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 biggest challenges faced by the world in this century is climate change, which is a theme that needs to be more studied in reason 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 at 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) affirm that long-term climate change projections (2079-2099) for the Northeast of Brazil point to an increase of 4.1 °C on annual average temperature.

The temperature increase impacts the hydrological variables, in consequence, affects the rain, evapotranspiration, runoff, and irrigation water demand, therefore, the watershed reservation capacity. Agriculture depends on these variables, which have direct interference on agricultural production. Then, 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 the rains (SAE, 2015), the irrigation water demand tends to increase over the years. As the use of irrigation is the best alternative for 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. Also, compared with industrial and urban sectors, water demand for irrigation is considered to be more sensitivity 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 around the world (FAO, 2020). Several studies have been developed with the theme of the climate change impacts 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 relate the consumption of water by crops and the use of water resources for irrigation are becoming more frequent, since irrigation is a factor that has a great influence on agricultural productivity and cost.

Through climate modelling, it is possible to estimate how climate change may affect the precipitation and temperature of our planet. The Global Circulation Models (GCM) and Reginal Circulation Models (RCM) provide projections of climate variables on the globe, 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 Pathways (RCP) scenarios were developed by the IPCC and are commonly used in studies involving climate change. They are expressed in $W.m^{-2}$ and defined as consistent sets of projections of radiative forcing components that are intended to serve as input to climate modelling (IPCC, 2014). The RCPs are divided into four scenarios (RCP 2.6, 4.5, 6.5 and 8.5) and are identified by their radioactive forcing in the year 2100 relative to 1759.

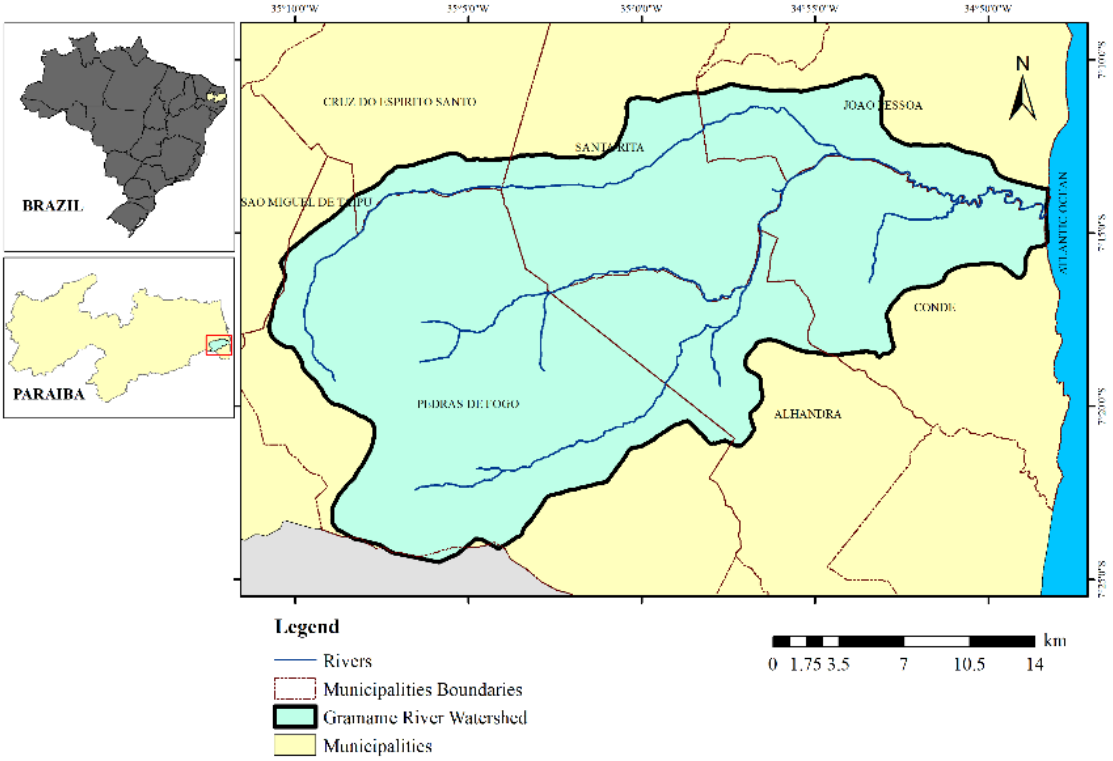
This study aims to assess the impacts caused by climate change on the irrigation water demand of sugarcane in the Gramame River Basin. For that, it is necessary to evaluate the existing uncertainties in the atmospheric model's simulated temperature of the current climate, and estimate the temperature projections for the future climate for two scenarios, RCP 4.5 as optimistic and RCP 8.5 as pessimistic. Then, to assess the impacts of water demand on irrigation for both scenarios.

The Gramame river basin is considered strategic as it supplies the population and various activities such as industrial and agriculture, in the 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. Irrigation activity is significant and the main exploitation crop is sugar cane.

4 MATERIAL AND METHODS

The Gramame River river basin (Figure 1) is located between latitudes 7° 11' and 7° 23' South and longitudes of 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 crosses seven municipalities, they are Alhandra, Conde, Cruz do Espirito Santo, João Pessoa, Santa Rita, São Miguel do Taipu, and Pedras de Fogo. The basin is responsible for the water supply of about 70% of the Grande João Pessoa. It has a drained area of 589.1 km² and 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 inserted in the river basin, four of those with the largest planted area of sugar cane 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

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 to 1990 in the city of João Pessoa. The data of the projected temperatures were provided from BRAMAR Project, which is a cooperation research project between Brazil and Germany that aims to improve the integrated water resources management in the semi-arid region of north-eastern Brazil. This data was originally obtained from the Coordinated Regional Climate Downscaling (CORDEX) and extracted from its original

Espírito Santo with 6,400 hectares and Alhandra with 3,150 hectares. The choice was made taking this criterion into consideration because the calculus of the sugarcane culture evapotranspiration depends on the value of the planted area. Sugar Cane was selected because it is the predominant crop in the basin.

format through a script prepared by BRAMAR Project.

To achieve the objectives proposed in this paper, three Regional Circulation Models (RCMs) were chosen. These models were regionalized using the dynamic downscaling technique and knowing that in this case an RCM is 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 that provided the boundary conditions for the regional model RCA4.

The three models have a grid of 0.44° x 0.44° (Lat x Lon) and projections for three scenarios: Historical (1951-2005), RCP 4.5 (2006-2069), and RCP 8.5 (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 RCP 4.5, which is considered to be a stabilization scenario with its radioactive strength equivalent to 4.5 $W.m^{-2}$ and RCP 8.5 which is the most pessimistic scenario with radioactive strength of 8.5 $W.m^{-2}$.

Knowing that these models simulate the temperature from 1951 to 2100, and objecting to know if they can simulate temperature satisfactorily, the observed data (monthly average temperatures provided by INMET) was compared to the simulated data (monthly averages of the temperatures simulated by the three RCMs) for the period from 1961 to 1990, considered in this study as the current climate.

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, then the information can be used without propagating errors.

To reduce uncertainties, the future temperature data was corrected based on the Delta method that 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 paper, temperature anomalies were divided into two intervals of time in order to reduce uncertainties and provide a better representation, Δ1= 2006-2037 e Δ2= 2038-2069.

The correction by the Delta method is given by Equation 1.

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

Where: $T_{f,corr}$ is the future temperature corrected in degrees Celsius; T_{obs} is the observed temperature in degrees Celsius; ΔT are the temperature anomaly values in degrees Celsius.

Therefore, for each model (ICHEC-RCA4, MPI-RCA4, and MPI-REMO2009) were made projections of future temperatures, for two IPCC scenarios (RCP 4.5 and RCP 8.5) and for two intervals of years (2006-2037, 2038-2069). Then, was obtained a set of four future temperatures 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), 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.

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

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); a = $(6.75 \times 10^7 \times I^3) - (7.71 \times 10^5 \times I^2) + (0.017\,91 \times I) + 0.492$ (mm month^{-1}).

The annual heat index is calculated by Equation 3.

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

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, being able to observe the impacts of climate change on this culture by comparing water demands of the optimistic scenario (RCP 4.5) with the pessimistic scenario (RCP 8.5). The purpose of performing these calculous for three different types of models is to be able to compare the results and observe the interference of each model in the calculation of evapotranspiration. The ETc is calculated from Equation 4.

$$\mathrm{ETc} = \mathrm{K}_c \times \mathrm{ETo} \times \mathrm{A_p} \qquad (4)$$

Where: ETc is the evapotranspiration of the crop given in mm month^{-1}; $\mathrm{K_c}$ is the culture coefficient; ETo is the reference evapotranspiration given in mm month^{-1}; $\mathrm{A_p}$ is the sugar cane planted area in hectares.

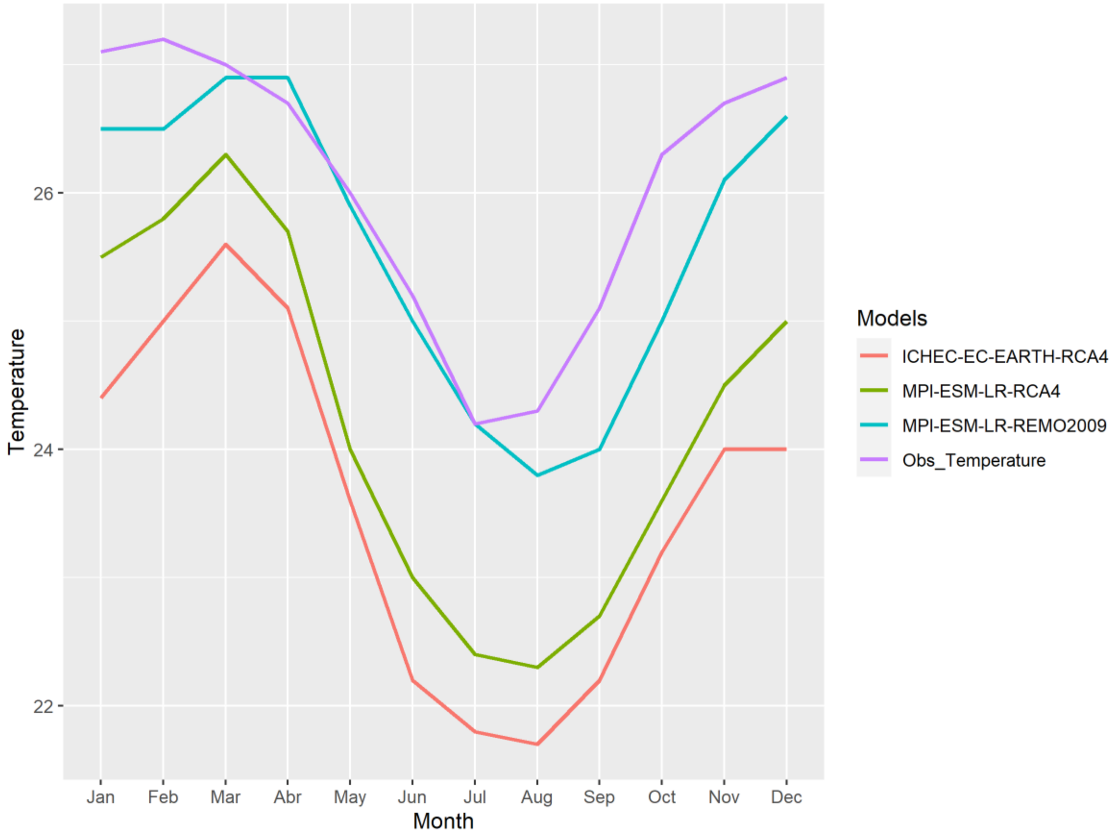
In the present study, the $\mathrm{K_c}$ value used was 0.75. The Food and Agriculture Organization of the United Nations (FAO) recommends to use this value to represent the final stage of development of the sugarcane culture (ALLEN et al., 1998). These $\mathrm{K_c}$ values are worldwide recommended (LIBARDI *et al.*, 2019) for places where the local data is not available (SILVA *et al.*, 2013). A single value was used, as it was impracticable to measure in the field the values referring to the phases of the phenological cycle of sugar cane, which would be ideal. For a better understanding of the results, it is convenient to convert the results from mm month^{-1} to m³ month^{-1}. Therefore, it is necessary to have the values of planted areas.

5 RESULTS AND DISCUSSION

5.1 Model performance evaluation

Comparing the monthly average of 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 (ºC) and the temperatures simulated (ºC) by the models for the period from 1961 to 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 the uncertainties presented by this model for this period of time are almost null. Between August and November, the model does not represent as well the temperatures, presenting greater uncertainties. The models MPI-RCA4 and ICHEC-RCA4 have similar patterns, with greater uncertainties during the period from May to December. Finally, the uncertainties showed 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 estimated the value at 23.6 °C, the MPI-RCA4 at 24.2 °C, and the MPI-REMO2009 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 analyze 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 Squared Error (RMSE) and Agreement Index of Willmott (d) (Table 1). It is confirmed that the MPI-REMO2009 model presents the best performance, with the values of the d and R^2 greatly close to the value considered ideal (equal to 1), being 0.92 and 0.84 respectively. Regarding their errors (ME, MAE, RMSE), they all had very small values, below 1.

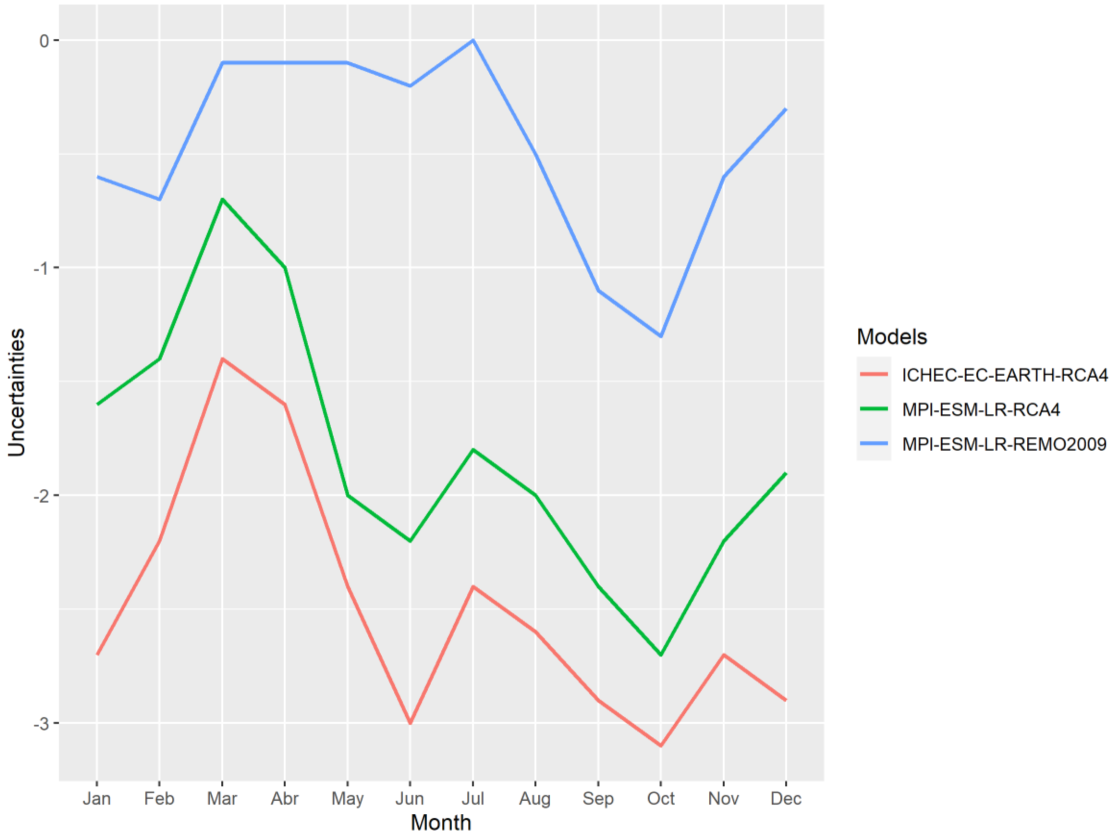
Table 1. Statistical metrics that compare the temperatures simulated by the three models with those observed for the period 1961-1990.

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

Source: Authors (2022)

The Figure 3 shows the pattern of model uncertainties over the years, in general, the models had more difficulties to simulate the month of October, with uncertainties of -3.1 °C for ICHEC-RCA4, -2.7 °C for MPI-RCA4 and -1.3 °C for the 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. Pattern of model uncertainties (°C).



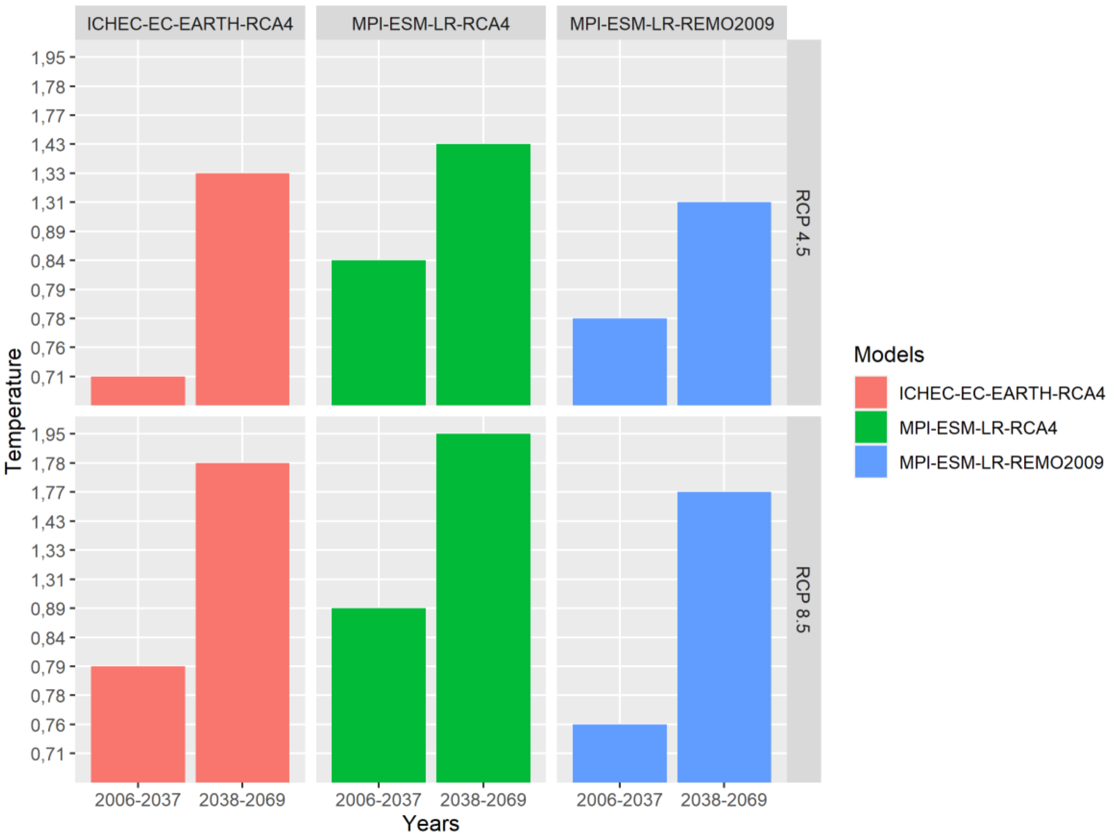
Source: Authors (2022)

Therefore, the MPI-REMO2009 model stands out by simulating the current temperature satisfactorily, in which the uncertainties from March to June are practically insignificant and those from August to February. In contrast, the ICHEC-RCA4 could not represent reality well. Although it follows the observed temperature pattern, ICHEC-RCA4 presents considerable uncertainties, such as, in October it reaches -3.1 °C. The MPI-RCA4 model was in the middle term compared to the other two.

5.2 Anomalies of future temperatures

Comparing the averages of anomalies in both scenarios (Figure 4), for the near future (2006 to 2037) temperature rising difference between the scenarios RCP 4.5 and RCP 8.5 is minimal, which indicates that for this period both, scenarios generated an equal impact of climate change. For the distant future (2038 to 2069), it is possible to observe a more significant difference of about 0.5 °C, which shows that the increase in temperature will be felt with greater intensity in the distant future in scenario RCP 8.5.

Figure 4. Annual averages of anomalies for the three models and both scenarios: RCP 4.5 RCP 8.5.

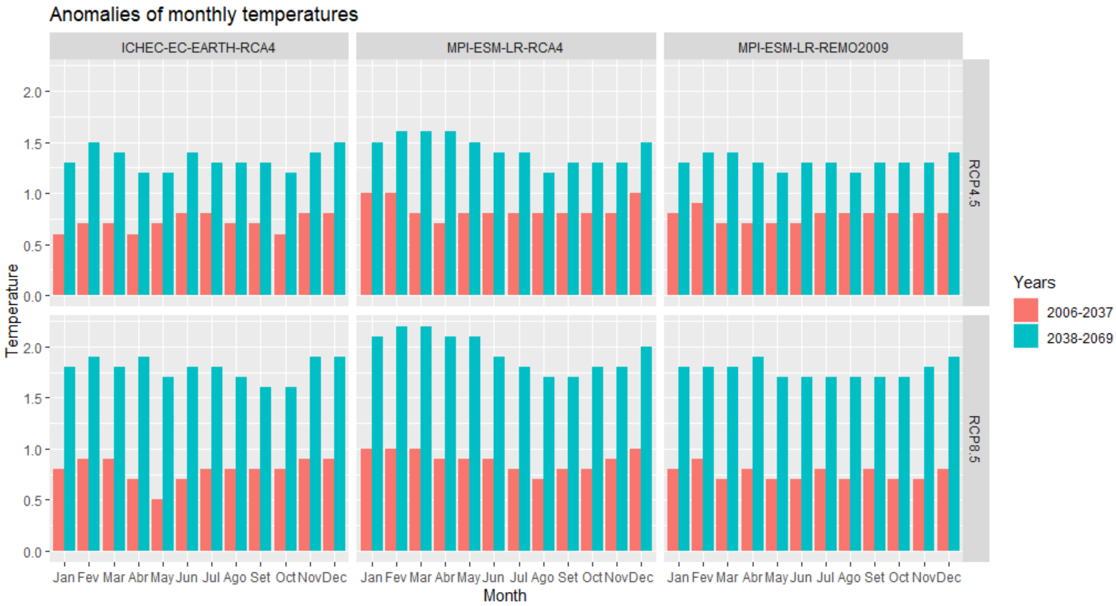


Source: Authors (2022)

Regarding the pattern presented by the models, the difference between them is not significant. MPI-RCA4 is the one with the highest temperature values in both scenarios and periods of years. 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, 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 by 0.1 °C (RCP 4.5) and 0.17 °C (RCP 8.5) from the ICHEC-RCA4 model and by 0.12 °C (RCP 4.5) and 0.18 °C (RCP 8.5) from the MPI-REMO2009 model (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 RCP 4.5 scenario, whereas, in the RCP 8.5 scenario these anomalies increase and remain above 1.5 °C at all months. For the MPI-RCA4 model, the situation worsens, wherein the RCP 4.5 scenario from December to May already reaches/exceeds 1.5 °C of increase, and in RCP 8.5 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: RCP 4.5 and RCP 8.5.



Source: Authors (2022)

Through this comparison between the scenarios and the periods of years, the temperature increase is evident 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 when compared to the period 1850-1900 in the last three scenarios proposed by the IPCC (RCP 4.5, 6.0 and 8.5). It is projected for the period 2016-2035 (in relation to 1986-2005) an increase in the variation of the global average temperature in the range of 0.3 to 0.7°C, while for the period 2081-2100, the rise may reach to the range of 2.6 to 4.8°C in the RCP 8.5 scenario (IPCC,2014).

Moreover, the 6th Assessment Report (AR6), published in the year 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 in fact interferes with the temperature increase. 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 in order to avoid the accumulation of uncertainties. Observing the values, it is noticed 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 anomalies 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 of maximum and minimum temperature is slight, and the 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) and 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, while the minimum coincides in all models (Table 3). This pattern of few changes in temperatures over the year is coherent with the pattern of the anomalies shown in Fig. 5. It is known that the average temperature in the Northeast of 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, while the MPI-RCA4 and MPI-REMO20009 did not change. In the distant future, the increases in maximum temperatures might be more intense, in which the ICHEC-RCA4 and MPI-REMO20009 increased by 1.4% and the MPI-RCA4 by 2.1% from the RCP 4.5 scenario to RCP 8.5.

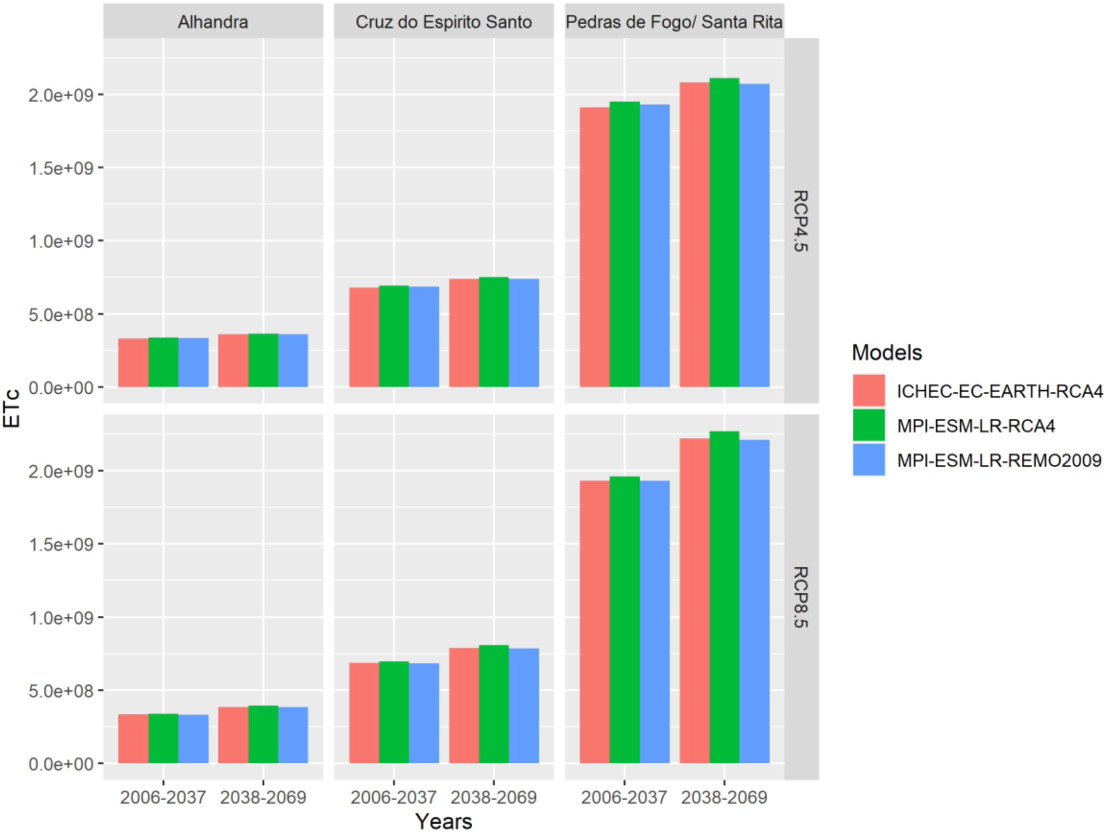
5.4 Evapotranspiration of sugarcane culture

Comparing the annual water demands of scenarios RCP 4.5 and RCP 8.5 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 is because the projections showed differences between both scenarios for the water demand, with the RCP 8.5 requiring more volume of water.

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

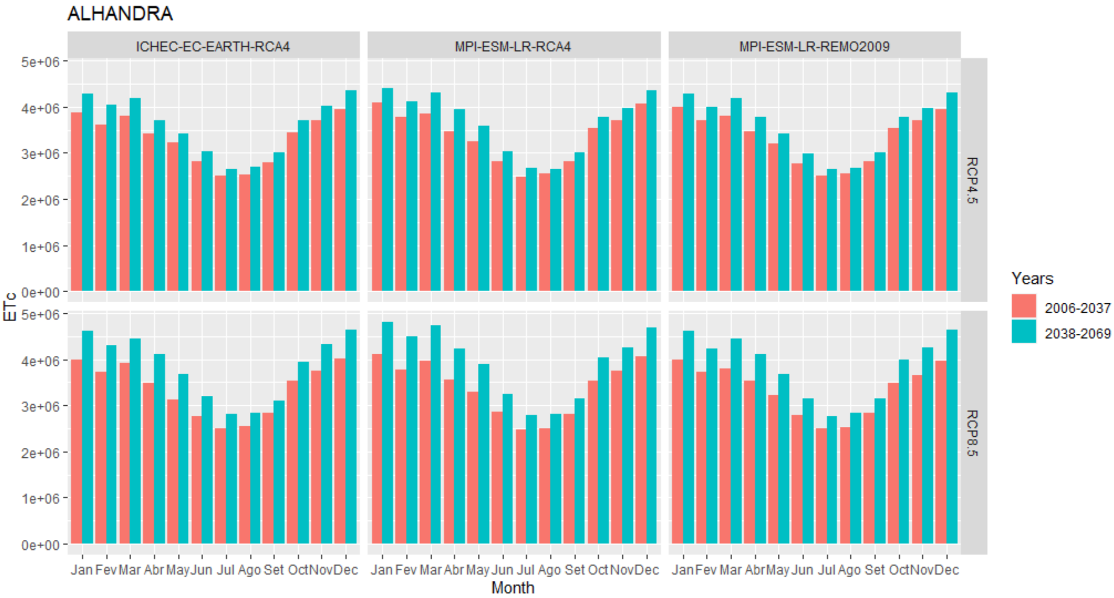
Overall, both in annual demand (Figure 6) and monthly demand (Figures 7, 8, 9) for the near future (2006-2037), the amount of water demanded in the pessimistic scenario (RCP 8.5) varies slightly in relation to that demanded by the most optimistic scenario (RCP 4.5). This can be explained by the fact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

Figure 6. Annual water demand for sugarcane ($m^3 year^{-1}$) in the four municipalities: Alhandra, Cruz do Espírito Santo, Pedras de Fogo/Santa Rita. And for the both scenarios: RCP 4.5 and RCP 8.5.



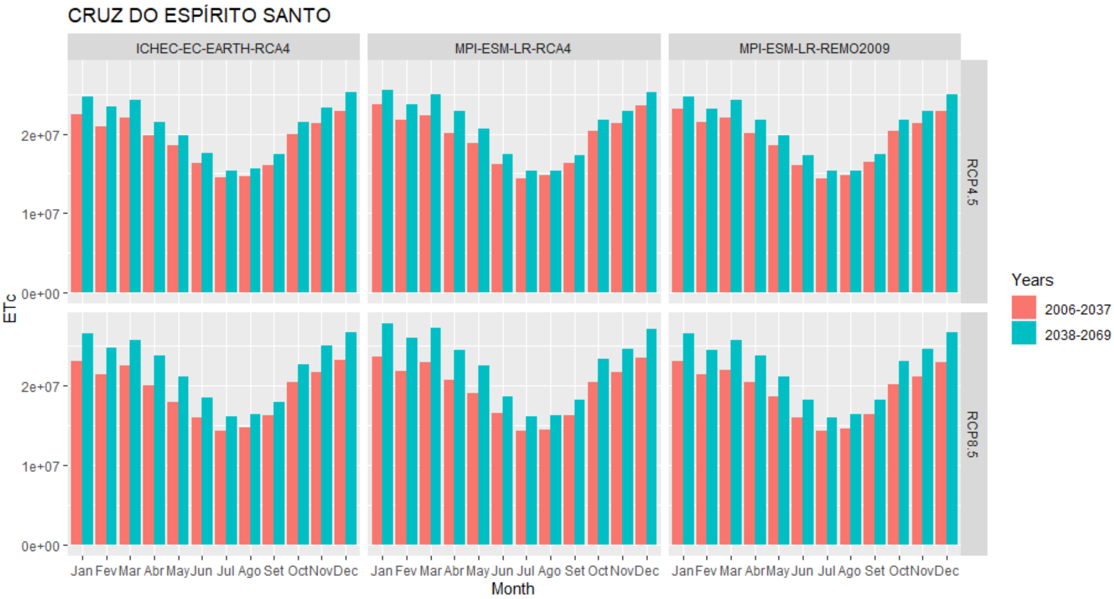
Source: Authors (2022)

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. And both scenarios: RCP 4.5 and RCP 8.5.



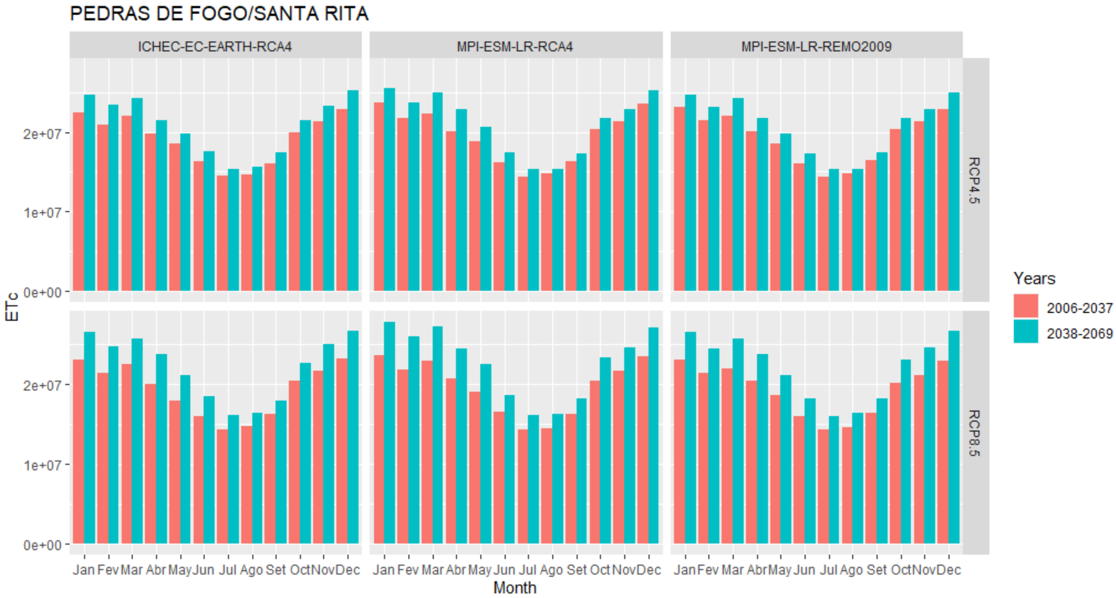
Source: Authors (2022)

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. And both scenarios: RCP 4.5 and RCP 8.5.



Source: Authors (2022)

Figure 9. Sugarcane monthly water demand (m³ 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. And both scenarios: RCP 4.5 and RCP 8.5.



Source: Authors (2022)

In the second period of years (2038-2069), which represents the distant future, it is possible to note a greater difference between the two scenarios, with the pessimist (RCP 8.5) presenting larger demands. Furthermore, in the RCP 8.5 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 found that the annual average of irrigation water demands for RCP 8.5 scenario projections is superior to the RCP 4.5 scenario for a basin in the Mediterranean region. They used four different GCMs and evaluated the 2017-2100 period of time.

In addition, Zullo, Pereira and Koga-Vicente (2018) projected that the demand for irrigation water will increase under the RCP 8.5 scenario in the near future, in the timeframe from 2021 to 2050, in the Brazilian south-central macro-region using eight GCMs. The authors associated this increase with projections of the decreasing water availability in the region.

Figures 7, 8, and 9 allow the assessment of the monthly water demand values of the studied municipalities. It is possible to observe that the four municipalities have similar behavior. From May to August, the amount of water demanded by sugarcane presents a drop because these are rainy months.

Regarding the models, the pattern shown estimating 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 (RCP 8.5).

From the values found in Table 4, it can be confirmed that the water demand for sugarcane in the watershed could increase, especially in the distant future (2038-2069) comparing the RCP 4.5 e 8.5 scenarios. For the near future (2006-2037), the model's average indicates that the annual demand will increase by 0.6% from the RCP 4.5 to RCP 8.5 scenario, and for the distant future this increase will be 7%. Therefore, the RCP 8.5 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 (m³ year^{-1})	2038-2069 (m³ year^{-1})	2006-2037 (m³ year^{-1})	2038-2069 (m³ year^{-1})
ICHEC-RCA4	$4.83\text{x}\ 10^7$	$5.26\text{x}10^7$	$4.89\text{x}\ 10^7$	$5.60\text{x}10^7$
MPI-RCA4	$4.95\text{x}10^7$	$5.40\text{x}10^7$	$4.96\text{x}10^7$	$5.75\text{x}10^7$
MPI-REMO2009	$4.88\text{x}10^7$	$5.24\text{x}10^7$	$4.87\text{x}10^7$	$5.59\text{x}10^7$

Source: Authors (2022)

According to Carvalho *et al.* (2015), the projections of increased temperatures lead to elevated evapotranspiration rates, which reduces 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, located in the state of Pernambuco, also inserted in the Northeast region of Brazil, Carvalho *et al.* (2015) projected for an intermediate climate change scenario a reduction in sugarcane productivity by 13% in the near future (2014-2040) and 23% in the more distant future (2041-2070) when compared to the present climate (1959-2013).

Still, according to Carvalho *et al.* (2015), areas in the northeast considered to be of low climatic risk showed a tendency to reduce sugarcane productivity, while areas considered to be of high climatic risk will be credited unsuitable for cultivation due to 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 observed that in scenarios where simulated temperature levels were higher, the average reduction in sugarcane productivity was more intense. It was also observed that in the medium (2040-2070) and long term (2070-2100), all northeastern states will have their productivity levels reduced. In a more pessimistic scenario, the state of Paraíba may have its productivity reduced by 6.55% (medium term) and 5.83% (long term) when compared to the period 1970-1995.

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

That expansion in sugarcane production can become a problem since Carvalho *et al.* (2015) say 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) state that to make Brazilian agriculture more resilient to climate change and contribute to its mitigation, it is necessary to adopt on a large scale sustainable practices and a better application of Brazilian law.

6 CONCLUSION

The three RCM analyzed are able to satisfactorily represent the observed temperature, with MPI-REMO2009 standing out as the one that presented the best performance. The uncertainties showed by the models were minimized by correcting future temperatures.

Through the calculus of sugarcane culture evapotranspiration for scenarios RCP 4.5 and 8.5, it is noted the water demand for irrigation will rise with the increase in temperatures caused by climate change, especially in the more distant future (2038-2069).

Comparing scenarios RCP 4.5 and RCP 8.5, it is clear that if the development of mitigation policies and reduction of greenhouse gas emissions would put into practice, the agricultural sector, more precisely irrigation, will not experience the impacts of the increase in temperature, a situation depicted by the RCP 4.5 scenario. However, if the emissions of these gases continue to increase over the years, the agriculture sector will face severe effects (RCP 8.5).

In the pessimist scenario, RCP 8.5, the conflicts over water uses in Gramame River Basin tend to intensify, since it will have to supply more water for irrigation. Also, the municipalities that have the largest planted area, as is the case of those addressed in this study, will be the most affected.

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