ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

IMPACTO DAS MUDANÇAS CLIMÁTICAS NA DEMANDA DE ÁGUA PARA IRRIGAÇÃO DA CANA-DE-AÇÚCAR NA BACIA HIDROGRÁFICA DO RIO GRAMAME

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1 RESUMO

As mudanças climáticas podem impactar variáveis climatológicas relacionadas com o processo de evapotranspiração das plantas e consequentemente, a demanda de água para irrigação das culturas. Este estudo busca avaliar os impactos gerados pelas mudanças climáticas nas demandas de água para irrigação da cana-de-açúcar em quatro municípios inseridos na bacia hidrográfica do Rio Gramame. Para isso, a demanda de água para irrigação foi estimada a partir do cálculo da evapotranspiração da cultura da cana-de-açúcar. Os dados de temperatura utilizados nessas estimativas foram obtidos das projeções de três Modelos de Circulação Regional: ICHEC-EC-EARTH-RCA4, MPI-ESM-LR-RCA4 e MPI-ESM-LR-REMO2009, retirados do Coordinated Regional Climate Downscaling (CORDEX). Essas demandas foram estimadas para dois intervalos de anos (2006-2037 e 2038-2069) e para dois cenários de emissão de Gases do Efeito Estufa, RCP 4.5 e RCP 8.5. Os padrões das projeções de temperatura dos três modelos foram avaliados e corrigidas afim de reduzir as incertezas. Os resultados indicam que o modelo MPI-ESM-LR-REMO2009 foi o que melhor representou a temperatura no clima atual (1961-2005), e que a demanda de água para irrigação será impactada levemente pelo aumento da temperatura decorrente da mudança climática no futuro próximo (2006-2037) e de forma mais significativa no futuro distante (2038-2069).

Palavras-chave: modelos de circulação regional, evapotranspiração, temperatura.

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IMPACT OF CLIMATE CHANGE ON THE SUGARCANE IRRIGATION WATER DEMAND IN THE GRAMAME RIVER BASIN

2 ABSTRACT

Climate change is a recurring theme as it impacts various sectors of society, including water resources, reflecting directly on human beings' activities. In this context, the objective of this study was to assess the impacts produced by climate change on the sugarcane water demands for irrigation in four municipalities within the Gramame River Basin. For this, the irrigation water demand was estimated from the calculation of the evapotranspiration of the sugarcane culture. The temperature data used in these estimates were obtained from the projections of

Recebido em 13/04/2022 e aprovado para publicação em 17/11/2022
DOI: http://dx.doi.org/10.15809/irriga.2022v27n4p667-684

three Regional Circulation Models: ICHEC-EC-EARTH-RCA4, MPI-ESM-LR-RCA4, and MPI-ESM-LR-REMO2009 taken from the Coordinated Regional Climate Downscaling (CORDEX). These demands were estimated for two intervals of years (2006-2037 and 2038-2069) and for two greenhouse gas emission scenarios, RCP 4.5 and RCP 8.5. The patterns of the temperature projections of the three models were evaluated and corrected in order to reduce uncertainties. The results indicate that the MPI-ESM-LR-REMO2009 model was the one that best represented the temperature in the current climate (1961-2005). Furthermore, the increase in temperature due to climate change affects irrigation water demand in the near future (2006-2037) with slight effects, and in the distant future (2038-2069) with stronger impacts.

Keywords: regional circulation models, evapotranspiration, temperature.

3 INTRODUCTION

One of the greatest challenges faced by the world in this century is climate change, which is a theme that needs to be further studied because of its interference in important sectors, such as agriculture and water resources (SAE, 2015). According to the Fifth Assessment Report (AR5) provided by the Intergovernmental Panel on Climate Change (IPCC), in the most pessimistic scenario (RCP 8.5), it is projected that by the end of the 21st century, the variation in global air temperature is likely to exceed 1.5 °C in relation to 1850--1900 (IPCC, 2013). Guimarães *et al.* (2016) reported that long-term climate change projections (2079--2099) for Northeast Brazil indicate an increase of 4.1 °C in the annual average temperature.

The temperature increase impacts the hydrological variables, consequently affecting rain, evapotranspiration, runoff, and irrigation water demand and, therefore, watershed reservation capacity. Agriculture depends on these variables, which directly influence agricultural production. Thus, agriculture will be affected by changes in climate, such as changes in the severity of extreme events.

Considering that the water supply source for cultivation in Brazil is almost entirely from rains (SAE, 2015), the demand for irrigation water has tended to increase over the years. As the use of irrigation is the best alternative for allowing crops to remain alive during drought periods, the increase in irrigation water demand can impact water availability in watersheds and intensify conflicts over water use. Additionally, compared with those of the industrial and urban sectors, the water demand for irrigation is considered to be more sensitive to climate change (GONDIM *et al.*, 2012).

Sugarcane is one of the main agricultural commodities in Brazil (IBGE, 2021), and since the colonial period, it has been growing in the country (CARDOSO *et al.*, 2019). Currently, Brazil is the largest sugarcane producer in the world (FAO, 2020). Several studies have focused on the impacts of climate change on sugarcane production in Brazil and address different aspects (CARVALHO *et al.*, 2015; MARIN *et al.*, 2013; ZULLO; PEREIRA; KOGA-VICENTE, 2018). According to Teodoro *et al.* (2013), studies that report the consumption of water by crops and the use of water resources for irrigation are becoming more common, since irrigation is a factor that has a great influence on agricultural productivity and cost.

Through climate modeling, it is possible to estimate how climate change may affect the precipitation and temperature of our planet. The global circulation model (GCM) and regional circulation model (RCM) provide projections of climate variables on the globe, and an RCM is simulated with the boundary conditions of a

GCM when one is interested in obtaining results on a larger scale and resolution. In this study, temperature projections of the following models were used: (a) MPI-ESM-LR, which provided the boundary conditions for the regional models RCA4 and REMO2009; and (b) ICHEC-EC-EARTH, which provided the boundary conditions for the RCA4 regional model.

The representative concentration pathway (RCP) scenarios were developed by the IPCC and are commonly used in studies involving climate change. They are expressed in Wm^{-2} and defined as consistent sets of projections of radiative forcing components that are intended to serve as inputs for climate modeling (IPCC, 2014). The RCPs are divided into four scenarios (RCPs 2.6, 4.5, 6.5 and 8.5) and are identified by their radioactive forcing in the year 2100 relative to 1759.

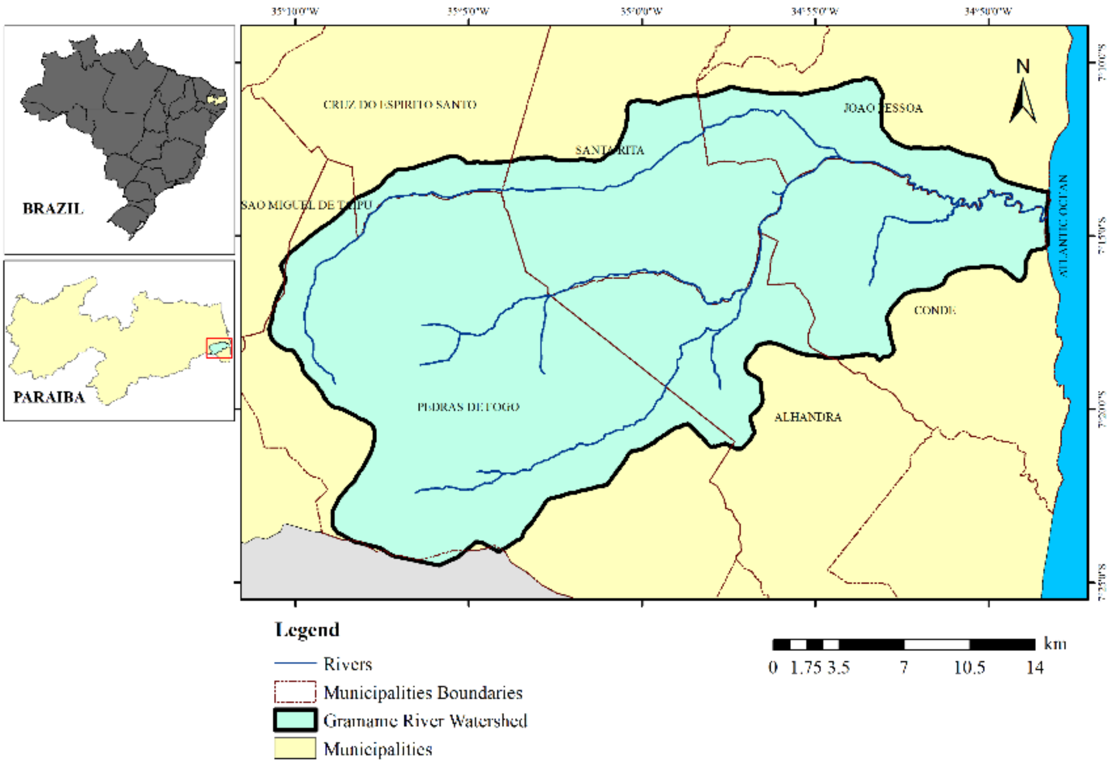
This study aims to assess the impacts of climate change on the irrigation water demand of sugarcane in the Gramame River Basin. For that, it is necessary to evaluate the existing uncertainties in the atmospheric model's simulated temperature of the current climate and estimate the temperature projections for the future climate for two scenarios, RCP4.5 as optimistic and RCP8.5 as pessimistic. Then, the impacts of water demand on irrigation for both scenarios were assessed.

The Gramame River Basin is considered strategic because it supplies the population and various activities, such as industrial and agricultural activities, in a set of cities called Grande João Pessoa. As it is a basin with multiple uses of water, there are different conflicts over the use of this resource, especially those involving water demand for human consumption and irrigation (GOVERNO DA PARAÍBA, 2000). Agricultural use represents the largest area of occupation in the basin and the largest consumption of water. The irrigation activity is significant, and the main exploitation crop is sugarcane.

4 Materials and methods

The Gramame River basin (Figure 1) is located between latitudes 7° 11' and 7° 23' South and longitudes 34° 38' and 35° 10' West, and it is situated on the southern coast of the state of Paraíba, close to the state capital, João Pessoa. The basin area spans seven municipalities: Alhandra, Conde, Cruz do Espirito Santo, João Pessoa, Santa Rita, São Miguel do Taipu, and Pedras de Fogo. The basin is responsible for approximately 70% of the water supply of Greater João Pessoa. It has a drained area of 589.1 km², its main watercourse is the Gramame River, which is 54.3 km long, and its main tributaries are the Mumbaba and Água Boa Rivers.

Figure 1. Gramame River Basin.



Source: Authors (2022)

Among the seven municipalities in the river basin, four with the largest planted area of sugarcane according to Municipal Agricultural Production - Temporary Crops (IBGE, 2014) were chosen for this study. The municipalities are Pedras de Fogo and Santa Rita, both with 18,000 hectares; Cruz do Espírito Santo, with 6,400 hectares; and Alhandra, with 3,150 hectares. This criterion was chosen because the calculation of sugarcane evapotranspiration depends on the value of the planted area. Sugarcane was selected because it is the predominant crop in the basin.

The values of the monthly average of observed temperatures used for the calculations were provided by the National Meteorological Institute (INMET); these values refer to the compensated average of temperature from the years 1961--1990 in the city of João Pessoa. The projected temperature data were obtained from the BRAMAR Project, which is a cooperative research project between Brazil and Germany that aims to improve integrated water resource management in the semiarid region of northeastern Brazil. These data were originally obtained from the Coordinated Regional Climate Downscaling (CORDEX) and extracted from its original format through a script prepared by the BRAMAR Project.

To achieve the objectives proposed in this paper, three regional circulation models (RCMs) were chosen. These models were regionalized via the dynamic downscaling technique, and in this case, an RCM was simulated with the boundary conditions of a global circulation model (GCM); therefore, the GCMs used were (a) MPI-ESM-LR, which provided the boundary conditions for the regional models RCA4 and REMO2009, and (b) ICHEC-EC-EARTH, which provided the boundary conditions for the regional model RCA4.

The three models have a grid of 0.44° × 0.44° (Lat × Lon) and projections for three scenarios: historical (1951--2005), RCP4.5 (2006--2069), and RCP8.5 (2006--2069). The period of time in each scenario is fixed. Although these models simulate daily temperatures for these intervals of years, in this study, they were evaluated in climate mode, that is, with the monthly average values of three intervals of years: 1961--1990 (current), 2006--2037 (near future), and 2038--2069 (distant future).

Two RCP scenarios developed by the IPCC were also selected to undertake the projections presented in this paper. They are RCP4.5, which is considered to be a stable scenario with a radioactive strength equivalent to 4.5 Wm $^{-2}$, and RCP8.5, which is the most pessimistic scenario with a radioactive strength of 8.5 Wm $^{-2}$.

Given that these models simulate temperatures from 1951--2100 and that they can simulate temperatures satisfactorily, the observed data (monthly average temperatures provided by INMET) were compared with the simulated data (monthly averages of the temperatures simulated by the three RCMs) for the period from 1961--1990, which were considered the current climate in this study.

Through this comparison, the existing uncertainties in the temperature simulation process for the current climate were evaluated for each model. This evaluation is necessary because the atmospheric models generate errors inherent to the simulation itself when simulating the current climate. Thus, the errors need to be mitigated, and the information can be used without propagating errors.

To reduce uncertainty, the future temperature data were corrected via the delta method, which considers the temperature anomaly. The correction can be understood as the observed temperature plus the increase in temperature provided by the model (future climate minus current climate). The difference between the temperatures of the future climate and the current climate is called an anomaly. In this work, temperature anomalies were divided into two intervals of time to reduce uncertainty and provide a better representation: Δ1= 2006--2037 and Δ2= 2038--2069.

The correction by the delta method is given by Equation (1).

$$T_{f,corr} = T_{obs} + \Delta T \quad (1)$$

where $T_{f,corr}$ represents the future temperature corrected in degrees Celsius; T_{obs} represents the observed temperature in degrees Celsius; and ΔT represents the temperature anomalous values in degrees Celsius.

Therefore, for each model (ICHEC-RCA4, MPI-RCA4, and MPI-REMO2009), projections of future temperatures were made for two IPCC scenarios (RCP4.5 and RCP8.5) and for two intervals of years (2006--2037, 2038--2069). A set of four future temperatures was subsequently obtained for each model, totaling twelve future temperatures for the three models.

With the corrected future temperature projections, it was possible to calculate the reference evapotranspiration (ETo), and the chosen method was Thornthwaite. The choice was based on the climatic data that were available for the studied region and the data provided by atmospheric models. This method starts from standard evapotranspiration (ETp), which considers evapotranspiration for a month of 30 days with 12 hours of sunlight per day. The formulation of the method is given by Equation 2.

$$ETo = F_c \times 16 \times \left(10 \times \frac{T}{I}\right)^a \quad (2)$$

where ETo is the reference evapotranspiration (mm month $^{-1}$); F_c is the correction factor as a function of latitude and month of the year; I is the annual heat index, corresponding to the sum of twelve-monthly indices; T is the estimated temperature for each month (°C); and a = $(6.75 \times 10^7 x\ I^3) - (7.71 \times 10^5 x\ I^2) + (0.017\ 91 \times I) + 0.492$ (mm month $^{-1}$).

The annual heat index is calculated via Equation 3.

$$I = \sum_{i=1}^{12} \left(\frac{T}{5}\right)^{1.514} \quad (3)$$

where T is the estimated temperature for each month (°C).

With the estimated values of ETo for each model, the evapotranspiration of the crop ETc was calculated, making it possible to estimate the water demand that sugarcane culture needs, and finally, the impacts of climate change on this culture could be observed by comparing the water demands of the optimistic scenario (RCP4.5) with those of the pessimistic scenario (RCP8.5). The purpose of performing these calculations for three different types of models is to compare the results and observe the interference of each model in the calculation of evapotranspiration. ETc is calculated via Equation (4).

$$ETc = K_c \times ETo \times A_p \quad (4)$$

where ETc is the evapotranspiration of the crop given in mm month $^{-1}$; K_c is the culture coefficient; ETo is the reference evapotranspiration given in mm month $^{-1}$; and A_p is the sugarcane planted area in hectares.

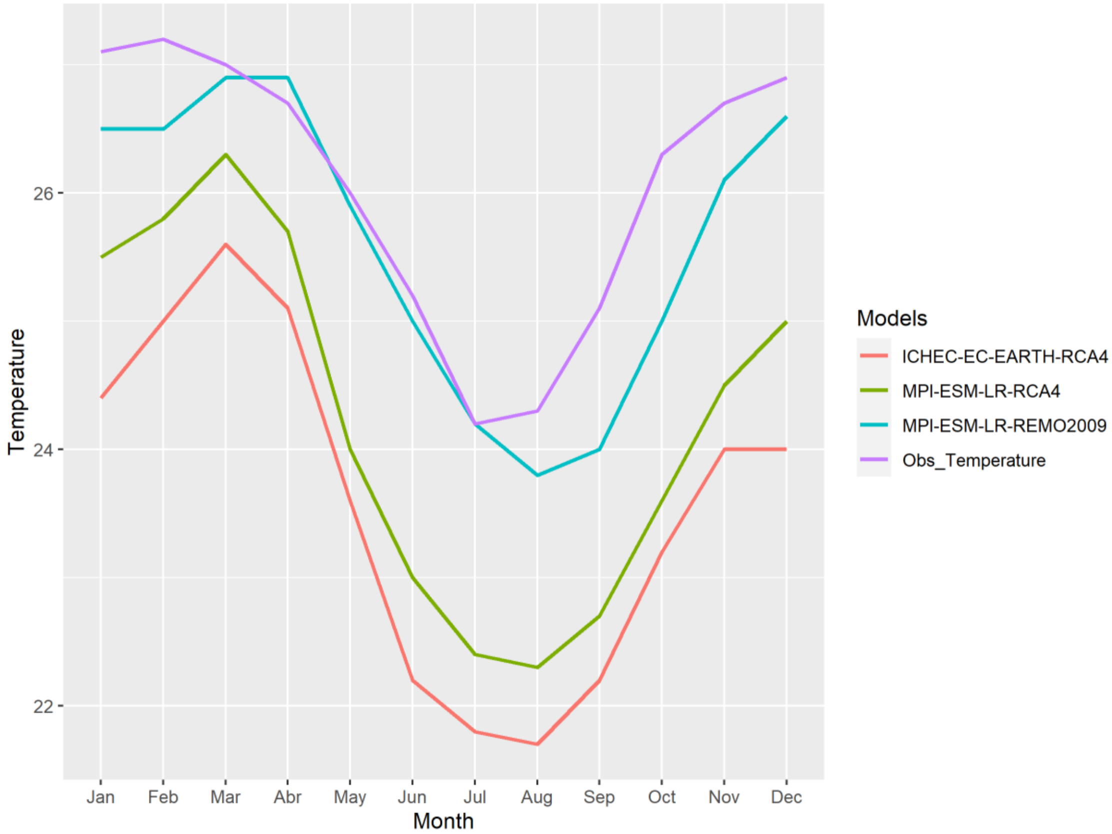
In the present study, the K_c value used was 0.75. The Food and Agriculture Organization of the United Nations (FAO) recommends the use of this value to represent the final stage of development of sugarcane culture (ALLEN *et al.*, 1998). These K_c values are recommended worldwide (LIBARDI *et al.*, 2019) for places where local data are not available (SILVA *et al.*, 2013). A single value was used, as it was impractical to measure in the field the values referring to the phases of the phenological cycle of sugarcane, which would be ideal. For a better understanding of the results, converting the results from mm month $^{-1}$ to m^3 month $^{-1}$ is convenient. Therefore, it is necessary to have the values of planted areas.

5 RESULTS AND DISCUSSION

5.1 Model performance evaluation

Comparing the monthly average observed temperatures with those simulated by the three models (Figure 2), the MPI-REMO2009 model showed the best performance. In general, the three models simulate the current temperature well, considering that they follow the same pattern for observed temperatures over the years, in which the temperatures are higher between January and April. In the period from May to August, they decrease and then start to rise again in September. However, the three models underestimate the temperatures, presenting values lower than those observed.

Figure 2. Comparison between the observed temperatures (°C) and the simulated temperatures (°C) by the models for the period from 1961--1990.



Source: Authors (2022)

The MPI-REMO2009 model presents values closer to the observed values, showing that for the months from March to July, the lines practically overlap. This means that temperatures are well simulated and that the uncertainties presented by this model for this period of time are almost null. Between August and November, the model does not represent the temperatures as well, presenting greater uncertainties. The MPI-RCA4 and ICHEC-RCA4 models have similar patterns, with greater uncertainties during the period from May--December. Finally, the uncertainties shown by ICHEC-RCA4 are greater (Figure 2).

On an annual basis, the annual average value of the observed temperature (1961--1990) is 26.1 °C, the ICHEC-RCA4 model estimates the value at 23.6 °C, the MPI-RCA4 estimates at 24.2 °C, and the MPI-REMO2009 estimates at 25.6 °C. Therefore, MPI-REMO2009 underestimates the annual observed average at -0.5 °C, MPI-RCA4 at -1.9 °C and ICHEC-RCA4 at -2.5 °C (Figure 2).

According to the quantitative analysis of the pattern of temperatures simulated by the models with the temperature observed through the statistical metrics: coefficient of determination (R^2), mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and agreement index of Willmott (d) (Table 1). The MPI-REMO2009 model presents the best performance, with d and R^2 values very close to the values considered ideal (equal to 1), 0.92 and 0.84, respectively. The corresponding errors (ME, MAE, and RMSE) all had very small values, i.e., less than 1.

Table 1. Statistical metrics that compare the temperatures simulated by the three models with those observed for the period of 1961--1990.

	ICHEC-RCA4	MPI-RCA4	MPI-REMO2009
R^2	0.78	0.81	0.84
ME	-2.49	-1.82	-0.44
MOTHER	2.49	1.82	0.47
RMSE	2.54	1.91	0.62
d	0.54	0.64	0.92

Source: Authors (2022)

Figure 3 shows the pattern of model uncertainties over the years; in general, the models had more difficulties simulating the month of October, with uncertainties of -3.1 °C for ICHEC-RCA4, -2.7 °C for MPI-RCA4 and -1.3 °C for MPI-REMO2009. On the other hand, it was easier to simulate the month of March, with -1.4 °C for ICHEC-RCA4, -0.7 °C for MPI-RCA4 and -0.1 °C for MPI-REMO2009.

Figure 3. Patterns of model uncertainties (°C).

Source: Authors (2022)

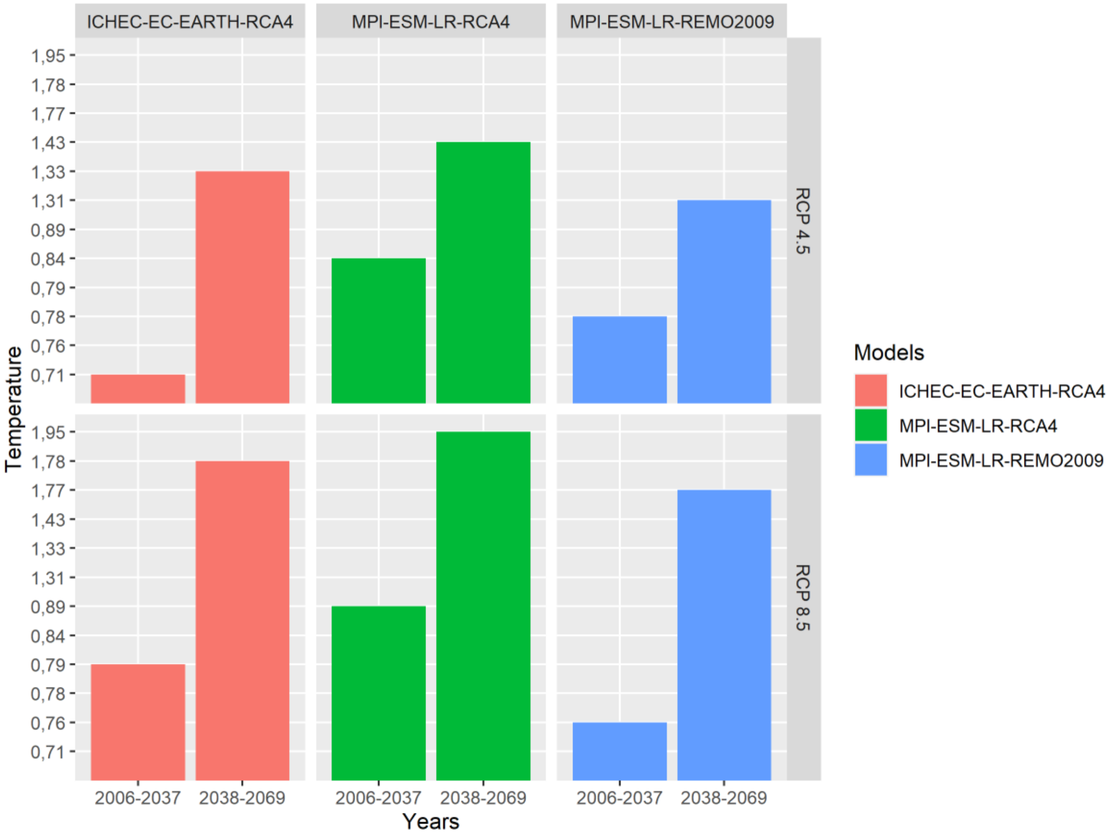
Therefore, the MPI-REMO2009 model stands out for simulating the current temperature satisfactorily, in which the uncertainties from March to June are practically insignificant and those from August to February are insignificant. In contrast, the ICHEC-RCA4 could not represent reality well. Although it follows the observed temperature pattern, ICHEC-RCA4 presents considerable uncertainties; for example, in October, it reaches -3.1 °C.

Compared with the other two models, the MPI-RCA4 model was in the middle term.

5.2 Anomalies in future temperatures

Comparing the averages of anomalies in both scenarios (Figure 4), for the near future (2006--2037), the temperature increase difference between the RCP4.5 and RCP8.5 scenarios is minimal, which indicates that for this period, both scenarios generated equal impacts from climate change. For the distant future (2038--2069), it is possible to observe a more significant difference of approximately 0.5 °C, which shows that the increase in temperature will be associated with greater intensity in the distant future under the RCP 8.5 scenario.

Figure 4. Annual averages of anomalies for the three models and both scenarios: RCP4.5, RCP8.5.

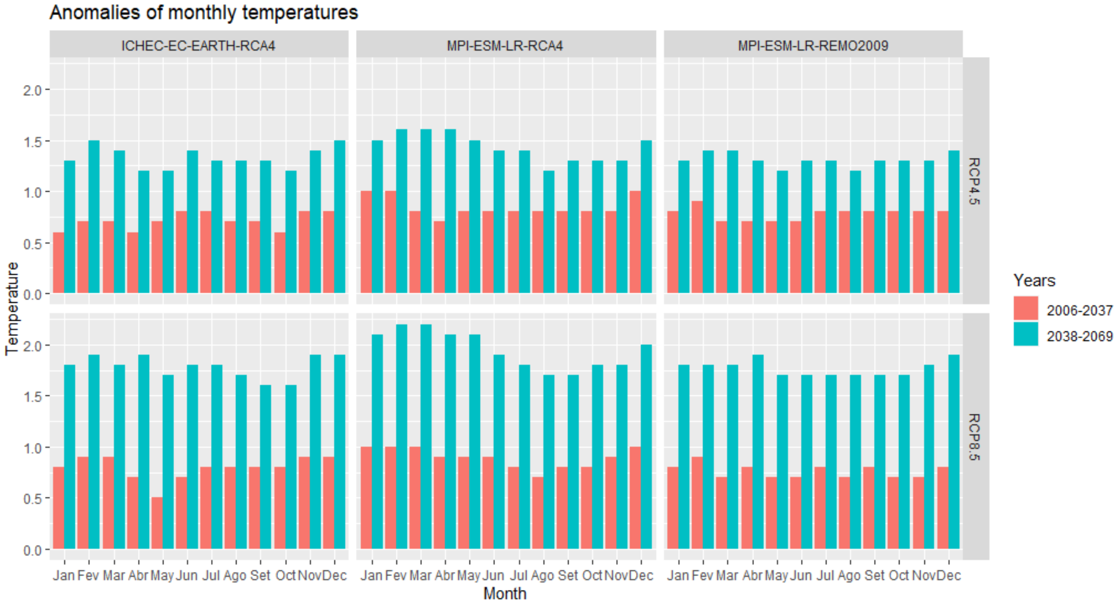


Source: Authors (2022)

The difference between the patterns presented by the models is not significant. MPI-RCA4 has the highest temperature values in both the scenarios and the periods of the year. In the near future (2006--2037), MPI-RCA4 differs by 0.13 °C (RCP 4.5) and 0.1 °C (RCP 8.5) from the ICHEC-RCA4 model and 0.06 °C (RCP 4.5) and 0.13 °C (RCP 8.5) from MPI-REMO2009. In the distant future, the MPI-RCA4 model differs from the ICHEC-RCA4 model by 0.1 °C (RCP 4.5) and 0.17 °C (RCP 8.5) and from the MPI-REMO2009 model by 0.12 °C (RCP 4.5) and 0.18 °C (RCP 8.5) (Figure 4).

Assessing monthly temperature anomalies (Figure 5), the ICHEC-RCA4 and MPI-REMO2009 models present anomalies below 1.5 °C every month in the distant future (2038--2069) for the RCP4.5 scenario, whereas in the RCP8.5 scenario, these anomalies increase and remain above 1.5 °C in all months. For the MPI-RCA4 model, the situation worsens, with the RCP4.5 scenario from December to May already reaching/exceeding a 1.5 °C increase, and in the RCP8.5 scenario, these months reach/exceed 2 °C.

Figure 5. Anomalies of monthly temperatures of the three models (ICHEC-EC-EARTH-RCA4; MPI-ESM-LR-RCA4; MPI-ESM-LR-REMO2009) and for the two scenarios: RCP4.5 and RCP8.5.



Source: Authors (2022)

Through this comparison between the scenarios and the periods of years, the temperature increase is evidently due to climate change. According to the 5th Assessment Report (AR5) published by the IPCC in 2014, by the end of the 21st century, it is likely that the variation in global surface temperature will exceed 1.5 °C compared to the period 1850--1900 in the last three scenarios proposed by the IPCC (RCPs 4.5, 6.0 and 8.5). For the period of 2016--2035 (in relation to 1986--2005), an increase in the variation in the global average temperature in the range of 0.3--0.7 °C is projected, whereas for the period of 2081--2100, the increase may reach the range of 2.6--4.8 °C in the RCP8.5 scenario (IPCC,2014).

Furthermore, the 6th Assessment Report (AR6), published in 2021, projected that in the next 20 years, the global average temperature will reach or exceed 1.5 °C above 1850--1900 levels (ZHOU, 2021). Therefore, these data are alarming and confirm that the increase in greenhouse gas emissions interferes with the increase in temperature. Thus, mitigation policies to reduce the emissions of these gases must be taken as soon as possible.

5.3 Future temperature correction

Table 2 shows the annual averages of future temperatures that were corrected to avoid the accumulation of uncertainties. The values indicate that the future temperatures have the same pattern as the anomalies previously assessed, which is natural considering that the corrections of these temperatures were carried out with anomaly values. This pattern confirms that the temperature increase will be greater in the distant future (2038--2069) and that the models have a similar standard, as the temperature difference between them is minimal.

Table 2. Annual averages of corrected future temperatures.

Models	RCP 4.5 scenario		RCP 8.5 scenario	
	2006-2037 (°C)	**2038-2069 (°C)**	**2006-2037 (°C)**	**2038-2069 (°C)**
ICHEC-RCA4	26.8	27.4	26.9	27.8
MPI-RCA4	26.9	27.5	27	28
MPI-REMO2009	26.8	27.4	26.8	27.8

Source: Authors (2022)

According to Table 3, the variation in maximum and minimum temperatures is slight, and an increase in maximum temperatures is observed when comparing the near future (2006--2037) with the distant future (2038--2069). The maximum and minimum temperatures occur in February (maximum), July and August (minimum).

Table 3. Average monthly maximum (Max) and minimum (Min) temperatures.

Models	RCP 4.5 scenario				RCP 8.5 scenario			
	2006-2037		**2038-2069**		**2006-2037**		**2038-2069**	
	Max (°C)	**Min (°C)**	**Max (°C)**	**Min (°C)**	**Max (°C)**	**Min (°C)**	**Max (°C)**	**Min (°C)**
ICHEC-RCA4	27.9	25	28.7	25.5	28.1	25	29.1	26
MPI-RCA4	28.2	25	28.8	25.5	28.2	25	29.4	26
MPI-REMO2009	28.1	25	28.6	25.5	28.1	25	29	26

Source: Authors (2022)

The MPI-RCA4 model presents the highest maximum temperatures, whereas the minimum temperatures coincide in all the models (Table 3). This pattern of few changes in temperature over the year is coherent with the pattern of anomalies shown in Fig. 5. The average temperature in Northeast Brazil is 26 °C without many intra-annual variations, as the seasons of the year in this region are not well defined. This fact justifies the pattern found in Table 3.

Comparing both scenarios in the near future, the ICHEC-RCA4 model showed a 2.7% increase in its maximum temperature from one scenario to another, whereas the MPI-RCA4 and MPI-REMO20009 models did not change. In the distant future, the increases in maximum temperatures might be more intense, in which the ICHEC-RCA4 and MPI-REMO20009 scenarios increased by 1.4% and the MPI-RCA4 scenario increased by 2.1% from the RCP4.5 scenario to RCP8.5.

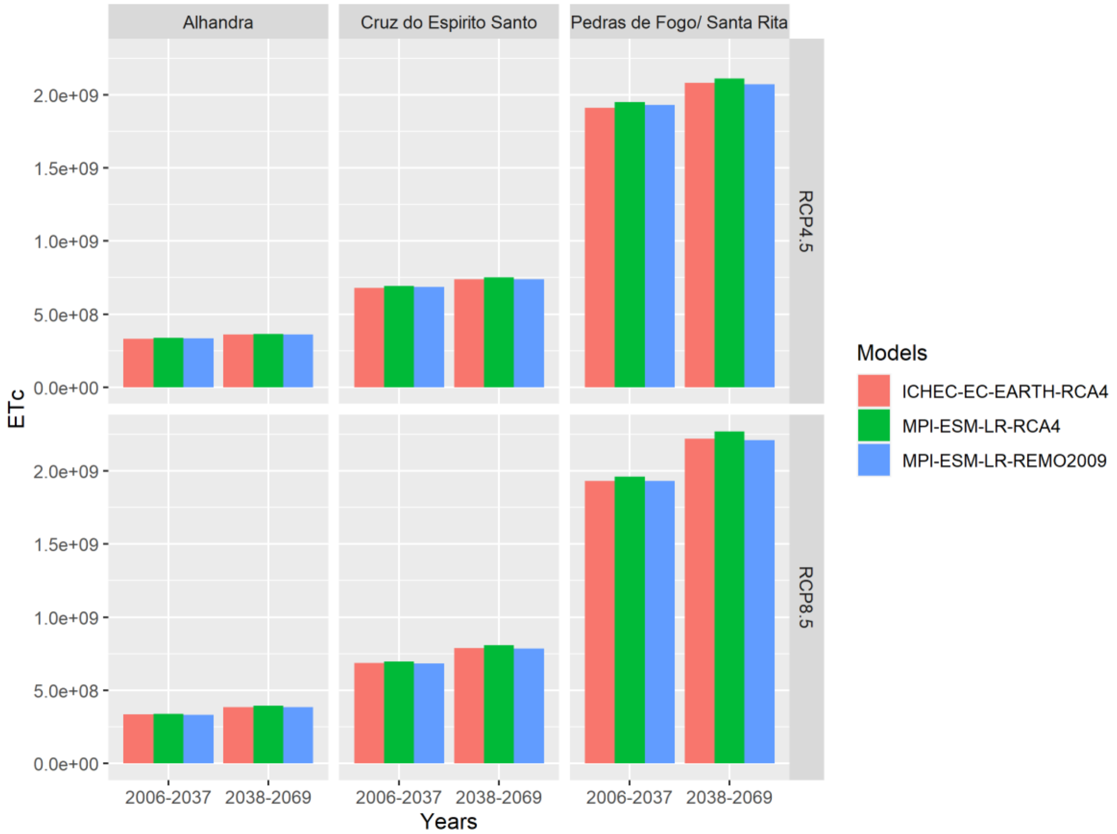
5.4 Evapotranspiration of sugarcane culture

Comparing the annual water demands of the RCP4.5 and RCP8.5 scenarios in each municipality, it is clear that the increase in temperature due to climate change could interfere with the amount of sugarcane cultivation water demand. This occurred because the projections differed between both scenarios in terms of water demand, with RCP8.5 requiring a greater volume of water.

The amount of water destined for irrigation of the sugarcane crop will be affected by climate change. Moreover, what differs in the amount of water demanded by each municipality is the size of its planted area, which means that municipalities with more planted area demand more water. In this case, Pedras de Fogo and Santa Rita had 18000 hectares of sugarcane planted area.

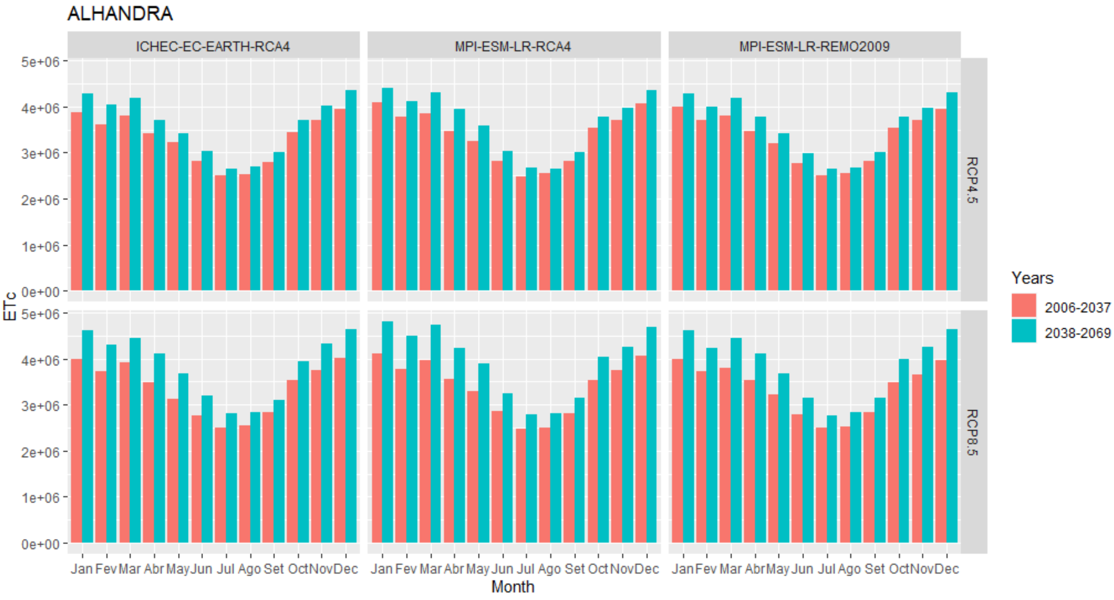
Overall, both in terms of annual demand (Figure 6) and monthly demand (Figures 7, 8, 9) for the near future (2006--2037), the amount of water demanded in the pessimistic scenario (RCP 8.5) varies slightly in relation to that demanded by the most optimistic scenario (RCP 4.5). This can be explained by the fact that the near future is still a recent period of years, so climate change is not intensely felt.

Figure 6. Annual water demand for sugarcane (m^3 $year^{-1}$) in four municipalities: Alhandra, Cruz do Espírito Santo, Pedras de Fogo/Santa Rita. Both scenarios include RCP4.5 and RCP8.5.



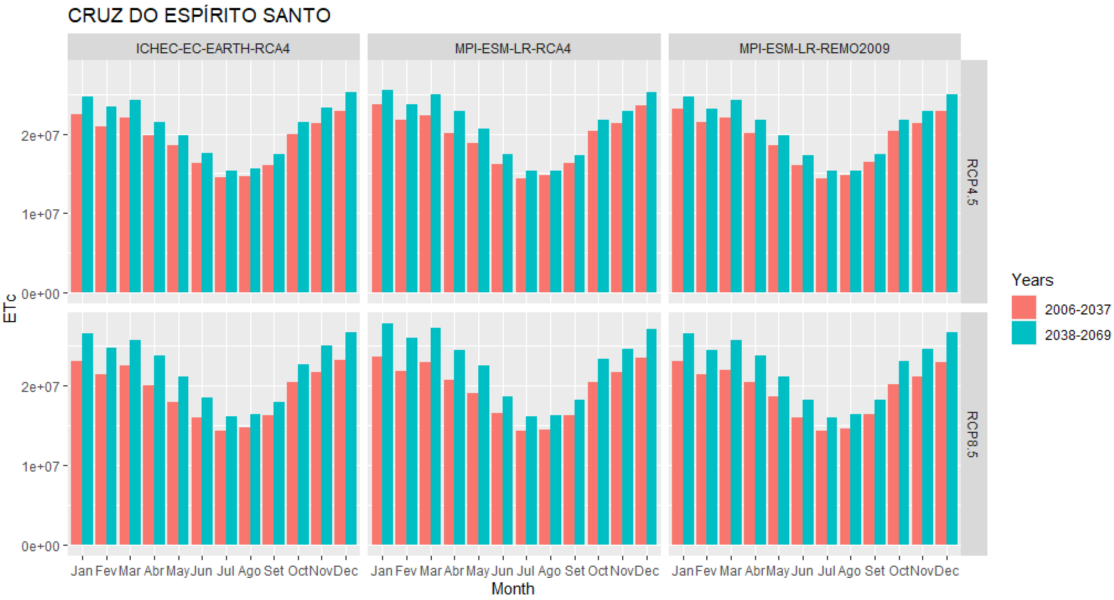
Source: Authors (2022)

Figure 7. Sugarcane monthly water demand (m³ year $^{-1}$) in the municipality of Alhandra for the three models: ICHEC-EC-EARTH-RCA4, MPI-ESM-LR-RCA4, MPI-ESM-LR-REMO2009. Both scenarios include RCP4.5 and RCP8.5.



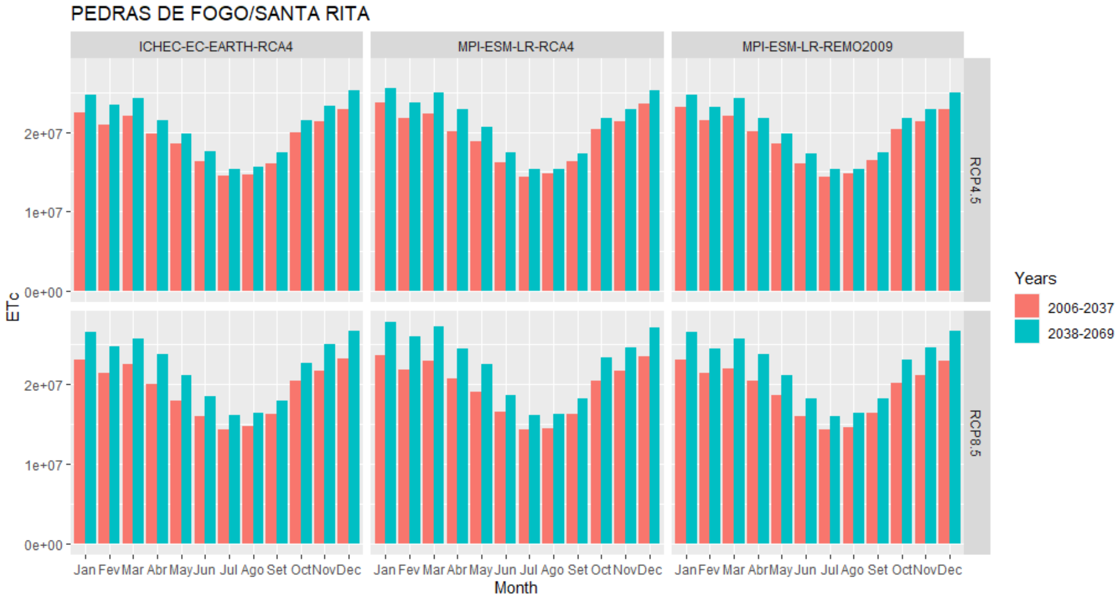
Source: Authors (2022)

Figure 8. Sugarcane monthly water demand (m³ year $^{-1}$) in the municipality of Cruz do Espírito for the three models: ICHEC-EC-EARTH-RCA4, MPI-ESM-LR-RCA4, MPI-ESM-LR-REMO2009. Both scenarios include RCP4.5 and RCP8.5.



Source: Authors (2022)

Figure 9. Sugarcane monthly water demand (m^3 year $^{-1}$) in the municipality of Pedras de Fogo/Santa Rita for the three models: ICHEC-EC-EARTH-RCA4, MPI-ESM-LR-RCA4, MPI-ESM-LR-REMO2009. Both scenarios include RCP4.5 and RCP8.5.



Source: Authors (2022)

In the second period of time (2038--2069), which represents the distant future, it is possible to note a greater difference between the two scenarios, with the pessimistic scenario (RCP8.5) presenting greater demands. Furthermore, in the RCP8.5 scenario, the water sources responsible for allocating water for irrigation may become overloaded and fail to meet the necessary demand.

Gorguner and Kavvas (2020) also reported that the annual average irrigation water demand under the RCP8.5 scenario is superior to that under the RCP4.5 scenario for a basin in the Mediterranean region. They used four different GCMs and evaluated the 2017–2100 period.

In addition, Zullo, Pereira and Koga-Vicente (2018) projected that the demand for irrigation water will increase under the RCP8.5 scenario in the near future, in the timeframe from 2021--2050, in the southern-central region of Brazil via eight GCMs. The authors associated this increase with projections of decreasing water availability in the region.

Figures 7, 8, and 9 allow the assessment of the monthly water demand values of the municipalities studied. The four municipalities exhibit similar behaviors. From May to August, the amount of water required by sugarcane decreases because these months are rainy.

With respect to the models, the pattern shown in the estimation of sugarcane evapotranspiration is compatible with the observed pattern of future anomalies and corrected future temperatures. In general, this pattern is characterized by little difference between the values, with the changes in climate being felt more intensively in the distant future (2038--2069) in the pessimistic scenario (RCP8.5).

The values in Table 4 indicate that the water demand for sugarcane in the watershed could increase, especially in the distant future (2038--2069), when the RCP4.5 and RCP8.5 scenarios are compared. For the near future (2006--2037), the model's average indicates that the annual demand will increase by 0.6% from the RCP4.5 scenario to the RCP8.5 scenario, and for the distant future, this increase will be 7%. Therefore, the RCP8.5 scenario presents the greatest water demands in the future, implying that the amount of water required for irrigation will also be greater.

Table 4. Total annual water demand for the four municipalities studied.

Models	RCP 4.5 scenario		RCP 8.5 scenario	
	2006-2037 (m^3 year $^{-1}$)	2038-2069 (m^3 year $^{-1}$)	2006-2037 (m^3 year $^{-1}$)	2038-2069 (m^3 year $^{-1}$)
ICHEC-RCA4	4.83×10^{7}	5.26×10^{7}	4.89×10^{7}	5.60×10^{7}
MPI-RCA4	4.95×10^{7}	5.40×10^{7}	4.96×10^{7}	5.75×10^{7}
MPI-REMO2009	4.88×10^{7}	5.24×10^{7}	4.87×10^{7}	5.59×10^{7}

Source: Authors (2022)

According to Carvalho *et al.* (2015), the projections of increased temperatures lead to elevated evapotranspiration rates, which reduce the amount of water available in the soil. As a result, sugarcane planting becomes more difficult, and in dry areas, it tends to be strongly reduced. Therefore, the projections of increased evapotranspiration and, consequently, water demand expected for the future may affect the planting of sugarcane, resulting in a reduction in its production.

For the municipality of Goiana, which is located in the state of Pernambuco and is also located in the Northeast Region of Brazil, Carvalho *et al.* (2015) projected, for an intermediate climate change scenario, a 13% reduction in sugarcane productivity in the near future (2014--2040) and a 23% reduction in the more distant future (2041--2070) compared with the present climate (1959--2013).

Nevertheless, according to Carvalho *et al.* (2015), areas in Northeast China are considered to be at low climatic risk and tend to reduce sugarcane productivity, whereas areas considered to be at high climatic risk are considered unsuitable for cultivation because of low water availability (SILVA *et al.*, 2013; OLIVEIRA *et al.*, 2012).

Araújo *et al.* (2014) analyzed the impact of climate change on sugarcane agricultural production in Brazil. The authors reported that in scenarios where the simulated temperature levels were relatively high, the average reduction in sugarcane productivity was relatively intense. It was also observed that in the medium term (2040--2070) and long term (2070--2100), the productivity levels of all the northeastern states decreased. In a more pessimistic scenario, the productivity of the state of Paraíba may have been reduced by 6.55% (in the medium term) and 5.83% (in the long term) compared with that in the period of 1970--1995.

In the next decade, an increase in sugarcane production is expected due to RenovaBio, which is a national program to promote the use of biofuels. Currently, in Brazil, approximately two-thirds of sugarcane production is converted to ethanol. Therefore, the use of irrigation water is expected to increase, consequently increasing the water demand in the Gramame River Basin (ZILLI *et al.*, 2020).

This expansion in sugarcane production can become a problem since Carvalho *et al.* (2015) reported that the possible reduction in water availability in some regions and the expected increase in water demand for other uses may be limiting factors for the desired increase in sugarcane production in the future.

However, Zilli *et al.* (2020) reported that to make Brazilian agriculture more resilient to climate change and contribute to its mitigation, large-scale sustainable practices and better application of Brazilian law are necessary.

6 CONCLUSION

The three RCMs analyzed are able to satisfactorily represent the observed temperature, with MPI-REMO2009 standing out as the one that presented the best performance. The uncertainty shown by the models was minimized by correcting future temperatures.

Through the calculation of sugarcane culture evapotranspiration for the RCP4.5 and RCP8.5 scenarios, the water demand for irrigation will increase with increasing temperature caused by climate change, especially in the more distant future (2038--2069).

Comparing scenarios RCP4.5 and RCP8.5, it is clear that if the development of mitigation policies and reduction of greenhouse gas emissions are put into practice, the agricultural sector, more precisely irrigation, will not experience the impacts of the increase in temperature, a situation described by the RCP4.5 scenario. However, if the emissions of these gases continue to increase over the years, the agricultural sector will face severe effects (RCP 8.5).

In the pessimistic scenario, RCP 8.5, the conflicts over water use in the Gramame River Basin tend to intensify since it will have to supply more water for irrigation. Additionally, the municipalities that have the largest planted area, such as those addressed in this study, will be the most affected.

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