dissonant health transition in the states of Mexico, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2016;**388**(10058):2386–402.
19. Peláez O, Guijarro M, Arias M. A state-level analysis of life expectancy in Mexico (1990-2006). *J Biosoc Sci* 2010;**42**(6):815–26.
20. Li Y. The spatial variation of China's regional inequality in human development. *Reg Sci Policy Pract* 2012;**4**(3):263–78.
21. Zubarevich NV, Safronov SG. Regional inequality in large post-soviet countries. *Reg Res Russia* 2011;**1**:17–30.
22. Simões CCS. Breve histórico do processo demográfico. In: Figueiredo AH, editor. *Brasil: uma visão geográfica e ambiental no início do século XXI*. Rio de Janeiro: IBGE; 2016.
23. Turner D, Salway S, Mir G, Ellison GT, Skinner J, Carter L, Bostan B. Prospects for progress on health inequalities in England in the post-primary care trust era: professional views on challenges, risks and opportunities. *BMC Public Health* 2013 26;**13**:274.
24. Mackenbach JP. Can we reduce health inequalities? An analysis of the English strategy (1997-2010). *J Epidemiol Community Health* 2011;**65**(7):568–75.
25. Paim J, Travassos C, Almeida C, Bahia L, Macinko J. The Brazilian health system: history, advances, and challenges. *Lancet* 2011;**377**(9779):1778–97.
26. Macinko J, Guanais FC, de Fátima M, de Souza M. Evaluation of the impact of the family health program on infant mortality in Brazil, 1990-2002. *J Epidemiol Community Health* 2006 Jan;**60**(1):13–9.
27. Dourado I, Oliveira VB, Aquino R, Bonolo P, Lima-Costa MF, Medina MG, Mota E, Turci MA, Macinko J. Trends in primary health care-sensitive conditions in Brazil: the role of the Family Health Program (Project ICSAP-Brazil). *Med Care* 2011 Jun;**49**(6):577–84.
28. de Souza RA, Nery JS, Rasella D, Guimarães Pereira RA, Barreto ML, Rodrigues L, Pereira SM. Family health and conditional cash transfer in Brazil and its effect on tuberculosis mortality. *Int J Tuberc Lung Dis* 2018 Nov 1;**22**(11):1300–6.
29. Machado DB, Rodrigues LC, Rasella D, Lima Barreto M, Araya R. Conditional cash transfer programme: impact on homicide rates and hospitalisations from violence in Brazil. *PLoS One* 2018 Dec 31;**13**(12):e0208925.
30. São Paulo. Fundação Sistema Estadual de Análise de Dados. PIB anual [internet]. [cited 2019 Jen2]. Available from: http://www.seade.gov.br/produtos/pib-anual/.
31. Roelfs DJ, Shor E, Davidson KW, Schwartz JE. Losing life and livelihood: a systematic review and meta-analysis of unemployment and all-cause mortality. *Soc Sci Med* 2011;**72**(6):840–54.
32. Bai R, Wei J, An R, Li Y, Collett L, Dang S, et al. Trends in life expectancy and its association with economic factors in the belt and road countries-evidence from 2000-2014. *Int J Environ Res Public Health* 2018;**15**(12).
33. Bor J, Cohen GH, Galea S. Population health in an era of rising income inequality: USA, 1980-2015. *Lancet* 2017;**389**(10077):1475–90.
34. Allen RT, Hales NM, Baccarelli A, Jerrett M, Ezzati M, Dockery DW, et al. Countervailing effects of income, air pollution, smoking, and obesity on aging and life expectancy: population-based study of U.S. Counties. *Environ Health* 2016;**15**(1):86.
35. Wang S, Ren Z. Spatial variations and macroeconomic determinants of life expectancy and mortality rate in China: a county-level study based on spatial analysis models. *Int J Public Health* 2019;**64**(5):773–83.
36. Jiang J, Luo L, Xu P, Wang P. How does social development influence life expectancy? A geographically weighted regression analysis in China. *Public Health* 2018;**163**:95–104.
37. Vogel L. Life expectancy grows with supply of primary care doctors. *CMAJ (Can Med Assoc J)* 2019;**191**(12):E347.
38. Basu S, Berkowitz SA, Phillips RL, Bitton A, Landon BE, Phillips RS. Association of primary care physician supply with population mortality in the United States, 2005-2015. *JAMA Intern Med* 2019;**2019179**(4):506–14.
39. http://atlasbrasil.org.br/2013/en/.