Impact of global warming on Potential Years of Life Lost by cardiopulmonary diseases in Brazilian capital cities

Impacto do aquecimento global nos anos potenciais de vida perdidos por doenças cardiorrespiratórias em capitais brasileiras

Ludmilla da Silva Viana Jacobson[a]

Beatriz Fátima Alves de Oliveira[b]

Letícia Palazzi Perez[c]

Sandra de Souza Hacon[d]

[a] *Doctor in Collective Health by the Social Medicine Institute, (IMS/UERJ), Federal Fluminense University (UFF), Niterói, RJ, Brazil*
E-mail: ludmillaviana@yahoo.com.br

[b] *Doctor in Sciences by the Sério Arouca National School of Public Health (ENSP/FIOCRUZ), Oswaldo Cruz Foundation Regional Office in the state of Piauí, Teresina, PI, Brazil*
E-mail: beatrizenf@gmail.com

[c] *Doctor in Physical Geography, Federal University of Paraíba (UFPB) João Pessoa, PB, Brazil*
E-mail: leticia.palazzi@gmail.com

[d] *Doctor in Geosciences by the Federal Fluminense University (UFF), National School on Public Health (ENSP/FIOCRUZ), Rio de Janeiro, RJ, Brazil*
E-mail: sandrahacon@gmail.com

doi:10.18472/SustDeb.v11n3.2020.33989

Received: 08/09/2020
Accepted: 11/11/2020

ARTICLE – DOSSIER

Data and results presented in this article were developed under the project of the "Fourth National Communication and Biennial Update Reports of Brazil to the Climate Convention", coordinated by the Ministry of Science, Technology and Innovations, with the support of the United Nations Program for the Development, through the resources of the Global Environment Facility, to which we offer our thanks.

ABSTRACT

This study aims at assessing the future impact of global warming in the Potencial Years of Life Lost (YLL) for cardiovascular diseases in adults (≥45 years) and respiratory diseases in the elderly (≥60 years). This is an ecological study, which includes all the capitals of Brazil. Future projections used temperature data sourced from the Eta-HadGEM2S Regional Model for the RCP8.5 scenario. YLL fractions attributable to temperature were estimated for global warming scenarios of 1.5°C, 2.0°C, and 4.0°C. The results showed that, in absolute numbers, Rio de Janeiro and São Paulo have presented the largest YLL contribution attributable to global warming among the capital cities. Campo Grande and Cuiabá were the most impacted capitals by a global warming of 1.5ºC compared to the baseline period (1961-2005), both for respiratory diseases in the elderly and for cardiovascular diseases in adults. Results of this research suggest that the impact of exposure to temperature on YLL tends to increase as the level of global warming increases.

Keywords: Climate Change. Temperature. Potential of Life Lost (YLL). Cardiovascular Diseases. Respiratory Diseases.

RESUMO

Este estudo tem o objetivo de avaliar o impacto futuro do aquecimento global nos Anos Potenciais de Vidas Perdidos (YLL) para as doenças cardiovasculares em adultos (≥ 45 anos) e respiratória em idosos (≥ 60 anos). Trata-se de um estudo ecológico, que inclui todas as capitais do Brasil. Nas projeções futuras, foram usados os dados de temperatura do Modelo Regional Eta-HadGEM2S para o cenário RCP 8.5. Foram estimadas as frações de YLL atribuíveis à temperatura para os níveis de aquecimento 1,5°C, 2,0°C e 4,0°C. Em números absolutos, Rio de Janeiro e São Paulo apresentaram a maior contribuição de YLL atribuível ao aquecimento global. Campo Grande e Cuiabá foram as capitais mais impactadas pelo aquecimento global de 1,5ºC comparado ao período baseline (1961-2005) para os dois desfechos avaliados. Os resultados desta pesquisa sugerem que o impacto da exposição à temperatura sobre o YLL tende a crescer conforme aumenta o nível de aquecimento global.

Palavras-chave: Mudanças climáticas. Temperatura. Anos potenciais de vida perdidos. YLL. Doenças cardiovasculares. Doenças respiratórias.

1 INTRODUCTION

In the past few decades, interest in climate change effects has increased due to the evidence of extreme events, such as the increase in heat waves, as well as projections of global temperature increase by the end of the century, which indicate a higher frequency of temperature extremes, increased rainfall and disasters (BARRETT; CHARLES; TEMTE, 2015; ROSSATI, 2017).

Under the Paris Agreement, governments have committed to implementing measures to hold the increase in global average temperature below 2°C above pre-industrial levels and to limit this temperature increase to 1.5ºC. Under the Agreement, the Brazilian Government committed to cutting 37% of its greenhouse gas emissions by 2025. Temperature projections based on the Eta-HadGEM2S Regional Model show the warming of 1.5ºC has been occurring in Brazil since 2010 (CHOU et al., 2014). Since the passing of the National Policy on Climate Change, establishing the first goal of reducing greenhouse gas emissions, the country had increased emissions of these gases by 28.2% (ALBUQUERQUE et al., 2020).

Land-use changes, aggravated by deforestation, are still the main cause of emissions. The Brazilian scenario contributes directly to the increased risk of mortality from cardiopulmonary diseases, as well as from comorbidities, especially in more vulnerable groups, such as the elderly, pregnant women, and those with previous diseases.

Studies suggest direct and indirect climate change effects on health. The direct association relates to the occurrence of non-communicable diseases, including, but not limited to cardiovascular and respiratory diseases; while the indirect association is related to transmittable diseases, such as vector and waterborne diseases caused by changes in ecosystems and biogeochemical cycles (SOUSA et al., 2018). There is evidence of negative impacts of climate variations on mortality (GUO et al., 2016), as well as future projections of increased deaths attributable to heat waves mainly in tropical and subtropical regions (GUO et al., 2018). Some studies point at temperature as a crucial determining factor for health.

Socioeconomic factors and access to health services were identified as important issues and modifiers of climate change effects on health (ZANOBETTI and O'NEIL, 2018), and some population groups, such as children, the elderly, and people with disabilities, are pointed out as more vulnerable to climatic variations (BUNKER et al., 2016; LI et al., 2016; WANG et al., 2017; HARTWIG and IGNOTTI, 2019; HARTWIG et al., 2019).

The Years of Life Lost (YLL) indicator was recommended as the most appropriate measurement tool in the construction of a ranking with the main causes of death at a given location (PEIXOTO E SOUZA, 1999). According to Werneck and Reichenheim (1992), the YLL indicator "qualifies deaths", as it incorporates the vulnerability criterion through sex and age variables, used in the construction of the index. Compared to mortality rates, YLL has been widely used as a more informative indicator to quantify premature death (ZHANG et al., 2018).

Thus, YLL is an often-used indicator to assess the impact of general mortality or mortality due to a specific problem for society and health services. This indicator considers life expectancy at the time of death (SEWE et al., 2018) and contributes to the establishment of health priorities for a given location.

In the context of climate changes, this indicator has been underused (HUANG et al., 2018, LI et al. 2018, ZHANG et al., 2018), however, a study suggests an increase in YLL for cardiovascular diseases in the elderly, even considering a future scenario with adaptation (HUANG et al., 2018). Li et al. (2018) concluded that YLL attributable to temperature may increase if global warming exceeds 2ºC.

There are still no studies in Brazil that use YLL to measure the health impacts of temperature exposure. Estimating future health impacts associated with exposure to temperature has the potential to contribute to the definition of priorities for risk management. Hence, this study aims at assessing the future impact of global warming on the disease burden, using the YLL indicator for cardiovascular diseases in adults and respiratory diseases in the elderly.

2 MATERIAL AND METHODS

This is an ecological study, which includes all the capitals of Brazil and the Federal District.

The burden of disease was measured by the Years of Life Lost (YLL) indicator. In calculating the indicator, a Mortality Table or Life Table was made available on the World Health Organization website (WHO, 2020: https://apps.who.int/gho/data/view.main.60220?lang=en, last accessed on 16 Aug 2020). The table estimates Life Expectancy in Brazil according to age, sex, and year. For this article's assessment, the daily total of YLL for the period from 2000 to 2010 was considered for all the country's capitals.

Mortality data were sourced from the Mortality Information System (SIM, in the Portuguese acronym). The health outcomes assessed were deaths from cardiovascular diseases (ICD10: I00 to I99) for people aged 45 or more; and mortality from respiratory diseases (ICD 10: J00 to J99) for people aged 60 or more.

Future projections used temperature data sourced from the Eta-HadGEM2S Regional Model for the scenario of high greenhouse gas emissions (RCP8.5), calibrated according to the method presented by Hempel et al. (2013). Quantification of future impacts for global warming of 1.5°C (2010-2039), 2.0°C (2040-2069), and 4.0°C (2070-2099) were conducted by the calculation of YLL fractions attributable to temperature.

Future impacts were quantified by attributable fractions calculated by the method used by Gasparrini et al. (2017). At first, concentration-response curves were estimated using Distributed Lag Non-linear

Models (DLNM), in which the average daily temperatures from the *Era-Interim do European Centre for Medium-Range Weather Forecasts (ECMWF)* model were considered for exposure and daily deaths, from 2000 to 2010. The health outcomes assessed were the same ones proposed in the present study. Details of these assessments will be presented in the Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change (UNFCCC). Next, the estimated concentration-response curves for each capital city were projected for the future, using the temperature data of the Eta-HadGEM2S Regional Model.

In order to calculate the attributable fractions (which are the percentages that can be attributed to climate change), initially a 365-day YLL daily time-series was constructed for each capital city and health outcome investigated (type of occurrence/disease), through daily averages, from 2000 to 2010 (Figure 1). For example, day 1 of the time series represents January 1st. Then, daily contributions of the YLL attributable to temperature were calculated, assuming population distribution and constant deaths, and using the concentration-response curves projected for the future.

Finally, YLL attributable to temperature exposure were aggregated, according to specific periods of global warming scenarios. The fractions attributable to heat, cold and total impact (heat + cold) were calculated. Heat is associated with temperatures above minimum risk temperatures (MRT), while cold is associated with temperatures below MRT. As for uncertainties, 95% empirical confidence intervals were calculated for attributable fractions based on the Monte Carlo simulation method (GASPARRINI et al., 2017).

Analyses were conducted in the R program (2017), and the main packages were *dlnm* (GASPARRINI, 2011) and *mvmeta* (GASPARRINI; ARMSTROG; KENWARD, 2012).

3 RESULTS

Table 1 presents estimates of average annual total YLL calculated through the daily time-series (Figure 1). In terms of absolute numbers, Rio de Janeiro and São Paulo presented the highest YLL contribution among capital cities. Minimum risk temperatures (MRT) estimated by concentration-response curves were higher for deaths from cardiovascular diseases in adults than for deaths from respiratory diseases in the elderly.

Table 1 | Total annual estimates of Potential Years of Life Lost (YLL), minimum risk temperatures and average temperature projections.

Capital /Region	*YLL*		*Minimum risk temperatures (ºC)**		*Global Warming Average Temperature**			
	*DR***	*DC*	*DR*	*DC*	*Baseline*	*1.5ºC*	*2.0ºC*	*4.0ºC*
NORTHERN								
Belém	3398	10877	24.6	25.6	26.3	27.9	29.3	31.5
Boa Vista	175	1173	24.1	25.8	26.8	28.8	30.7	33.1
Macapá	273	1380	24.5	28.7	25.7	27.5	29.2	31.3
Manaus	1850	7559	24.2	29.9	25.8	27.8	29.7	33.4
Palmas	97	749	24.0	31.2	25.9	28.5	30.2	32.7
Porto Velho	507	2347	23.4	25.5	24.8	27.1	28.9	31.7
Rio Branco	477	1425	26.4	26.4	24.3	26.8	28.5	31.4
NORTHEASTERN								
Aracaju	851	4310	23.5	28.4	25.8	27.0	28.2	29.7
Fortaleza	3588	14032	25.3	28.5	26.6	27.7	29.0	30.4
Joao Pessoa	1136	5881	23.9	28.2	25.8	27.0	28.3	29.8

Capital /Region	YLL		Minimum risk temperatures (ºC)*		Global Warming Average Temperature*			
	DR**	DC	DR	DC	Baseline	1.5ºC	2.0ºC	4.0ºC
Maceió	1683	9540	26.4	28.1	25.2	26.5	27.7	29.2
Natal	1127	6940	24.0	28.4	25.9	27.2	28.4	29.8
Recife	3560	20711	22.9	27.8	25.0	26.2	27.5	28.9
Salvador	5005	23946	27.0	28.2	25.3	26.6	27.9	29.4
São Luís	1027	6535	26.7	29.0	26.8	28.0	29.4	31.1
Teresina	1119	7422	24.8	25.8	27.9	29.4	31.0	32.9
CENTER-WEST								
Brasília	2341	17591	24.0	27.9	22.2	25.0	26.7	29.0
Campo Grande	1451	7927	25.6	26.8	23.2	26.6	28.0	30.9
Cuiabá	842	4588	25.4	26.6	25.1	28.4	29.8	32.8
Goiânia	2243	11503	24.6	25.7	22.9	26.1	27.8	30.4
SOUTHEASTERN								
Belo Horizonte	4939	24958	22.5	25.6	20.5	23.0	24.4	26.7
Rio de Janeiro	21219	92695	24.4	26.0	23.1	24.8	25.7	27.5
São Paulo	28265	140890	25.6	26.3	19.9	22.2	23.3	25.5
Vitoria	351	3118	19.5	27.8	23.7	25.0	26.0	27.6
SOUTHERN								
Curitiba	3837	19108	23.5	25.4	18.2	20.4	21.3	23.4
Florianópolis	639	3153	23.6	25.8	21.0	22.1	22.8	24.3
Porto Alegre	4217	19784	25.9	26.3	18.7	20.4	21.1	22.8

Note: *baseline = 1961 to 2005, 1.5ºC = 2010 to 2039, 2.0ºC = 2040 to 2069; 4.0ºC = 2070 to 2099; MRT = Minimum Risk Temperature, estimated in the 4NC project for the period from 2000 to 2010 (ERA-Interim). **DR – Respiratory Disease in the elderly, DC – Cardiovascular disease in adults.

Source: Elaborated by the authors

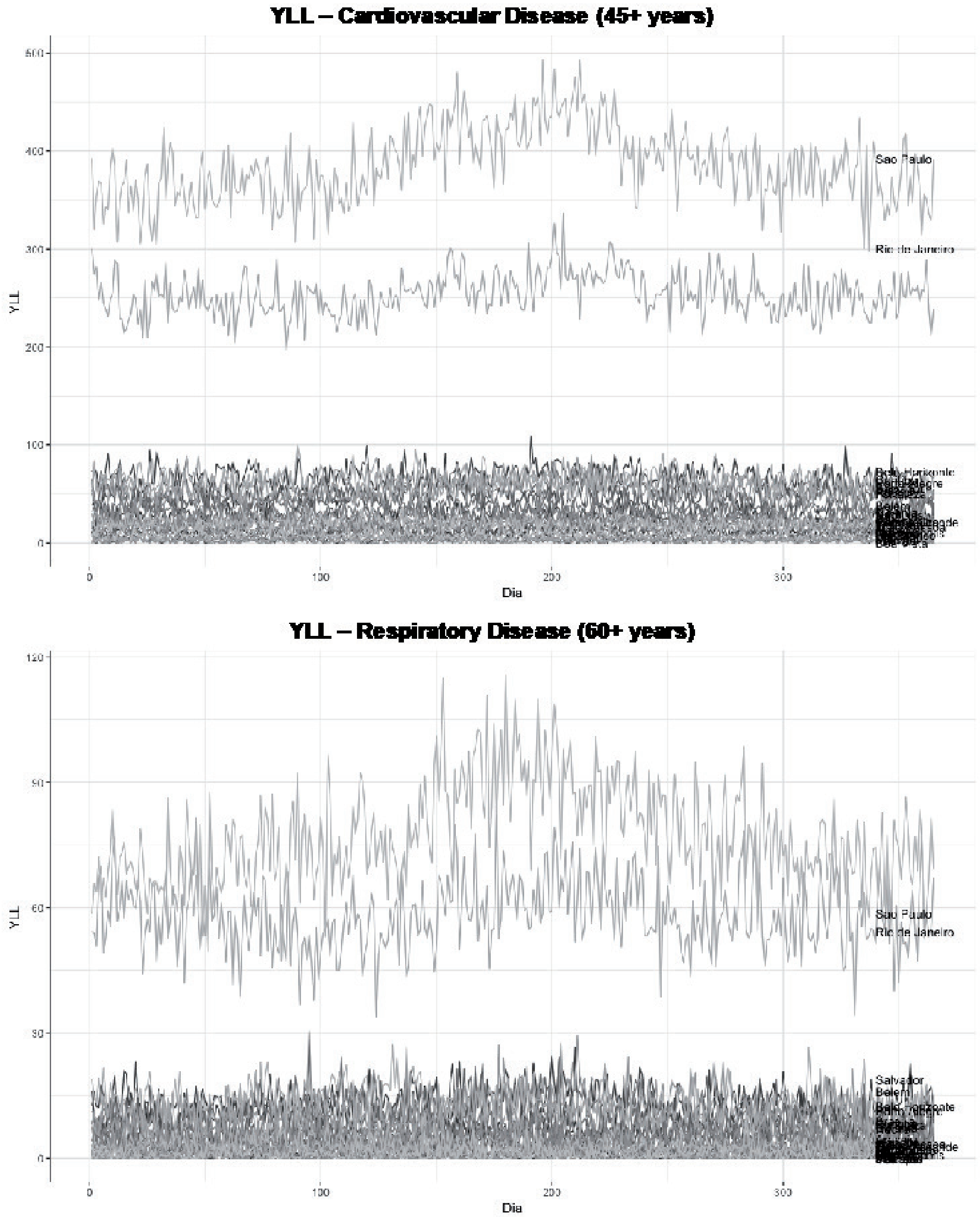

Figure 1 | Daily time-series of average Years of Life Lost (YLL) according to the Brazilian capital.

Source: Elaborated by the authors.

Figure 2 presents temperature distribution in capital cities, aggregated by region and for Brazil, according to global warming scenarios. The same trend for temperature distribution is observed in all regions, with density shifting to high temperatures. An increase in the frequency of days with close temperatures is observed, for example, at 30ºC in global warming scenarios of 2.0ºC and 4.0ºC.

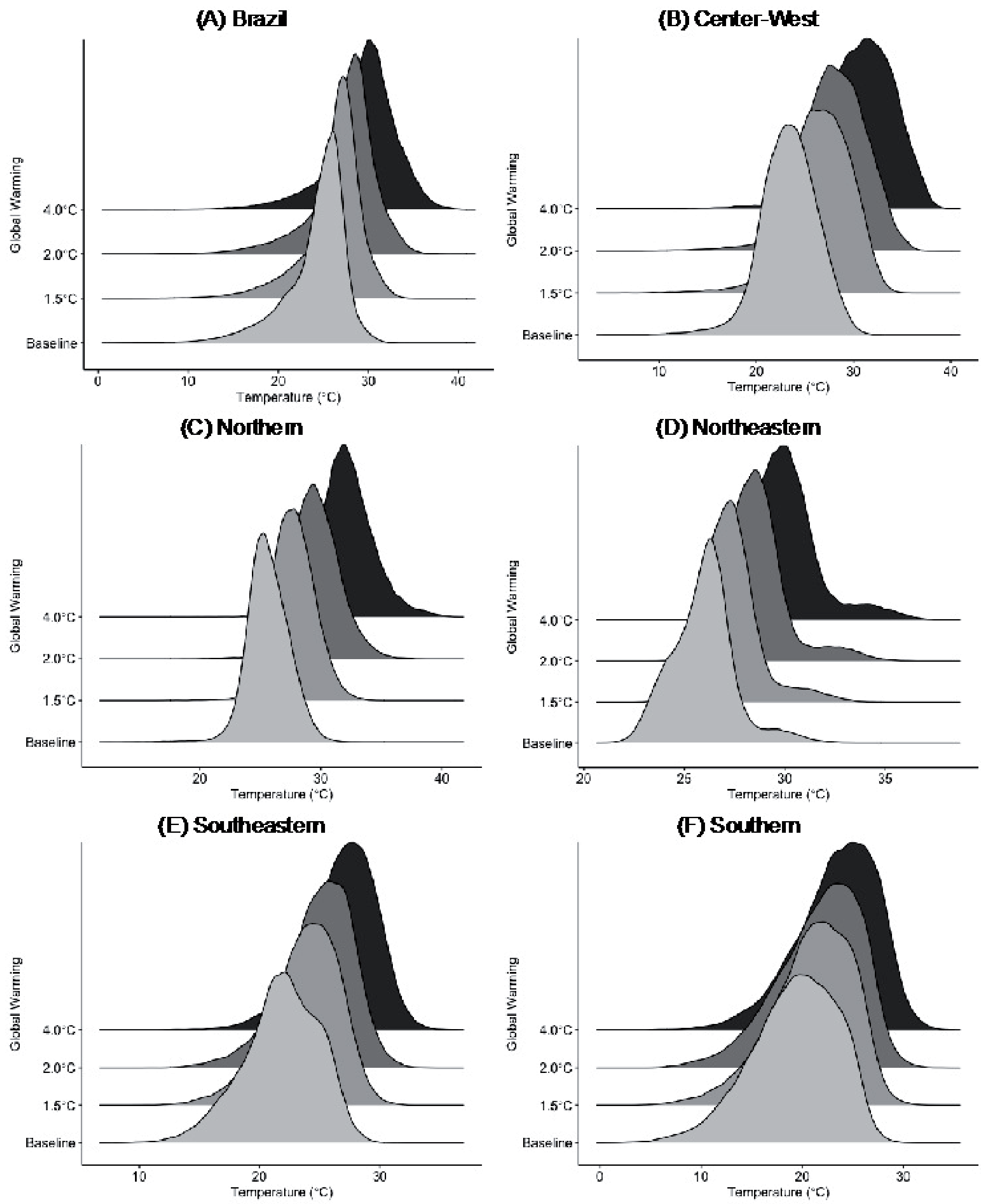

Figure 2 | Distribution of temperature projections for capital cities, aggregated by region and, according to global warming scenarios. Brazil 1961 to 2099.

Source: Elaborated by the authors.

Global temperature impact in YLL according to global warming scenarios was presented in Figure 3. In terms of respiratory diseases in the elderly, an upward trend is observed in YLL as the level of warming increases. Of note, Brasília and other capital cities (Cuiabá, Campo Grande, Goiânia, Porto Velho, Rio Branco, Rio de Janeiro, São Paulo, Belo Horizonte, Recife, Teresina, Curitiba, and Porto Alegre).

As for cardiovascular diseases in adults, the same trend occurs only in Cuiabá, Campo Grande, Goiânia, Rio de Janeiro, and Teresina. In other capital cities, results suggest stationarity or a downward trend.

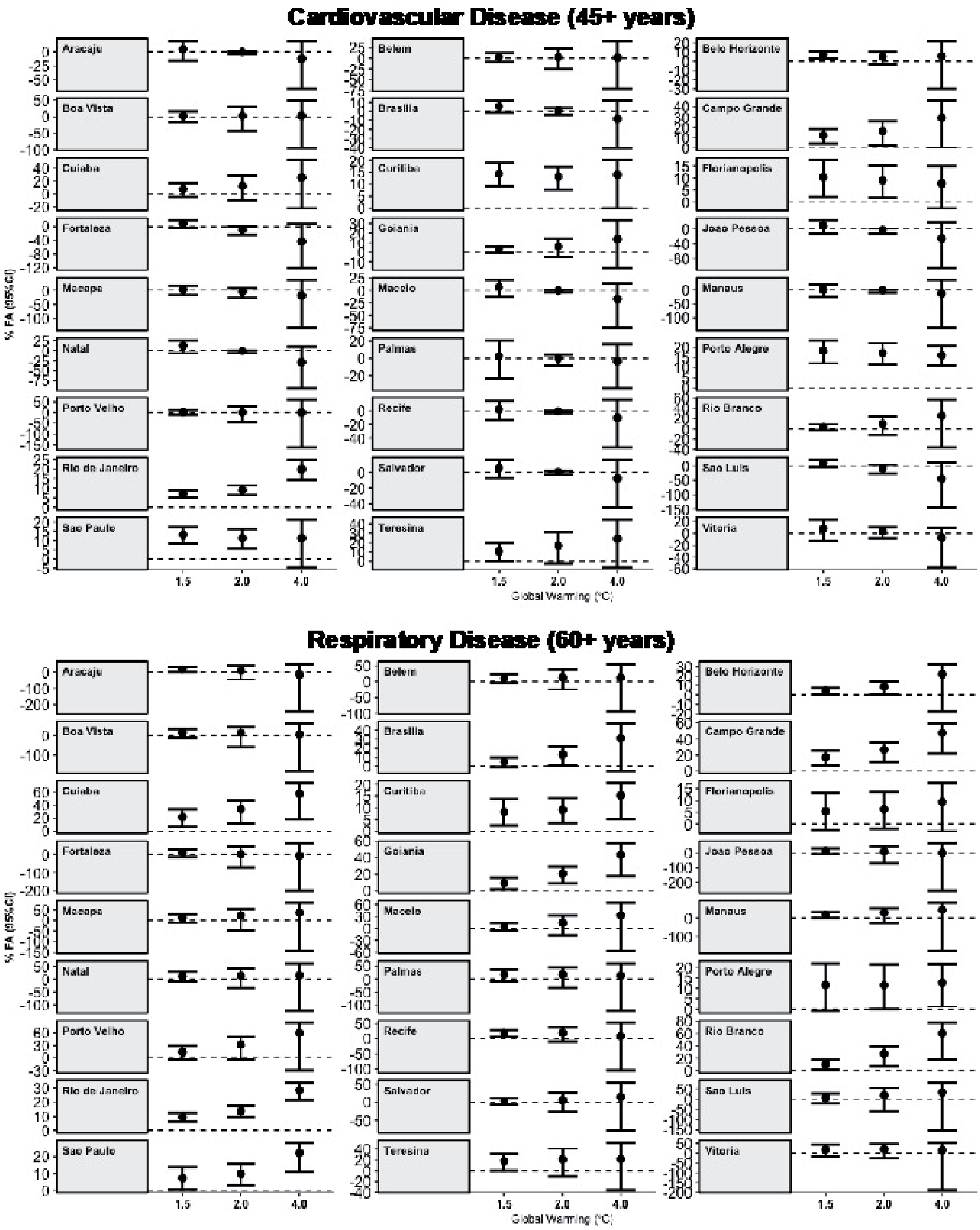

Figure 3 | Fraction of the YLL attributable (Total=Cold+Heat) to global warming. Brazil, capital cities.

Source: Elaborated by the authors.

As for impact percentage increase in the warming of 1.5ºC in relation to the baseline period (1961 to 2005), Campo Grande, and Cuiabá are the most impacted capital cities for both respiratory and cardiovascular diseases (Figure 4).

Regarding the statistical significance measured by the 95% confidence intervals, significant relative impacts were observed for respiratory diseases in Campo Grande, Cuiabá, Goiânia, Rio Branco, Belo Horizonte, Rio de Janeiro, São Paulo, Curitiba, Florianópolis, and Porto Alegre. As for cardiovascular diseases, relative impacts were more significant in Rio de Janeiro and Porto Alegre. Rio de Janeiro, São

Paulo, and the capital cities in the Southern region were the cities with less uncertainties, as assessed by the 95% empirical confidence intervals for respiratory diseases in the elderly. As for cardiovascular diseases in adults, smaller uncertainty measurements were found in Brasília and capital cities in the Northeastern, Southeastern, and Southern regions.

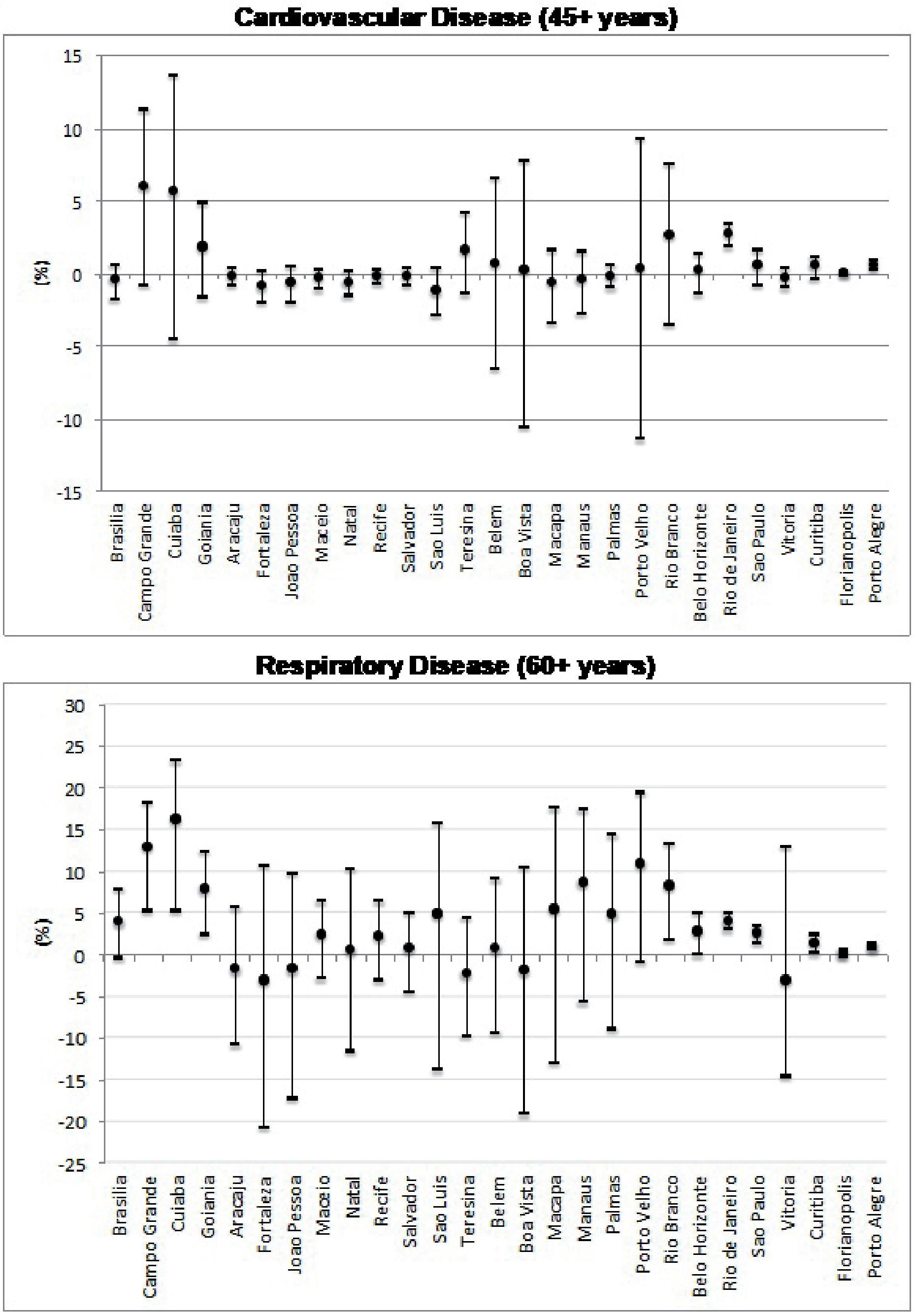

Figure 4 | Relative percentage difference in YLL attributable to global warming of 1.5º compared to the baseline period (1961 - 2005), according to the capital cities of Brazil.

Source: Elaborated by the authors.

When assessing YLL impacts for heat-related respiratory diseases, the results suggest that over 90% of the global impact on YLL is due to exposure to temperatures above MRT for capital cities in the Northern, Northeastern, and Center-West regions. A linear upward trend was observed in the share of the global impact attributable to heat for capital cities of the Southern and Southeastern regions. However, in terms of absolute numbers, the Southeastern region may have the highest YLL attributable to heat (Table 2). As for cardiovascular diseases, the share of the global impact attributable to heat will be higher in capital cities in the Center-West and Southeastern regions. On the other hand, the impact on heat-related YLL reduction will be stronger in the capital cities in the Northeastern region, except for Teresina.

Table 2 | Years of Life Lost (YLL) attributable to heat, aggregated by regions, according to global warming scenarios. Brazil, capital cities.

Region	*Global Warming*	*Respiratory Diseases (≥60)*	*Cardiovascular Diseases (≥ 45)*
Center-West	Baseline	3555.1	4091.0
	1.5º	21408.7	30588.7
	2.0º	42410.0	53635.7
	4.0º	85582.7	98890.1
Northeastern	Baseline	52927.2	17549.2
	1.5º	54361.6	9609.8
	2.0º	63095.0	-109840.7
	4.0º	59426.6	-523286.5
Northern	Baseline	18455.8	8038.1
	1.5º	27434.2	10914.4
	2.0º	40930.9	7511.4
	4.0º	58954.7	-18805.3
Southeastern	Baseline	28058.1	40653.7
	1.5º	80507.9	143342.0
	2.0º	149961.0	276379.2
	4.0º	387051.0	816321.9
Southern	Baseline	1134.0	1724.1
	1.5º	4168.0	8872.1
	2.0º	8309.1	19868.4
	4.0º	23923.2	68185.6

Source: Elaborated by the authors.

4 DISCUSSION

Results of this research suggest that the impact of exposure to temperature on YLL tends to increase as the level of global warming increases, mainly in terms of respiratory diseases in the elderly. Of note, Brasilia and other capital cities (Cuiabá, Campo Grande, Goiânia, Porto Velho, Rio Branco, Rio de Janeiro, São Paulo, Belo Horizonte, Recife, Teresina, Curitiba, and Porto Alegre) are the most impacted by respiratory diseases. As for cardiovascular diseases in adults, the most affected capital cities are Cuiabá, Campo Grande, Goiânia, Rio de Janeiro, and Teresina.

In order to assess the impact on health, the indicator used was the YLL, which measures how many years the individual lost, indicating premature death Deaths at a younger age have a greater weight and, in theory, would be easier to prevent. Results showed that global warming has the potential to increase premature deaths from respiratory and cardiovascular diseases, mainly in the capital cities in the Center-West and Southeastern regions.

In terms of cardiovascular diseases in adults, results suggest a reduction in YLL attributable to cold in all regions of Brazil, as global warming increases. On the other hand, for most capital cities, YLL attributable to heat may increase. The results were consistent with studies on mortality, with a reduction in cold-related mortality and an increase in heat-related mortality, proportionally to the degree of heating and, therefore, more intense according to higher emission scenarios (GASPARRINI et al., 2017; LI et al., 2018; ZHANG et al., 2018).

However, in terms of absolute numbers, an increase in YLL attributable to heat does not seem to exceed the reduction in YLL attributable to cold. This association interfered with total impact projections since the total attributable YLL is the sum of the YLL attributable to cold and the YLL attributable to heat. Thus, for some capitals, the results suggest stationarity or a downward trend in total impact on YLL associated with global warming.

In addition, other factors may have influenced the global impact of temperature exposure on cardiovascular diseases, such as the estimated MRT, which have shown to be high for most capitals, the low frequency of days with temperatures above MRT and the reduction of days with low temperatures. In some capital cities, increased heat impact may not outweigh that of reduced cold, but as the RCP8.5 scenario expects continuous GHG emissions after 2100, the trend is that the impact at higher temperatures will stand out at some point.

Results suggest a lower global warming impact on the YLL in the capitals of the Northeast region. The Northern and Northeastern regions are the ones with high temperatures all year round and lower thermal amplitude than other regions of Brazil, which favors an adaptive response of their population. This lower sensitivity to the effects of heat in warmer regions has already been suggested by some studies (BASU, 2009; YE et al., 2012; ZHAO et al., 2017; ZHAO et al., 2019). On the other hand, Hacon et al. (2016) pointed out a precarious condition of human development in the municipalities in the Northern and Northeastern regions with limited capacity to tackle climate change.

Studies in China assessed the future impacts of exposure to heat stress in YLL. Huang et al. (2018) found in a Chinese city that the YLL due to cardiovascular diseases in the elderly, attributable to heat, may increase between 3.1 and 11.5 times in the 2050s and 2070s in relation to the baseline period, even considering 30% adaptation. Li et al. (2018) conducted a study in Tianjin, China, and the results showed a fall in the YLL due to cerebrovascular accident with percentage reductions by approximately 1% in the 2050s and 2070s in three greenhouse gas emissions scenarios. Another study in Tianjin showed that the effects of cold on YLL in women were greater than in men, with an opposite trend to heat (LI et al., 2018).

In some capital cities, it appears that YLL impacts stabilize in the warming scenario of 2ºC to 4ºC for RCP 8.5. Despite more optimistic scenarios, with the stabilization of greenhouse gas (GHG) emissions, emissions continue to increase, with a 20% chance of global warming above 4.0°C with respect to pre-industrial levels (WORK BANK, 2012).

In case this scenario does occur, the risks of global climate change will be extremely catastrophic, including impacts on premature mortality, as presented herein. The warming of 4.0°C, reached only in the RCP 8.5 scenario, corresponds to a high level of radiative forcing, with the projection of a non-compliance of the goals established in the Paris Agreement. In terms of health, the most pessimistic scenario is often used as a precautionary principle as a guarantee against potential risks that, according to future uncertainties, cannot be exactly estimated or calculated.

This study presents some limitations, one of them is the YLL series used, which corresponds to a daily average of YLL in years prior to the global warming period of 1.5ºC. Projections of this series for the future implies that population distribution and deaths will be constant by 2099. However, population projections indicate that the Brazilian population age pyramid will change (IBGE, 2020). The population distribution trend, by age groups, shows an increase in the proportion of elderly people and a decrease in the proportion of people under 30. An increase in life expectancy and an aging population are expected, which will certainly overburden the health system and increase the number of deaths, especially for individuals with comorbidities.

Therefore, in the context of climate change, preventive measures (especially for chronic diseases) are relevant for the control and management of health risks. Future climate conditions may have an influence on the adoption of new human and institutional behaviors, due to the direct or indirect need of populations to adapt to new climate conditions and new life styles. Daily practices, eating habits, difficulty in accessing drinking water may be modified, resulting in new nosological profiles.

Another limitation refers to the exposure-response curves used in this study to estimate the impacts of global warming on YLL. The curves were estimated using a modeled exposure data from the European Center for Medium-Range Weather Forecast (ECMWF) ERA-Interim reanalysis. The use of data from global atmospheric models in time series studies is a good strategy when there are flaws in the historical series measured by weather stations, but on the other hand, they add another source of uncertainty on the inferences based on these data. In Brazil, the ERA-Interim model has shown good accuracy (DEE et al., 2011; SANTOS et al., 2017; APARECIDO et al., 2019).

5 FINAL CONSIDERATIONS

This study expanded knowledge on climate change impacts on health, and the outcomes suggest an increase in YLL attributable to global warming of 1.5ºC compared to the baseline period (1961 to 2005), with an upward trend for warming scenarios of 2ºC and 4ºC. It also brings an analysis of the potential use of YLL in climate change studies.

Knowing climate change risks and impacts on human health is pivotal in order to plan specific public policies. Brazil is a country of great territorial dimension, with different characteristics of vegetation, climate, socioeconomic conditions and vulnerabilities, and projections indicating rising global temperatures make it urgent to plan strategic actions for climate adaptation and emissions mitigation.

To be able to respond to these trends, it is necessary to invest in several adaptation measures that are generally associated with the reduction of vulnerabilities and access to policies and tools that minimize exposure to heat, such as the use of air conditioning, behavioral changes, and investment in infrastructure and urban planning.

For example, in urban areas, some actions such as incorporating green spaces into the urban landscape to create comfortable environments, encouraging comfortable buildings according to the climate in which they are inserted, and the improvement of precarious housing are some measures that can help in the process of climate adaptation. For instance, green spaces have helped ecosystem resilience and human benefits through ecosystem services (DERKZEN et al., 2017), reducing local heating (RAGULA & CHANDRA, 2020), and increasing permeable areas, thus improving the cities' ecological conditions (VAROL et. al, 2019).

For Romero (2006), in cities, building design should be thought in line with energy balance, so that thermal comfort is inherent to the building; and at the neighborhood and the city levels, natural elements, such as open spaces and trees, as well as protected areas, are essential in order to reduce the effects of heating for urban inhabitants.

The more effective the adaptation policies, the lower the impact on years of life lost due to climate change. These measures and policies will be required as warming scenarios progress. According to a study carried out in Brisbane, if the increase in global average temperature is 2.0°C, a 10% reduction in the population's vulnerability to hot temperatures will be necessary. An increase of 4°C ensures a reduction of approximately 40% (HUANG et al., 2012).

In addition to adaptation policies and measures, it will be necessary to strengthen mitigation measures in Brazil in order to reduce greenhouse gas emissions and limit global warming to 1.5ºC and reduce health impacts, with the use of the legal instruments of the National Policy on Climate Change, compliance with international agreements to mitigate greenhouse gas emissions, compliance with emission reduction targets and the application of the National Adaptation Plan on Climate Change.

For the health sector, according to climate and impact projections on health indicators, investments will be necessary to expand the health services response capacity, with the development of alert and surveillance systems and specific outpatient services to meet patients with signs and symptoms resulting from increased temperature. In order to do so, it will be necessary to improve the capacity-building of health-care workers and health services management.

ACKNOWLEDGEMENTS

This work was supported by the National Council of Technological and Scientifc Development (CNPq, Brazil, Process 381160/2018-1) and by the Brazilian Network on Global Climate Change Research funded by CNPq (Nº 550022/2014-7), FINEP (Nº 01.13.0353.00) and the Pos-Graduate Program of Public Health and Environment at National School of Public Health/ FIOCRUZ.

REFERENCES

ALBUQUERQUE, I. et al., 2020. Análise das emissões brasileiras de gases de efeito estufa e suas implicações para as metas do clima do Brasil 1970-2019. Disponível em: <http://www.observatoriodoclima.eco.br/wp-content/uploads/2020/11/OC_RelatorioSEEG2020_final.pdf>. Acesso em: 08 nov. 2020.

APARECIDO, L. E. O. et al. Acurácia da Reanálise ERA-Interim do ECMWF e sua Aplicação na Estimativa da Deficiência Hídrica no Estado do Paraná*, Brasil*. **Revista Brasileira de Meteorologia**, v. 34, n. 4, 515-528, 2019.

BARRETT, B.; CHARLES, J. W.; TEMTE, J. L. Climate change, human health, and epidemiological transition. **Prev. Med.**, v. 70, p. 69-75, 2015.

BASU, R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. **Environmental Health**, v. 8, 2009.

BUNKER, A. et al. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: a systematic review and meta-analysis of epidemiological evidence. **EBioMedicine**, v. 6, p. 258-268, 2016.

CHOU, S. C. et al. Assessment of Climate Change over South America under RCP 4.5 and 8.5 Downscaling Scenarios. **American Journal of Climate Change**, v. 3, p. 512-527, 2014.

DEE, D. et al. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. **Quarterly Journal of the Royal Meteorological Society**, v. 137, p. 553-597, 2011.

DERKZEN, M. L.; VAN TEE_ELEN, A. J. A.; VERBURG, P. H. Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences? **Landsc. Urban Plan**, v. 157, p. 106-130, 2017.

GASPARRINI, A. Distributed Lag Linear and Non-Linear Models in R: the package dlnm. **Journal of Statistical Software**, v. 43, p. 1-20, 2011.

GASPARRINI, A. et al. Projections of temperature-related excess mortality under climate change scenarios. **The Lancet Planetary Health**, v. 1, p. e360-e367, 2017.

GASPARRINI, A.; ARMSTRONG, B.; KENWARD, M. G. Multivariate meta-analysis for non-linear and other multi-parameter associations. **Statistics in Medicine**, v. 31, p. 3821-39, 2012.

GUO, Y. et al. Temperature Variability and Mortality: a multi-country study. **Environ Health Perspect**., v. 124, p. 1554-1559, 2016.

GUO, Y. et al. Quantifying excess deaths related to heatwaves under climate change scenarios: a multicountry time series modelling study. **PLoS Med.**, v. 15, p. e1002629, 2018.

HACON, S. et al. Capítulo 5: Saúde. **Mudanças climáticas em rede:** um olhar interdisciplinar. NOBRE, C. A.; MARENGO, J. A. (Org.). São José dos Campos, SP: INCT, 2016.

HARTWIG, S. V.; IGNOTTI, E. Variações meteorológicas e as alterações de pressão arterial dos pacientes em hemodiálise: revisão sistemática. **Revista Brasileira de Climatologia**, Ano 15, v. 25, JUL/DEZ 2019 ISSN: 2237-8642 (Eletrônica).

HARTWIG, S. V. et al. Seasonal variation of biochemical parameters of hemodialysis patients in a tropical climate area. **O Mundo da Saúde**, v. 43, p. 566-585, 2019.

HEMPEL, S. et al. A trend-preserving bias correction. The ISI-MIP approach. **Earth System Dynamics**, v. 4, p. 219-236, 2013.

HUANG, J. et al. Projections for temperature-related years of life lost from cardiovascular diseases in the elderly in a Chinese city with typical subtropical climate. **Environ Res.**, v. 167, p. 61-621, 2018.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Projeção da população do Brasil e Unidades da Federação, 2019. Disponível em: <https://www.ibge.gov.br/apps/populacao/projecao/>. Acesso em: 21 ago. 2020.

LI, G. et al. Projected Temperature-Related Years of Life Lost From Stroke Due to Global Warming in a Temperate Climate City, Asia: disease burden caused by future climate change. **Stroke**, v. 49, p. 828-834, 2018.

LI, Q. et al. Does local ambient temperature impact children's blood pressure? A Chinese National Survey. **Environ Health**, **v. 16, p. 15-21, 2016.**

LI, Y. et al. Projecting temperature-related years of life lost under different climate change scenarios in one temperate megacity, China. **Environmental Pollution**, v. 233, p. 1068-1075, 2018.

PEIXOTO, H. C. G.; SOUZA, M. L. O Indicador Anos Potenciais de Vida Perdidos e a Ordenação das Causas de Morte em Santa Catarina, 1995. **Informe Epidemiológico do SUS**, v. 8, p. 17-25, 1999.

RAGULA, A.; CHANDRA, K. K. Tree species suitable for roadside afforestation and carbon sequestration in Bilaspur, India. **Carbon Management**, p. 1-12, 2020.

ROMERO, M. B. Desenho da Cidade e Conforto Ambiental. **RUA**: **Revista de Urbanismo e Arquitetura da UNB**, v. 7, n. 1, 2006.

ROSSATI, A. Global Warming and Its Health Impact. **Int J Occup Environ Med.**, v. 8, p. 7-20, 2017.

SANTOS, S. R. Q. et al. Variabilidade sazonal da precipitação na Amazônia: validação da série de precipitação mensal do GPCC. **Revista Brasileira de Geografia Física**, v. 10, p. 1721-1729, 2017.

SEWE, M. O. et al. Estimated Effect of Temperature on Years of Life Lost: a retrospective time-series study of low, middle, and high-income regions. **Environmental Health Perspectives**, v. 126, p. 017004, 2018.

SOUSA, T. C. M. et al. Doenças sensíveis ao clima no Brasil e no mundo: revisão sistemática. **Rev. Panam. Salud Publica**, v. 42, p. e85, 2018.

VAROL, T. et al. Determining potential planting areas in urban regions. **Environmental monitoring and assessmen**t, v. 191, n. 3, p. 1-14, 2019.

WANG, Q. et al. Environmental ambient temperature and blood pressure in adults: a systematic review and meta-analysis. **Sci Total Environ**, v. 575, p. 276-286, 2017.

WERNECK, G. L.; REICHENHEIMM, E. **Anos potenciais de vida perdidos no Rio de Janeiro, 1985.** As mortes violentas em questão. Universidade do Estado do Rio de Janeiro. (Série: Estudos em Saúde Coletiva), v. 4, p. 1-20, 1992.

WORLD BANK. **4°C: turn down the heat.** A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics, November 2012, Washington DC 20433.

YE, X. F. et al. Ambient temperature and morbidity: a review of epidemiological evidence. **Environ Health Perspect.**, v. 120, p. 19-28, 2012.

ZANOBETTI, A.; O'NEILL, M. S. Longer-Term Outdoor Temperatures and Health Effects: a review. **Curr. Epidemiol. Rep.**, v. 5, p. 125-139, 2018.

ZHANG, Y. et al. The burden of ambient temperature on years of life lost: a multi-community analysis in Hubei, China. **Science Total Environment**, v. 621, p. 1491-1498, 2018.

ZHAO, O. et al. Assessment of Intraseasonal Variation in Hospitalization Associated with Heat Exposure in Brazil. **JAMA Network Open**, v. 2, p. e187901, 2019.

ZHAO, Q. et al. Impact of ambient temperature on clinical visits for cardio-respiratory diseases in rural villages in northwest China. **Sci Total Environ**., v. 612, p. 379-385, 2018.