Climate Change and Heatwave-related Elderly Mortality in Brazil

Fernanda Rodrigues Diniz and Fabio Luiz Teixeira Gonçalves

***Abstract*—** According to IPCC´s sixth report (AR6) the heat waves (HW) will be even more often, more intense and more severe by the end of the century. The elderly population is among the most vulnerable to heat waves, due to the sensitive thermoregulatory system. Brazil is considerate a vulnerable country to heatwave- related elderly mortality. In this context, the objective of this study is to quantify the heatwave-related elderly mortality from cardiovascular (CVD) and respiratory (RD) diseases in Brazil in the present (1996-2016), in the near future (2030-2050) and in the distant future (2079- 2099). The results show that if there is no adaptation the heatwave-related elderly mortality from cardiovascular and respiratory disease will increase a lot in Brazil. This study is important to public polices to implement adaptive measures to reduce the elderly mortality in the future.

***Keywords*—** Climate Change, Elderly, Heatwave, Mortality

I. Introduction

Extreme weather events have become common throughout the world, whether due to warming, cooling, drought or storms [1], [2]. These events generate both economic and social impacts on society, as they affect infrastructure, agricultural production, population health and often cause fatalities [1], [3]. Currently, there is no doubt that there is an increase in the global average temperature that has intensified since the 1980s [4].

The sixth IPCC report (AR6) brought worrying predictions regarding the planet's climate, according to which the average global temperature is expected to increase by 1.5ºC in the coming decades, even if greenhouse gas emissions are stopped in the current affairs [5]. If greenhouse gases continue to be emitted, by 2100 the average global temperature could increase by up to 4ºC [5]. This trend of increasing surface temperature, in addition to increasing the values of the parameter itself, can also increase the frequency and intensity of climatic extremes such as heat waves [5].

Several regions around the globe are already experiencing days with extreme heat, which affects the entire population, whether in agricultural production, economy and health [6-8]. In terms of the health of the world population, heat waves can cause direct impacts on health, causing heat-related diseases, or indirect impacts, determining the decompensation of a chronic disease [9]. Studies have shown associations between heat waves and mortality in different regions of the world [10-12].

Studies show that the elderly population is among the most vulnerable to heat waves, due to the more sensitive thermoregulatory system. Physiological responses to the environment deteriorate with aging and some drugs interact with thermoregulation, increasing the risk [13]. According to the World Health Organization (WHO), high air temperatures directly contribute to deaths from cardiovascular and respiratory diseases, particularly among the elderly, as high temperatures, in addition to affecting thermoregulation, also raise ozone levels that exacerbate cardiovascular and respiratory diseases, which sometimes result in deaths.

In [14] and [15] Brazil proved to be a vulnerable country in relation to the mortality of elderly people with cardiovascular and respiratory diseases due to the occurrence of heat waves. According to [16] episodes of heat waves have become more frequent over the years in the country. According to the sixth IPCC report (AR6), the projections up to 2100, indicate in the worst case that the temperature increase in the interior of Brazil should be up to 4ºC and for regions close to the coast up to 3ºC.

In this context, the objective of this study is to quantify the mortality of elderly people due to diseases respiratory and cardiovascular diseases associated with heat waves in the present (1996-2016), in the near future (2030-2050) and in the distant future (2079-2099), considering the climate change scenarios RCP4.5 and RCP8.5 and two hypotheses of adaptation and no adaptation.

II. Data

Daily mortality data were obtained from the website of the Department of Informatics of the Brazilian Unified Health System (DATASUS) from 1996 to 2016. Mortality information was obtained from the capitals of the 26 Brazilian states and the Federal District only from deaths related to diseases of the circulatory and respiratory system of people aged 60 years and over.

The meteorological data refer to the daily maximum temperature data of each capital of the Brazilian states obtained from the reanalysis of the ERA-Interim from 1996 to 2016 [17]. The historical climate simulations and daily climate change projections of the maximum air temperature at 2 meters in the RCP4.5 and RCP8.5 climate change scenarios were obtained from the output of the Eta-HadGEM2-ES model [18]. The

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model's historical data refer to the period 1996-2016 and climate projections are for the near future (2030-2050) and distant future (2079-2099).

III. Heatwaves identification

The heatwaves were identified using the definition given by [19], where a heatwave is defined as a period of at least three consecutive days with maximum temperatures above the threshold of the ninetieth percentile of the daily maximum temperature of the reference period. The threshold is defined as the 90th percentile of daily highs, centered on a 31-day window.

The same method described above was used to identify heat waves in the near future (2030-2050) and distant future (2079-2099). However, there were changes in the data and values of the daily thresholds. To verify the impacts of future heat waves on health, we used the same methodology first applied in [20] and later in [15]. Two assumptions about adapting to heat waves were considered here:

1) Non-adaptation: to identify heat waves in the near future (2030-2050) and distant future (2079-2099) in a non-adaptation hypothesis, the daily thresholds were calculated for the present period (1996-2016). These thresholds were used to identify heat waves in the present (1996-2016), in the near future (2030-2050) and in the distant future (2079-2099). In this condition, it is assumed that humans cannot adapt to the increase in temperature with the same response to the temperature distribution [15], [20]. This method is often used to characterize heatwaves in the future.

2) Hypothetical full adaptation: In this condition, the daily threshold is recalculated, considering reference periods of the future, such as the period from 2030 to 2050 to identify heat waves in the near future and from 2079 to 2099 to identify heat waves in the distant future. The new reference periods for the near future and the distant future are used as an indication of a complete human adaptation to heat waves in the future, through changes in human physiology and behavior, such as changes in clothing, diet, physical activity, lifestyle, housing and city planning itself (creation of parks and green areas).

IV. Historical heat-wave elderly mortality relationships

To verify the impact of heat waves on the elderly mortality from 1996 to 2016, statistical models were run for each Brazilian State capital separated by disease. The statistical model used was the Generalized Linear Model (GLM) with quasi-Poisson distribution combined with the Distributed Lagging Nonlinear Model (DLNM)[21].

According to [21] the effects of heat during heat waves can be described as the sum of two contributions: the independent effects of daily air temperature levels (known as main effects) and the added effects due to duration. heat for several consecutive days (heat wave period). These contributions were analyzed by the results of the statistical models, the first contribution (main effects) being an exposure-response function for the temperature and health (*Basis*). The second contribution (added effects) is an indicator function of days with heat waves (equal to 1) and days without heat waves (equal to zero) (*HW*). An algebraic representation is given by (1):

$$Log|E(Y_i)| = \beta_0 + \beta_1 HW + \beta_2 Basis + \beta_3 DOW + \beta_4 ns(Time, df = 10 * 14) \quad (1)$$

where Yi is the mortality count, assuming it follows a quasi-Poisson distribution for each day i.

The relative risk of the main effect is predicted between the median temperature over heatwave days versus the Minimum Mortality Temperature (MMT). MMT refers to a temperature at which little or no adverse effect of temperature on mortality is expected [15], [21]. The added effect is estimated as the exponential coefficient of the indicator variable (HW). The total effect was also estimated by adding individual contributions.

After obtaining an estimate for each specific Brazilian capital, a meta-analytic process was performed based on the constrained maximum likelihood to group the estimates and obtain a summary measure for Brazil and each administrative region [22].

V. Projection of relative risk

The relative risk was initially projected for each contribution of heat to elderly mortality during heat waves, in order to obtain the projection of the total contribution of heatwave-related elderly mortality. Therefore, the projections of the relative risk of mortality in the elderly associated with the average persistence of heat waves were made based on the value of the estimated coefficient for added effects. This coefficient is equivalent to the increase or decrease in elderly mortality (from respiratory and/or cardiovascular diseases) in one (1) heat wave day. Regarding the main effect of heat, projections were made based on the coefficient estimated for the main effects of heat on mortality by the statistical model. This coefficient is equivalent to the increase or decrease in elderly mortality every 1ºC. Therefore, the relative risk can be projected for the future period for each contribution, based on the following equations [15], [23]:

$$RR_{proj\_add} = e^{(\beta\Delta L)} \quad (2)$$

$$RR_{proj\_main} = e^{(\beta\Delta T)} \quad (3)$$

where β is the value estimated by the statistical model for the added effects and main effects, respectively. ΔL and ΔT are respectively the difference in the average duration of heat waves and the difference in the median temperature during heat waves between the present and in each of the future periods (near and distant) in the RCP4,5 and RCP8,5 scenarios of climate change.

After obtaining the projections of the relative risk of individual contributions, the projection of the relative risk of the total contribution of heatwaves in the mortality of the elderly was calculated, adding the individual contributions in each Brazilian capital. To obtain a summary measure of the projected relative risk for Brazil and its administrative regions, meta-analytic processes were applied [22].

VI. Projection of Relative Risk

The heatwave-related elderly mortality from CVD and RD were calculated for the present (1996-2016) and projected for the near future (2030-2050) and future distant (2079-2099). Two hypothesis were considerate: adaptation and non-adaptation to the future climate. The annual heatwave – related elderly mortality were obtained using (4)[23]:

$$ED = N \times (RR - 1) \times HW \quad (4)$$
$$N = POP \times MR \quad (5)$$

where ED is the excess deaths related to heat waves, N is the average number of deaths on non-heat waves days, RR is the projected relative risk associated with the total contribution of heat waves to mortality in the elderly. HW is the number of annual days of heat waves in each period for which mortality is estimated, also varying for the hypotheses of adaptation and non-adaptation. POP is the annual population, for the projections, the POP with median variance was used. MR is the historical daily mortality rate on non-heatwave days.

VII. Results and Discussion

We analyzed all 26 Brazilian state capitals from 1996 to 2016. The average mortality rate in Brazil of deaths of elderly people from cardiovascular diseases is 1296 deaths per 100,000 inhabitants. The average mortality rate from respiratory diseases in Brazil is much lower than that from cardiovascular diseases, with an average of 607 deaths per 100,000 inhabitants. The studies [24] and [25] show that the average mortality rate from cardiovascular diseases in the elderly is high compared to other diseases in Brazil. Fig. 1 presents the estimated and projected elderly population in Brazil. The elderly population is projected to increase by the end of the century, increasing 142% by 2050 and 175% by 2100 in relation to 2020 (Fig.1).

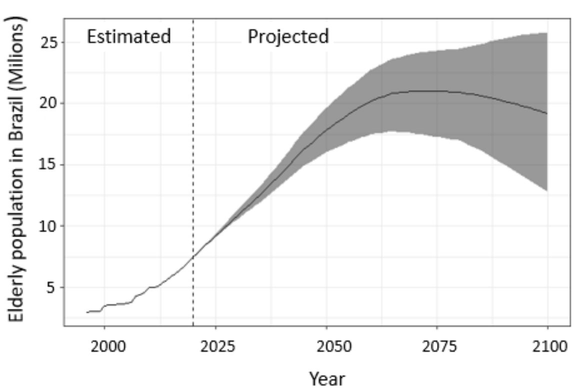

Fig. 1 – Elderly population in Brazil.

Fig. 2 shows the difference between the mean temperature of the present (1996-2016) and in the future (2030-2050 and 2079-2099).

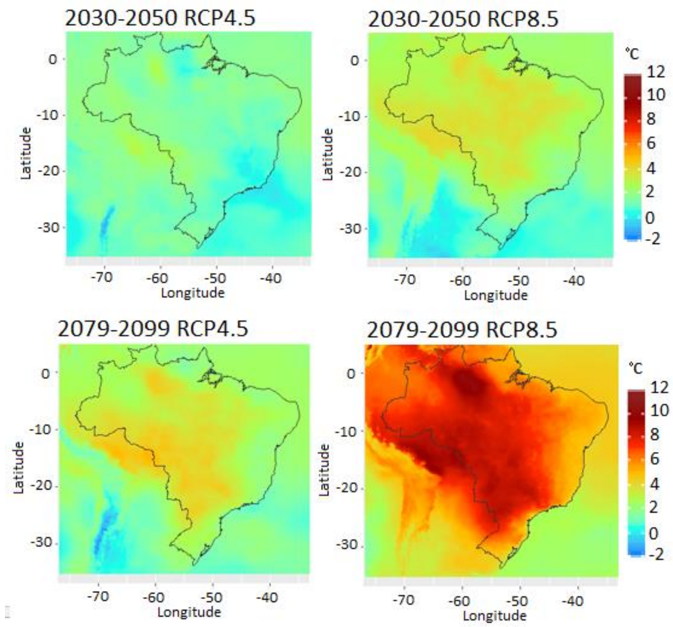

Fig. 2 Difference between present and future maximum temperature.

An increase in maximum temperature is observed in the projections in both climate scenarios for Brazil. Projections show that the maximum temperature should increase by an average of 1ºC to 4ºC in the near future (2030-2050) and from 3ºC to 9ºC in the distant future (2079-2099), being higher in the RCP8.5 scenario.

TABLE I presents the annual characteristics of heat waves in the historical period, near future and distant future considering the RCP4.5 and RCP8.5 climate change scenarios and non-adaptation and adaptation assumptions. Such characteristics are the annual number of days of heat waves (HW), average duration and average intensity.

TABLE I: Annual average characteristics of heat waves in all Brazilian state capitals

		Scenario	HW (days)	Duration (days)	Intensity (ºC)
	1996-2016	-	10±2	6±2	32±2
Non-Adaptation	2030-2050	RCP4.5	41±8	7±2	32±2
		RCP8.5	76±15	8±2	33±1
	2079-2099	RCP4.5	62±12	10±3	32±3
		RCP8.5	143±28	41±12	35±2
Adaptation	2030-2050	RCP4.5	11±2	6±2	33±1
		RCP8.5	7±1	6±2	33±1
	2079-2099	RCP4.5	11±2	6±2	33±2
		RCP8.5	11±2	6±2	34±2

Projections of the annual average of days with heat waves in the capitals of Brazilian states show an increase in the number of days, duration and intensity of heat waves in the near future (2030-2050) and an even greater increase in the distant future (2079-2050). 2099), mainly in the RCP8.5 scenario. In the event of no adaptation to the climate, heat waves could increase by up to 1275% compared to the present by the end of the century. Regarding the average duration of heat waves, they can increase by up to 605% and the average intensity shows an absolute increase of 2.6C in the worst-case scenario. In a hypothesis that there is adaptation, the projections show an increase of only 11% in days with heat waves and the average duration remains close to what is observed at present.

Fig. 3 presents the elderly mortality risk associated with individual and total heat contributions during heat waves.

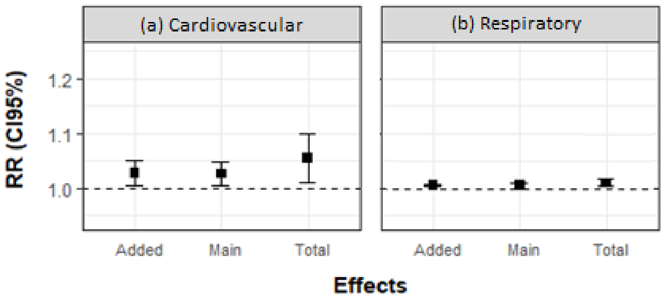

Fig. 3 Effects of heatwave on elderly mortality.

On average in Brazil, there is not a great difference between exposure to the persistence of the heat wave (added effect) and the increase in temperature (main effect), both of which pose a risk for mortality among the elderly in Brazil. Both effects (total) contribute to a 6% increase in elderly mortality from CVD and a 2% increase from RD in Brazil.

Fig. 4 shows the projection of the total contribution of heat waves in the mortality of the elderly from CVD and DR in the near and distant future, considering the scenarios RCP4.5 and RCP8.5.

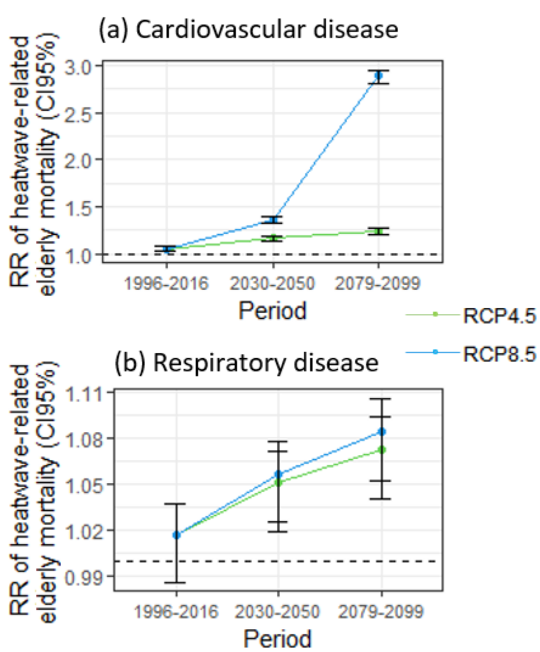

Fig. 4 Projection of total risk during heat waves on mortality of older adults from (a) Cardiovascular diseases and (b) Respiratory diseases.

Projections show an increase in the relative risk of mortality of elderly people from CVD associated with the total contribution of heat during heat waves in Brazil, both in the near future (2030-2050) and in the distant future (2079-2099) (Fig. 4 (a)). Projections show higher risks when the RCP8.5 scenario is considered. In the RCP4.5 scenario, projections show that CVD mortalities are expected to increase by 20% during heat waves in the near future and 25% in the distant future. In the RCP8.5 scenario, the projections show an increase of 30% in the near future and 190% in the distant future.

Compared to CVD, the RR projections of mortality from DRSP associated with heat waves (Fig. 4 (b)) show lower values in the future, since the RR in the present already has lower values in relation to CVD. In the RCP4.5 scenario, the projections show a 5% increase in elderly mortality from PR in the near future and a 7% increase in the distant future. In the RCP8.5 scenario, projections show an increase of 6% in the near future and 8% in the distant future.

Fig. 5 presents the projection of heatwave-related elderly mortality in Brazil.

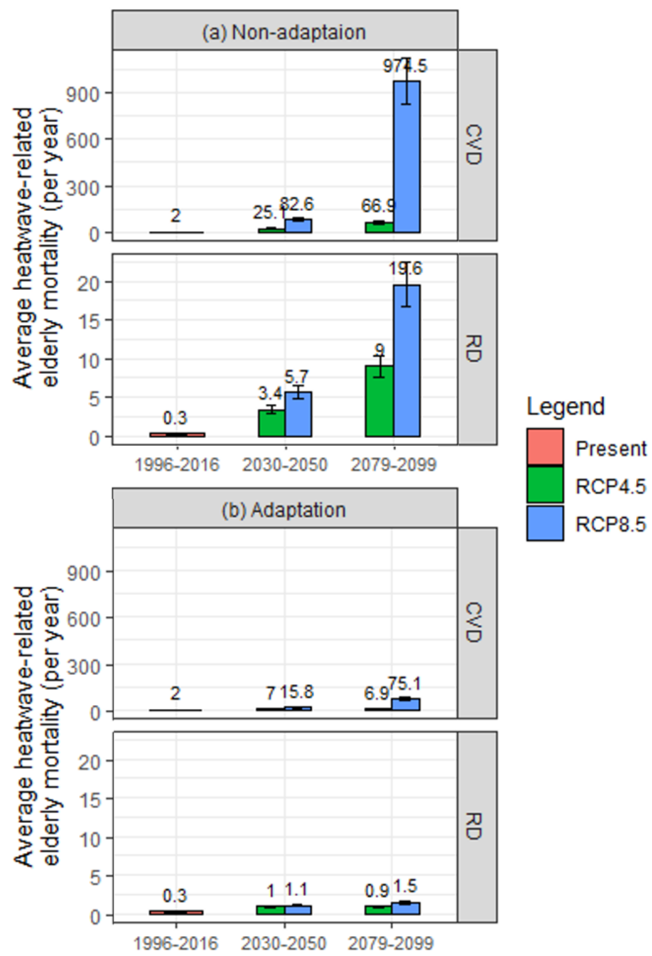

Fig. 5 Annual heatwave-related elderly mortality in each 100,000 inhabitants in Brazil from cardiovascular and respiratory diseases in the hypothesis of (a) non-adaptation and (b) adaptation.

The results show that if there is no adaptation, the heatwave-related excess mortality of elderly people in Brazil is expected to increase, especially in 2079-2099 in the RCP8.5

scenario (on average 974 annual deaths per 100,000 inhabitants from CVD and 20 annual deaths per 100,000 inhabitants from RD). If we consider hypothetical adaptation, the heatwave-related excess mortality is still expected to increase, but the increase is much smaller than under the hypothesis of no adaptation (on average 1.1 annual deaths per 100,000 inhabitants from CVD and 1.5 annual deaths per 100,000 inhabitants from RD).

VIII. Conclusion

Our results showed that the frequency, duration and intensity of heat waves in Brazil will increase in climate change scenarios. Due to the increase in these events, the relative risk and consequently the number of heatwave-related elderly mortality is expected to increase. If there is no adaptation in the future the heatwave-related elderly mortality from CVD and RD in Brazil should increase significantly compared to the present, especially in 2079-2099 in the worst scenario. With adaptation, that is, with changes in behavior (clothing, food, physical activity) and infrastructure in cities (more green areas, parks, transport and housing adapted to heat), the excess heatwave-related mortality should decrease in relation to the hypothesis of non-adaptation. These results can be used in decision-making by public policies so that preventive and adaptive measures are implemented to avoid an increase in mortality in the coming years.

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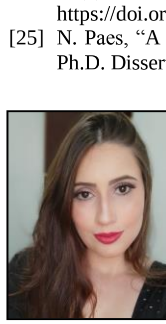

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