v. 2, n. 3, 2022

Journal of
Engineering
Research

ANALYSIS OF CHANGES IN WEATHER PATTERNS IN CAXIAS DO SUL-RS

Bianca Breda
Universidade de Caxias do Sul (UCS) – Environmental Sanitation Institute (ISAM)

Morgana Vigolo
Universidade de Caxias do Sul (UCS) – Environmental Sanitation Institute (ISAM)

Vania Elisabete Schneider
Universidade de Caxias do Sul (UCS) – Environmental Sanitation Institute (ISAM)

Abstract: Although the greenhouse effect is a natural phenomenon for the planet, human-induced changes end up causing its intensification. Global warming can result in different temperatures on regional scales, and its effects are evidenced essentially on a local scale. This study aims to identify climate change in the municipality of Caxias do Sul-RS, comparing the data series from 1991 to 2019 with the climatological normal for the period from 1961 to 1990, through the information recorded by the municipality's meteorological station. Regarding the average annual temperature, there was an increase of 0.73 °C. The monthly averages of precipitation were similar to each other, however, it was observed that the pluviometric regime suffered alterations both in the monthly precipitation volume and in its temporal distribution. There was no evidence of water deficit during the period, since the annual monthly mean of ETP was 68.31 mm in the series from 1961 to 1990 and 72.38 mm in the subsequent series. Relative humidity also showed changes, going from 78.42% to 77.67%. There was a reduction in the average annual intensity of the winds in relation to the oldest data, reducing from 2.67 m/s to 1.75 m/s. According to the Köppen-Geiger Model, the climate of the municipality can be classified as Cfb and shows a tendency for the temperature to continue increasing. The evidenced scenario indicates the importance of climatological studies to manage future scenarios, since it can support decision-making and the formulation of public policies oriented towards sustainable development.
Keywords: Climate changes, Urban climate, Meteorology, Climatological normal.

INTRODUCTION

Since the Industrial Revolution, the search for technological development and economic growth have caused an increase in anthropogenic emissions - mainly carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) - characterized as greenhouse gases (GHG). These emissions occur as a result of deforestation, burning of fossil fuels, industrial processes, urbanization, population growth and agricultural activities which, in turn, are driven by land use and occupation, the population's lifestyle and economic activities that are part of a particular region (TONG & EBI, 2019).

In 2018, the total GHG emitted in the world was equivalent to 36.6 GtCO2, which resulted in an average increase of 2.1% compared to 2017 (GCP, 2019). In Brazil, 1.94 Gt of greenhouse gases were released, remaining practically stagnant compared to the previous year. The sectors that contributed the most in the country were: land use change and forests, agriculture and the energy and transport sector (SEEG BRASIL, 2019). This year, the global concentration of CO2 in the atmosphere hit a new record, reaching 416.21 ppm. Despite the crisis caused by the Covid-19 pandemic, the intense production of electricity derived from fossil fuels was the main reason for the increase in carbon dioxide emissions (UNITED NATIONS, 2020).

Although the greenhouse effect is a natural and essential phenomenon for the planet, human-induced changes in the chemical composition of the atmosphere end up causing its intensification. As a result of this scenario, the global mean surface temperature has increased by approximately 1.0 °C compared to pre-industrial levels and, if it continues at this same pace, between 2030 and 2052, global warming could reach 1.5 °C (IPCC, 2018). Also, considering that they do not occur homogeneously, according to Seneviratne et al. (2018), global warming can result in different temperatures on regional scales, due to geographic location, variations in density and in the rate of warming.

The effects of human activities also affect the climate on a local scale, both in urban and rural areas. In rural areas, agriculture is the most dependent on climatic conditions and, therefore, becomes the most vulnerable, since the risks in agricultural production increase and these directly affect the supply of subsequent sectors (JUNGES, et al., 2019). In urban areas, where more than half of the population lives, up to 70% of greenhouse gas emissions are generated (ALI, et al., 2019; LIOUBIMTSEVA & DA CUNHA, 2020), capable of, according to Lima et al., (2020), generate a climate of its own, called urban climate. This potential to promote climate change within the city is related to the physical conditions of the surface components - architectural sets and non-artificial elements - as well as industrial and transport activities (FERREIRA & UGEDA JÚNIOR, 2020).

The current scenario already allows changes to be observed at all spatial scales, both in the pluviometric regime, as in evapotranspiration and in other elements of the climate, which corroborate and intensify impacts and create new risks to humanity and the environment. Among these, it is evident the increase in the level of the oceans, the alterations of the hydrological processes in hydrographic basins, the modification of the distribution of species, the loss of biodiversity and, the increase in the frequency and intensity of heat waves, floods, droughts, rains acids and forest fires (TONG & EBI, 2019; SOUSA et al., 2019).

Changes in weather patterns have been evidenced in numerous studies by the scientific community, proving to be one of the greatest challenges of this time and occupying not only a central place in academia and science, but also in the political and economic agenda (HIERA, et al., 2019; FUNATSU et al., 2019). Brazil, as a member country of the Paris Agreement, has committed to minimizing GHG emissions by 37% by 2025 compared to 2005 levels, equivalent to approximately 1.3 GtCO2 (BRASIL, 2015). To achieve this ambitious goal, in its Nationally Determined Contribution (NDC), as well as in the National Policy on Climate Change (PNMC), Law number, promote new standards of clean technologies, improve transport infrastructure, among others (BRASIL, 2015, 2009).

However, cities have a fundamental role in terms of enhancing efforts to mitigate climate change, as they are important engines of economic, intellectual, technological and political development. Local planning aims to adjust human-environmental systems to minimize damage and explore beneficial opportunities, providing learning opportunities and resources in all sectors, so that they can adapt and thus benefit from successful practices (LIOUBIMTSEVA & DA CUNHA), 2020).

Considering the importance of climatology for the sustainable planning of activities and for minimizing the possible impacts caused by climate change, this study aims to identify and analyze climate change in the municipality of Caxias do Sul-RS through a series of data that comprises the period from 1991 to 2019 with the Climatological Normal for the period from 1961 to 1990.

MATERIAL AND METHODS

STUDY AREA

The municipality of Caxias do Sul is located at 760 m above sea level, in the northeast of the state of Rio Grande do Sul, in southern Brazil (Figure 1), being the second most populous city in the state (CAXIAS DO SUL, 2020). According to the population estimate of the Brazilian Institute of Geography and Statistics (IBGE) in 2020, the municipality has more than half a million inhabitants (IBGE, 2020).

The municipality is characterized by accelerated urban growth, caused mainly by economic development throughout the 20th

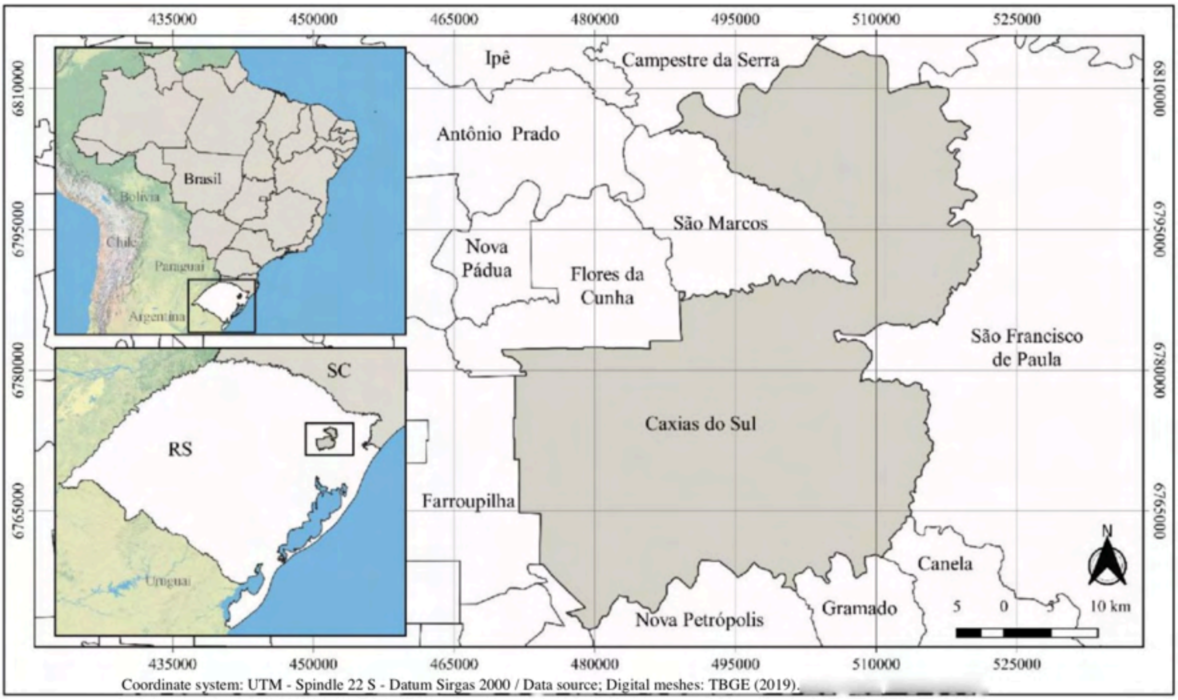

Figure 1 – Location map of the municipality of Caxias do Sul/RS.

Source: prepared by the authors.

century. As a result, it formed an important and diversified industrial sector, which currently stands out for being the second largest metal-mechanic center in the country, and, consequently, made the tertiary sector the most representative in the municipality's economy (CAXIAS DO SUL, 2020).

The primary sector also stands out due to the strong presence of agricultural activity, mainly on small properties. The city's agricultural Gross Domestic Product (GDP) is one of the largest in the state, as the municipality is the largest fruit and vegetable producer in Rio Grande do Sul, standing out in the production of grapes, apples, peaches and garlic. As for livestock, the main activities are: poultry and cattle breeding (CAXIAS DO SUL, 2020).

The expansion of the city, however, led to a series of economic, social, environmental and structural demands, which Caxias do Sul has responded to in order to be a reference in the region in health services, urban cleaning, basic sanitation and higher education. Of note is higher education, which indirectly reaches more than 1 million people.

DATA COLLECTION

To analyze the climate changes in the city of Caxias do Sul, the average values of the climatological normal between 1961 and 1990, provided by the National Institute of Meteorology (INMET) were sought. These climatological data refer to the elements of the climate: air temperature (minimum, average and maximum), precipitation, winds, air humidity and atmospheric pressure.

The values of this climatological normal were compared with the average data, of the same climatic variables, made available by the Meteorological Database for Teaching and Research (BDMEP) of INMET, referring to the subsequent period, which comprises from 1991 to 2019, as it is not yet full climatological normal available.

The information collected from both periods were recorded by the conventional station operating in Caxias do Sul, with identification code 83942 and located at south latitude -29.16º and west longitude -51.20º.

To correct the faults found in the most recent historical series, it was not possible to use usual methods, such as Regional Weighting and Linear Regression, because all conventional meteorological stations operating in Rio Grande do Sul have the same fault, for all atmospheric variables, in nine months of the year 2001. Therefore, as a way to get around this problem, all missing values were replaced by the average of each month of the historical series, since according to Vieira et al. (2018) this method preserves the structure and characteristics of the original series, as well as being efficient in their study.

Considering the lack of potential evapotranspiration (ETP) data from meteorological stations, the average values of this variable were collected for the two historical series analyzed, through the Web System for estimating ETP developed by Bortolin et al. (2019). This web application uses data from meteorological stations operated by INMET to calculate the ETP in an automated way, using various mathematical methods found in the literature, for a given period of time (BORTOLIN et al., 2019). In this study, we chose to run the system using the method of Thornthwaite (1948).

Based on the average values of temperature and precipitation of the series that covers from 1991 to 2019, the current climate of the municipality was classified by the quantitative classification model of world climates, called the Köppen-Geiger Climate Classification (1928). There was a possible change in the climate classification in the years 2050 and 2100 based on the study by Rubel and Kottek (2010), who presented a series of world maps with the climate classification in the period from 1901 to 2100, portraying the trends climate change and future projected scenarios.

RESULTS AND DISCUSSION

The results obtained with the historical series analyzed for the different elements of the climate are presented below. The monthly variation of the average temperature for the two historical series studied is shown in Figure 2.

It is possible to observe that the curves of the different analyzed periods present parallelism with each other, indicating that the variation of the average temperature during the year still follows the same trend, that is, the hottest months continue corresponding to January, February and December (summer) and, the coldest months to the months of June, July and August (winter). However, the average annual temperature verified between 1991 and 2019, of 17.02 °C, denotes an average increase of 0.73 °C, being close to the global increase evidenced by the IPCC (2018) of 1.0 °C in relation to the pre-industrial levels. The month of April presented the biggest increase in the average monthly temperature, pointing to 1.43 ºC above the average temperature evidenced in the climatological normal for the same month.

As for the annual average thermal amplitude, it was evidenced that in the historical series from 1961 to 1990, the oscillation between the hottest month (January) and the coldest month (June) was 8.5 ºC, while for the historical series of 1991 In 2019, there was an oscillation between the hottest month (January) and the coldest month (July), of 9.25 ºC, which can be explained mainly by the hotter summers.

The averages of minimum and maximum temperatures also showed changes, as can be seen in Figure 3.

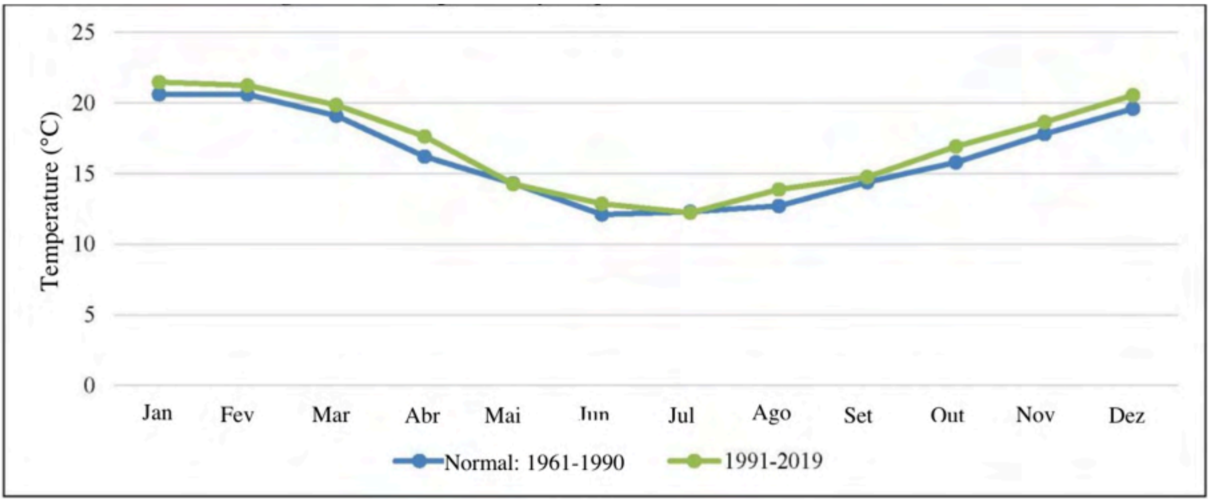

Figure 2 – Average monthly temperature variation in Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

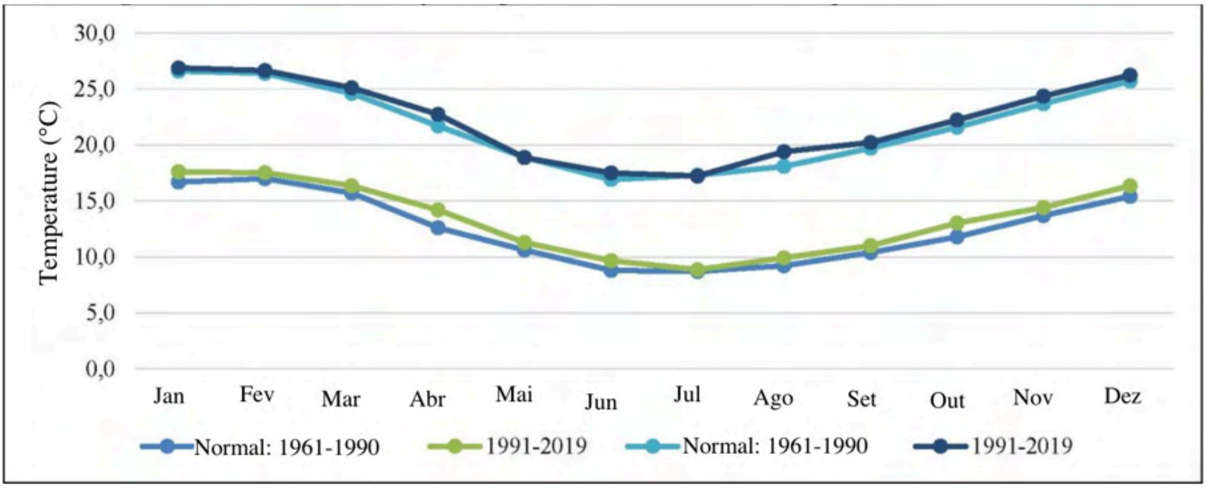

Figure 3 – Variation of monthly average maximum and minimum temperatures in Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

The annual average minimum temperature increased by about 0.8 °C, while the maximum temperature increased by 0.5 °C. The months of December, January, February and March continue to have the highest maximum temperatures, and the months of May, June, July and August continue to be the months with the lowest monthly minimum temperatures.

Thus, it is believed that, because the weather station operates within the urban infrastructure of the municipality, the increase in temperature is a consequence of the urbanization process. It is observed in the land use and occupation map of Caxias do Sul, presented in Figure 4, referring to the years 1985 and 2018, that the expansion of the urbanized area doubled in size during this period, occupying the space previously belonging to agriculture and livestock and to vegetation. Agriculture also expanded within the territory, replacing areas that were previously vegetated.

The increase in built-up areas and the consequent decrease in the areas of green coverage increase the surface exposure to sunlight and reduce the albedo index, resulting in an increase in the amount of absorbed radiation and a decrease in the amount of reflected energy (OLIVEIRA et al, 2020). These factors associated with the alteration of direct radiation by diffuse light, due to the concentration of pollutants and microparticles in suspension in the atmosphere, caused by intense vehicle traffic, high population density and industrial activities, favor the occurrence of a positive thermal anomaly in relation to periphery and rural areas, known as urban heat islands, which exacerbate environmental problems and increase the vulnerability of the population (LIMA et al., 2020; CONTI, 2011).

Unlike temperature, the annual distribution of rainfall over the municipality behaves uniformly, as shown in Figure 5, contributing to agricultural activities and to the recharge of surface reservoirs, from where most of the municipality's population is supplied.

The disparity between the average values of monthly precipitation between the climatological normal and the sequential historical series is evident, although the monthly averages of precipitation are similar to each other, 151.93 mm and 152.42 mm, respectively. Through the available data, it was also obtained that the total annual volume precipitated over the municipality was 1,823.10 mm based on the climatological normal and 1,829.10 mm based on the consecutive historical series, confirming the parity of the annual amount of rainfall. in the different historical series.

However, when analyzing the months individually, the picture changes. The lowest average rainfall seen in the climatological normal data from 1961-1990 was in April (100.20 mm), while the highest was in August (185.40 mm), with autumn being characterized as the season with the most dry season and winter as the wettest season. The month of April continued to be the driest month of the year in the subsequent series, however the average rainfall increased by 23.33 mm and the month with the highest volume of precipitation became October, with 198.97 mm. The driest season of the year continued to be autumn, however the rainiest season became spring. Thus, it is noticeable that the municipality's rainfall regime has changed both in terms of monthly rainfall and in its temporal distribution.

These changes in rainfall may also be related to the growth of the city, given that the increase in the concentration of particulate matter in the atmosphere, which acts as an incentive for condensation, leads to anomalies in the precipitation regime (JARDIM, 2011). Another interfering factor is the set of

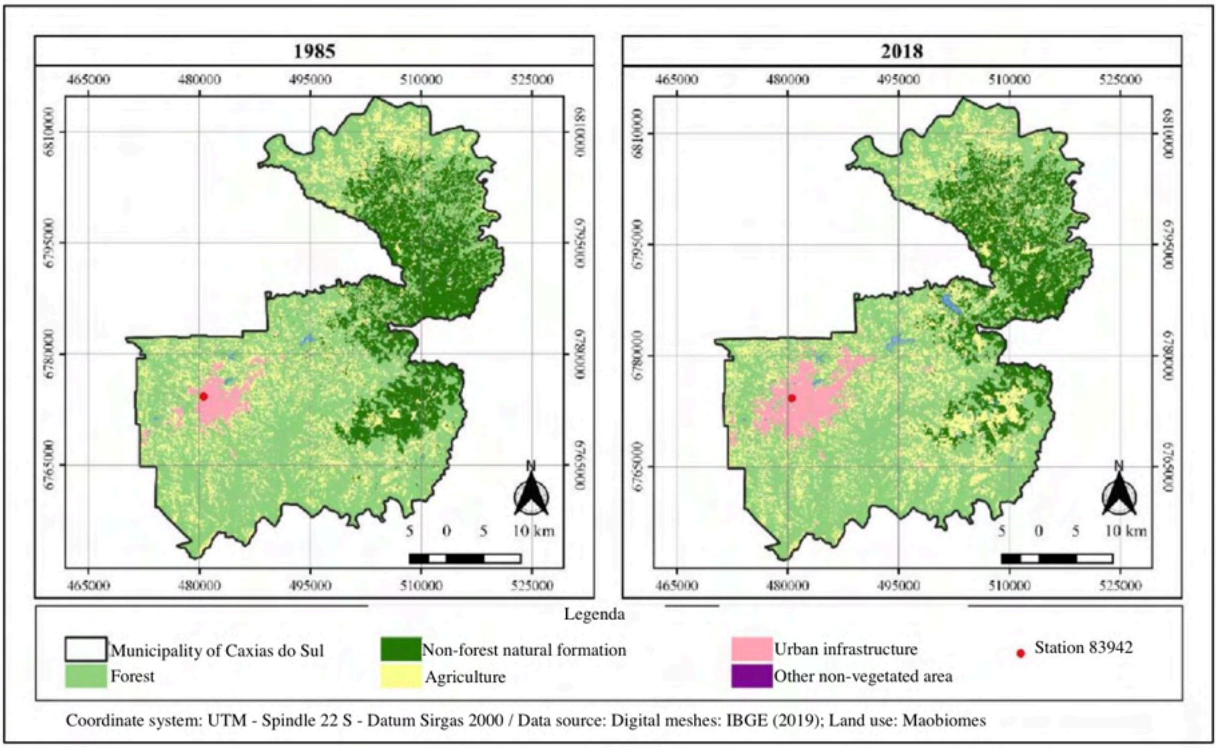

Figure 4 – Land use and occupation map of the municipality of Caxias do Sul for the years 1985 and 2018.

Source: prepared by the authors.

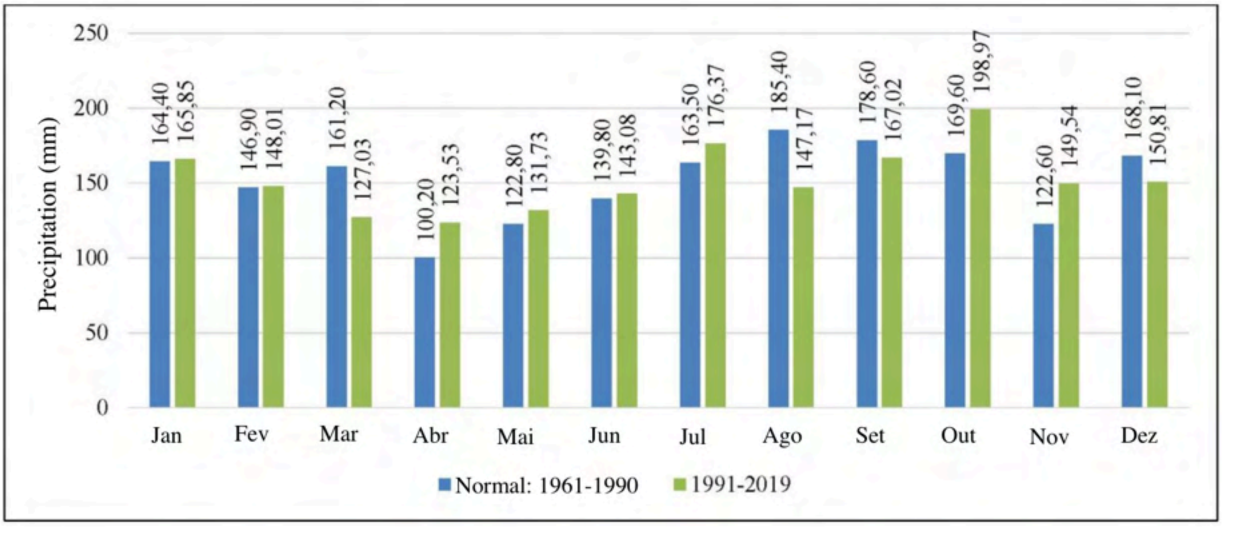

Figure 5 – Variation of the average monthly precipitation in the municipality of Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

architectural works in the urban center of Caxias do Sul, characterized mainly by large buildings, which according to Conti (2011) stimulate atmospheric instability, which can trigger the so-called urban storms, which influence the volume of precipitation.

Rainfall, together with temperature, also intervenes in the evapotranspiration (ETP) regime, and therefore influences the climatological water balance. In the comparison between the monthly average rainfall and the monthly average ETP of both historical series, there was no water deficit during the year, instead, every month presented water surplus, indicating that there is water available and stored in the soil to provide the whole the evapotranspirometric potential, which in turn is a favorable climatic condition for the development of agriculture in the municipality (CASSETTARI & QUEIROZ, 2020; PINHEIRO et al., 2019; CARVALHO et al., 2016). The annual monthly average of evapotranspiration was 68.31 mm in the series from 1961 to 1990 and 72.38 mm in the subsequent series, noting a water surplus of 83.62 mm and 80.04 mm, respectively. Based on Medeiros and Holanda (2020), it is assumed that the 4.08 mm increase in evapotranspiration potential may have been caused by vertical growth, lack of afforestation and soil compaction at the site.

The variation during the year of evapotranspiration in the municipality of Caxias do Sul in the two historical series analyzed is shown in Figure 6.

Taking into account that evapotranspiration is a complex and important process in the water cycle, as well as dependent on several climatic variables, one of the most expressive being air temperature, it is noted that the values compiled for both series show the same trend. of the monthly average temperature curve (MACEK; BEZAK & SRAJ, 2018; BLAIN & PIRES, 2011). In the months in which the average temperature of the most recent series increased in relation to the previous one, there was also an increase in the ETP, with March and April being the most representative, denoting the increase of 9.9 and 8.2 mm, respectively. On the other hand, in the months in which the decrease in average temperature was verified (May and July) in the series from 1961 to 1990 compared to the series from 1991 to 2019, the ETP was also lower. Thus, the hottest summers and the harsh winters mean that ETP peaks in the months of December, January and February and the minimums in the months of May, June, July and August.

Relative humidity also showed changes in its behavior over the years, especially with regard to the months of March and August, as shown in Figure 7.

In general, the average annual relative humidity did not obtain such divergent values, being 78.42% for the climatological normal and 77.67% for the most recent historical series. The greatest similarity is found between the months of January and October, while the reduction in relative humidity that occurred in most of the other months can be explained mainly by the increase in temperature, as well as by the reduction of vegetated areas and the greater roughness of the surface caused by buildings, which reduces wind speed and affects moisture transport (OLIVEIRA et al., 2020; LIMA et al.2020; MARTINI; BIONDI & BATISTA, 2013). The intensity of the winds is shown in Figure 8.

It is observed that there was a reduction in the intensity of the winds, at a rate that varies between 29.9% and 41.5% during the analyzed interval. While the climatological normal brings an annual average monthly speed of 2.67 m/s, the series from 1991 to 2019 presents 1.75 m/s. This fact confirms the statement made earlier, in which the reduction of wind speed close to the ground is a result of

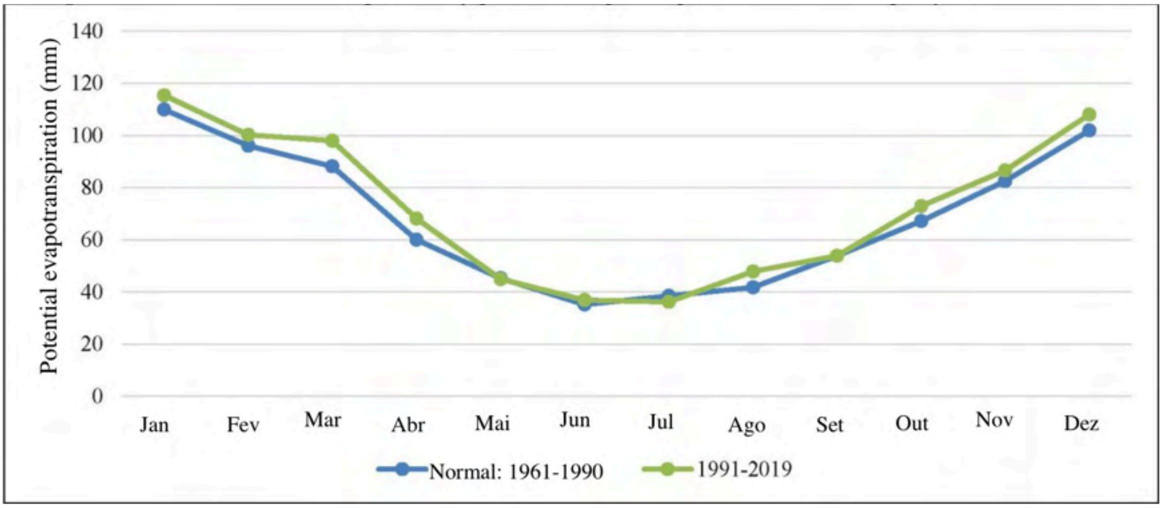

Figure 6 – Variation of the average monthly potential evapotranspiration in the municipality of Caxias do Sul.

Source: prepared by the authors based on a Web System for Estimating Potential Evapotranspiration (2020).

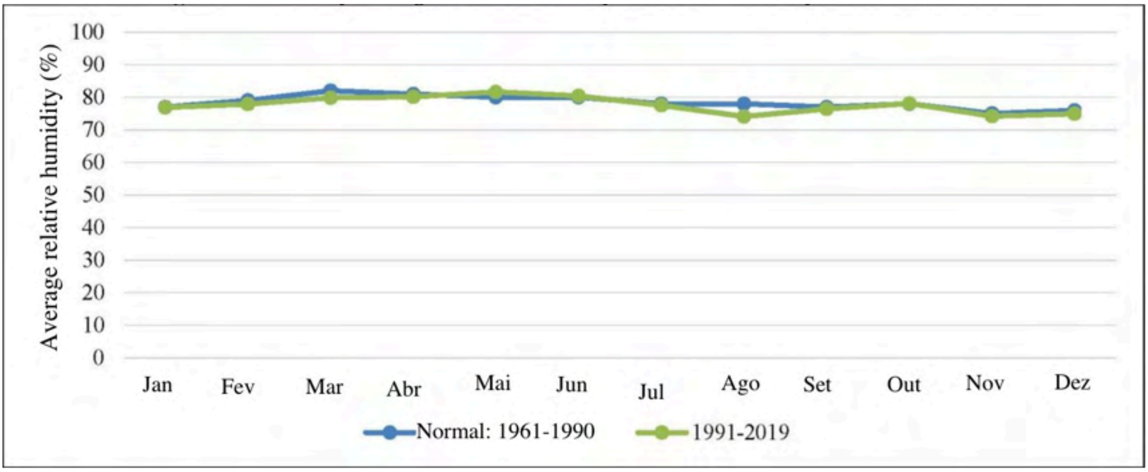

Figure 7 – Monthly average relative humidity variation in the city of Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

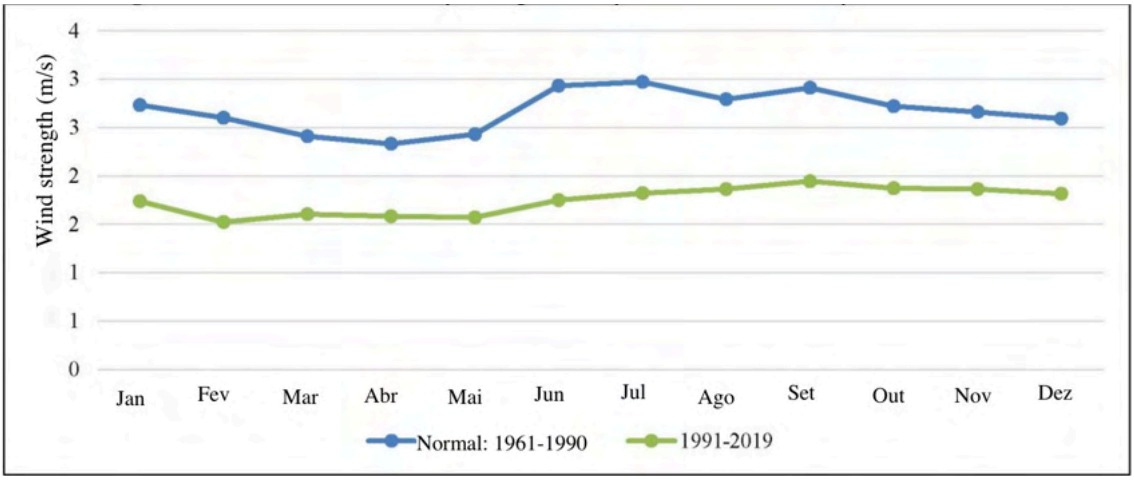

Figure 8 – Variation of the monthly average intensity of the winds in the city of Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

urban architecture, since the diversification of materials, structures and forms present there are capable of creating disturbances in air circulation. As a result of this scenario, there is also a change in the rainfall regime in the place, since there is a decrease in the transport of moisture ("flying rivers") (CASSETTARI & QUEIROZ, 2020).

The atmospheric pressure obtained in the most recent series remains with the same tendency as the climatological normal, but with an average increase of 1 mbar in all months, as can be seen in Figure 9.

It can be seen that in the coldest months, the pressure is higher, because in the periods when the temperatures are lower, the air molecules of the atmosphere unite, becoming denser and consequently increasing the pressure, while the heat, dilates the air causing low pressure phenomena (TORRES & MACHADO, 2011).

From a conceptual point of view, it was expected that the atmospheric pressure of the historical series from 1991 to 2019 would decrease in relation to the climatological normal, since an increase in temperature was evidenced and, according to Jardim (2011) a field is normally established. pressure over densely urbanized areas. However, it is inferred that the increase in atmospheric pressure in the municipality is not directly related to the increase in temperature. However, as explained by Jardim (2011), this element may follow its own rhythm or be a characteristic of the place, depending on its land use, relief, latitude and altitude.

In a general context, the local climate is governed by the aforementioned factors, by the occurrence of the El Niño Southern Oscillation (ENSO) phenomenon, by the passage of frontal systems and by the active air masses. The air masses, in turn, directly influence the definition of the seasons of the year in Caxias do Sul, since in winter the Atlantic Polar Mass (MPA), characterized as cold and humid, reaches all of Rio Grande do Sul with more force and in summer, in addition to the MPA, the Atlantic Tropical Mass (MTA), qualified as hot and humid, and the Continental Tropical Mass (TCM), identified as hot and dry, also affect the state (MENDONÇA & DANNI-OLIVEIRA,

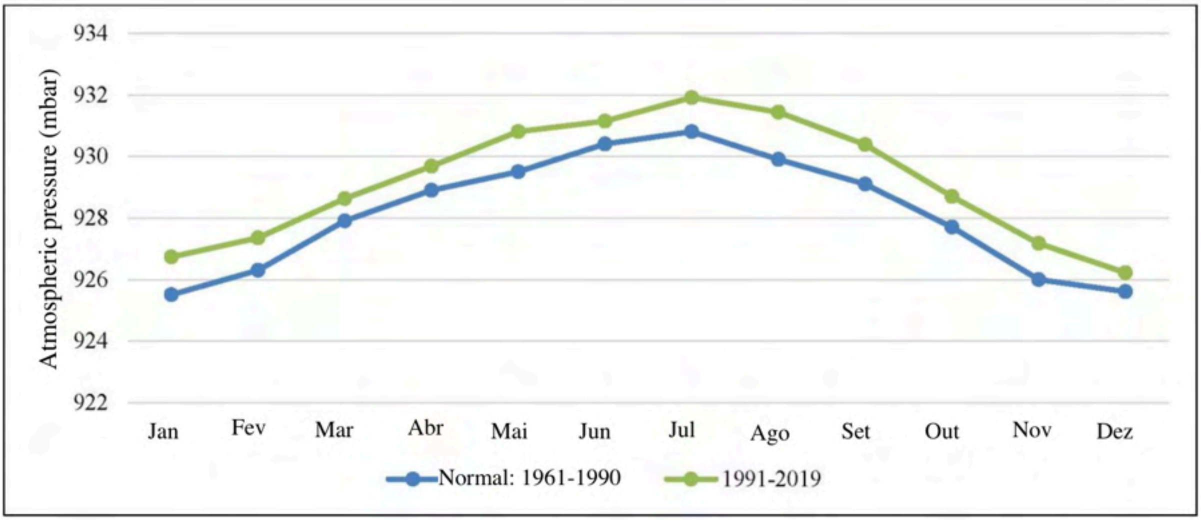

Figure 9 – Monthly atmospheric pressure variation in Caxias do Sul.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3172322100210

2007). Still, the distribution of rainfall throughout the year, without periods of drought in the municipality can be explained by the fact that it is located in a zone of confrontation between opposing forces, that is, the advance of systems of polar origin towards those of tropical origin (ROSSATO, 2011).

With the average values of precipitation and average temperature, main variables of the Köppen-Geiger Model (KÖPPEN & GEIGER, 1928), and in the climograms of both series evaluated, it was possible to characterize the climate of Caxias do Sul, as shown in Figure 10.

Thus, the climate of the municipality can be classified as Cfb, defined as humid subtropical climate in all seasons, with total rainfall in the dry month greater than 30 mm, moderately hot summer, being the hottest month with average temperatures below 22 ºC and the coldest month with an average temperature lower than 18ºC (CARDOSO, et al., 2014).

In the world map of the climate classification projection for the year 2050 and 2100, prepared by Rubel and Kottek (2010), it is noted that the climate trend for Caxias do Sul is continuing to change, as shown in Figure 11. study predicts that in the year 2050 the climate classification of Caxias do Sul will be Cfa. This climate group is defined as subtropical, with more than 30 mm of precipitation in the driest month and with a hot summer, where the average temperature of the hottest month is above 22ºC (CARDOSO, et al., 2014; MENDONÇA & DANNI-OLIVEIRA, 2007).

Thus, the climate change from Cfb to Cfa in the municipality indicates the tendency for the temperature to continue increasing, as well as it is assumed that in 30 years the average temperature of the month of January in the municipality will increase by at least about 0.52 ºC, the which is a smaller increase between the climatological normal and the 29-year sequential historical series. However, the striking feature of rainfall distributed throughout the year tends to remain.

In the scenario predicted for the year 2100, the municipality continues with the same classification assumed for 2050. However, the study assumes that in a considerable area of Rio Grande do Sul the climate classification is changed from Cfa to Af. This shows that the projection made by Rubel and Kottek (2010) for the end of this century predicts a climate characterized as tropical rainforest and with temperatures between 24 °C and 25 °C in the hottest months for regions very close to the municipality, assuming a change in the regional climate status (CARDOSO, et al., 2014; MENDONÇA & DANNI-OLIVEIRA, 2007).

CONCLUSION

The study of the climate provides in-depth knowledge of all its conditions and consequently allows for better planning of human activities, whether in urban or rural areas. However, current patterns are causing several changes in climate behavior, which affect the quality of life of the population, as well as the entire chain of primary, secondary and tertiary sectors of the economy, in addition to causing severe impacts on the environment.

The climatological analysis of the municipality of Caxias do Sul made it possible to show locally the effects resulting from climate change. Regarding the average temperature, an increase of almost 1º C has already been observed in the last 29 years, as a result of the constant process of urbanization, industrialization and the progress of mobility with motor vehicles. These factors provide a decrease in the intensity of the winds, which associated with the lack of vegetation, lead to changes in the amount of evapotranspiration that, therefore, cause changes in the rainfall

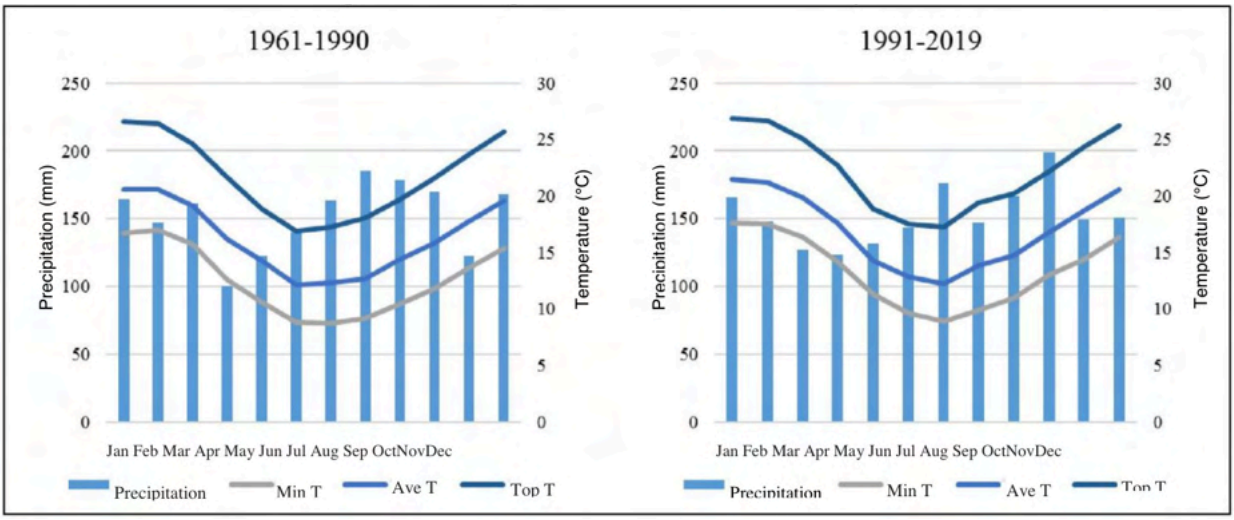

Figure 10– Climograms of the historical series analyzed.

Source: prepared by the authors based on INMET (2020) and BDMEP (2020).

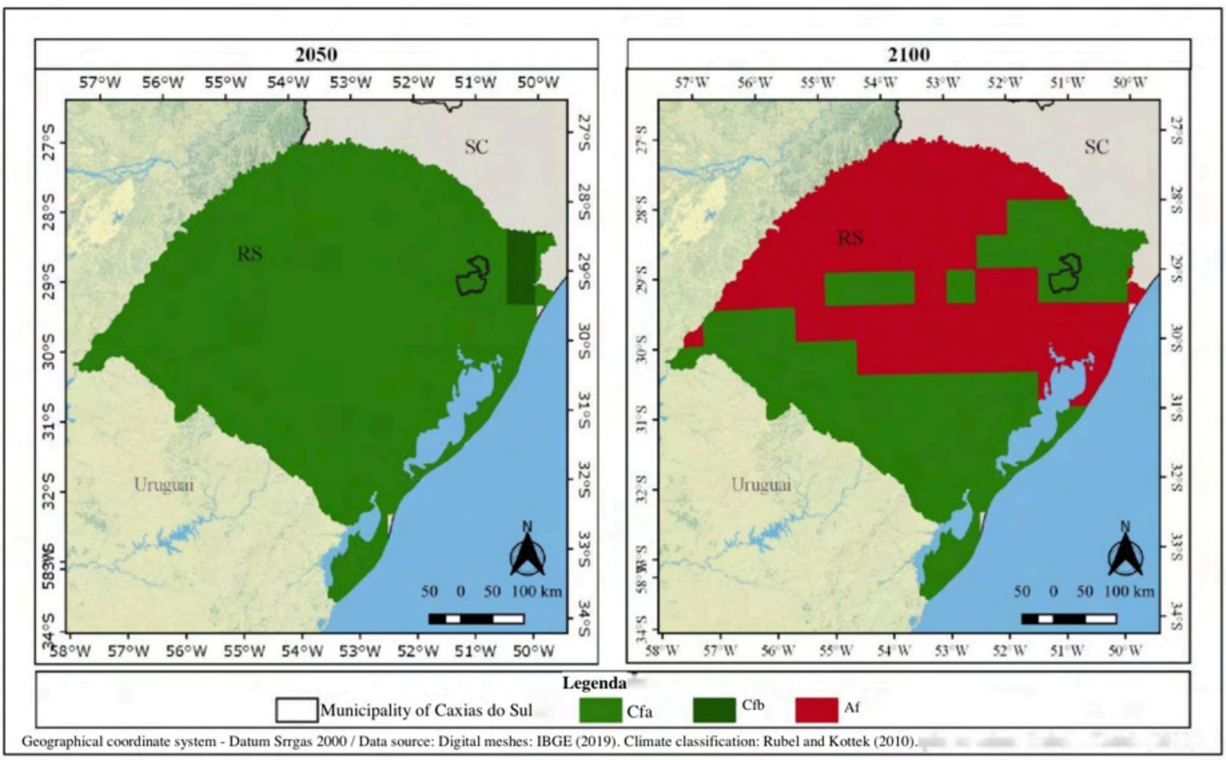

Figure 11 – Climate classification projected for the municipality of Caxias do Sul in 2050 and 2100.

Source: prepared by the authors.

regime (spatial and temporal), compromising the hydrological cycle.

These verified facts explain why summers and winters are hotter and also create the possibility of increasingly extreme events, such as prolonged droughts, intense rainfall, loss of biodiversity, among others. However, future predictions are not friendly. If this rhythm continues, the environment will be increasingly degraded, the average temperature will continue to grow and changes in the climatological state of the municipality and the region will be increasingly affected. This directly implies the production and yield of crops, the availability of water and the well-being of the population, which can mean a lack of food, compromising public supply and making society more vulnerable, respectively.

In this context, the study of climate and weather variables are essential to manage future scenarios, taking all the necessary precautions, changing habits, reducing risks, setting new goals and creating new policies in order to provide a balanced environment and pursue sustainable development.

REFERENCES

Ali, R.; Bakhsh, K. & Yasin, M. A. (2019). Impact of urbanization on CO2 emissions in emerging economy: Evidence from Pakistan. **Sustainable Cities and Society**, 48. DOI: https://doi.org/10.1016/j.scs.2019.101553. Acesso em: 18 abr. 2020.

Banco de Dados Meteorológicos para Ensino e Pesquisa – BDMEP. **Dados Históricos.** 2020. Disponível em: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. Acesso em: 20 mar. 2020.

Blain, G. C. & Pires, C. M. P. (2011). Variabilid ade temporal da evapotranspiração real e da razão entre evapotranspiração real e potencial em Campinas, Estado de São Paulo. **Bragantia**, 70(2), 460-470.

BRASIL. **Pretendida Contribuição Nacionalmente Determinada: para consecução do objetivo da Convenção-Quadro das Nações Unidas sobre Mudança do Clima.** 2015. Disponível em: <http://www.itamaraty.gov.br/images/ed_desenvsust/BRASIL-iNDC-portugues.pdf.> Acessado em: 31 mar. 2020.

BRASIL. **Lei nº 12.187, 29 de dezembro de 2009**. Institui a Política Nacional sobre Mudança do Clima – PNMC e dá outras providências. Brasília, DF: 2009. Disponível em: <http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l12187.htm>. Acessado em: 31 mar. 2020.

Bortolin, T. A., Santos, M. S., Silva, A. G., & Schneider, A. E. (2019). Sistema Web para estimativa de Evapotranspiração Potencial por diferentes métodos. **Ciência e Natura**, 41(22), 01-14. DOI:10.5902/2179460X36937.

Cardoso, M. R. D., Marcuzzo, F. F. N., & Barros, J. R. (2014). Classificação climática de Köppen-Geiger para o estado de Goiás e o Distrito Federal. **Acta Geográfica,** 8(16), 40-55. DOI: 10.5654/actageo2014.0004.0016.

Carvalho, T. O., Conceição, R. S., Silva, J. A. S. S., & Veiga, A. J. P. (2016). Análise da temperatura do ar, precipitação, evapotranspiração e índice hídrico do município de Itapetinga-BA. **Revista de Geociências do Nordeste**, 2(número especial), 344-353.

Cassettari, G. A., & Queiroz, T. M. (2020). Balanço hídrico e classificação climática na bacia do rio Jauquara, região de transição entre o Cerrado Amazônia brasileira. **Revista Brasileira de Climatologia.** 26, 70-88. DOI: http://dx.doi.org/10.5380/abclima.v26i0.59513.

Global Carbon Project - GCP. CO2. (2019). **Emissions**. 2019. Disponível em: http://www.globalcarbonatlas.org/es/CO2-emissions. Acesso em: 18 abr. 2020.

Caxias do Sul. (2020). **Perfil Socioeconômico**.Disponível em: https://caxias.rs.gov.br/cidade/perfil-socioeconomico. Acesso em 25 mar. 2020.

Conti, J. B. (2011). **Clima e meio ambiente** (7a. ed.) São Paulo: Atual.

Ferreira, H. V. L., & Ugeda Júnior, J. C. (2020). Variação da temperatura da superfície através de imagens Aster em Zonas Climáticas locais da cidade de Cuiabá, Brasil. **Revista Brasileira de Climatologia.** 26, 393-410. DOI: http://dx.doi.org/10.5380/abclima.v26i0.

Funatsu, B. M., Dubreuil, V., Racapé, A., Debortoli, N. S., Nasuti, S., & Tourneau, F. L. (2019). Perceptions of climate and climate change by Amazonian communities. **Global Enviromental Change**, 57. DOI: https://doi.org/10.1016/j.gloenvcha.2019.05.007.

Hiera, M. D., Lima Júnior, A. F., & Zanella, M. E. (2019). Tendência da precipitação no estado do Ceará. **Revista Brasileira de Climatologia**. 24,300-321. DOI: http://dx.doi.org/10.5380/abclima.v24i0.54207.

Instituto Nacional De Meteorologia – INMET. (2020). **Normais Climatológicas do Brasil.** Disponível em: http://www.inmet.gov.br/portal/index.php?r=clima/normaisClimatologicas. Acesso em: 20 mar. 2020.

Intergovernmental Panel On Climate Change – IPCC. (2018). **Summary for Policymakers. In: Global Warming of 1.5°C.** Disponível em: https://www.ipcc.ch/report/ar5/syr/. Acesso em: 25 mar. 2020.

Instituto Brasileiro de Geografia E Estatística – IBGE. (2019). **Cidades e Estados: Caxias do Sul.** Disponível em: https://www.ibge.gov.br/cidades-e-estados/rs/caxias-do-sul.html. Acesso em: 31 mar. 2020.

Instituto Brasileiro de Geografia E Estatística – IBGE. (2019). **Malha Municipal.** Disponível em: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/estrutura-territorial/15774-malhas.html?=&t=downloads. Acesso em: 31 mar. 2020.

Jardim, C. H. (2011). Relações entre temperatura, umidade relativa do ar e pressão atmosférica em área urbana: comparação horária entre dois bairros no município de São Paulo-SP. **Geografias - Artigos Científicos**, 7(1), 128-142.

Junges, A. H., Bremm, C., & Fontana, D. C. (2019). Climatologia, variabilidade e tendências da precipitação pluvial em Veranópolis, Rio Grande do Sul, Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 23(3), 160-166. DOI: https://doi.org/10.1590/1807-1929/agriambi.v23n3p160-166.

Köppen, W., & Geiger, R. (1928). **Klimate der Erde.** Gotha: Verlag Justus Perthes.

Lima, M. S., Anjos, M. W. B., Ramos, P. H. S., & Alves, E. D. L. (2020). Temperatura do ar no meio urbano: primeiros experimentos em Ceres - Goiás. **Revista Brasileira de Climatologia**. 26, 286-295. DOI: http://dx.doi.org/10.5380/abclima.v26i0. Acesso em: 03 abr. 2020.

Lioubimtseva, E., Da Cunha; C. (2020). Local climate change adaptation plans in the US and France: Comparison and lessons learned in 2007-2017. **Urban Climate**, 31. DOI: https://doi.org/10.1016/j.uclim.2019.100577.

Macek, U., Bezak, N., & Sraj, M. (2018), Reference evapotranspiration changes in Slovenia, Europe. **Agricultural and Forest Meteorology**, 260-261, 183-192. DOI: https://doi.org/10.1016/j.agrformet.2018.06.014.

Mapbiomas. (2019). **Brazil collection 4.0: Caxias do Sul 2018.** Disponível em: https://plataforma.mapbiomas.org/faq.

Martini, A., Biondi, D., & Batista, A. C. (2013) Variação Diária e Estacional do Microclima Urbano em Ruas Arborizadas de Curitiba-PR. **Floresta e Ambiente**, 20(4), 460-469. DOI: https://doi.org/10.4322/floram.2013.045.

Medeiros, R. M., & Holanda, R. M. (2020). Sequential water balance for lagoa seca - Paraíba – Brazil. **Research, Society and Development**, 9(7), 1-26. DOI: http://dx.doi.org/10.33448/rsd-v9i7.4691.

Mendonça, F., & Danni-Oliveira, I. M. (2007). **Climatologia: noções básicas e climas do Brasil.** São Paulo: Oficina de Textos.

Nações Unidas – Brasil. (2020). **Concentração global de CO2 bate recorde mesmo durante crise da COVID-19**. Disponível em: https://nacoesunidas.org/concentracao-global-de-co2-bate-recorde-mesmo-durante-crise-da-covid-19/. Acesso em: 17 jul. 2020.

Oliveira, J. V., Cohen, J. C. P., Pimentel, M., Tourinho, H. L. X., Lôbo, M. A., Sodré, G., & Abdala, A. (2020). Urban climate and environmental perception about climate change in Belém, Pará, Brazil. **Urban climate**, 31. DOI: https://doi.org/10.1016/j.uclim.2019.100579.

Pinheiro, M. A, B., Oliveira, A. L. M., Borges Jpunior, J. C. F., Oliveira, E. C., & Carvalho, L. G. (2019). Reference evapotranspiration based on temperature in Minas Gerais state, Brazil. **Ciência e Agrotecnologia**, 43. DOI: http://dx.doi.org/10.1590/1413-7054201943004219.

Rossato, M. S. (2011). **Os climas do Rio Grande do Sul: variabilidade, tendências e tipologia**. Tese de doutorado, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brasil.

Rubel, F., & Kottek, M. (2010(. Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. **Meteorologische Zeitschrift**, 19(2), 135-141. DOI: 10.1127/0941-2948/2010/0430.

Sistemas de Estimativas de Emissões de Gases de Efeito Estufa - SEEG Brasil. (2019). **Emissões Totais.** Disponível em: http://plataforma.seeg.eco.br/total_emission#. Acesso em: 18 abr. 2020.

Sistemas de Estimativas de Emissões De Gases de Efeito Estufa - SEEG Brasil. (2020). **Impacto da pandemia de COVID-19 nas emissões de gases de efeito estufa no Brasil.** Disponível em: http://seeg.eco.br/nota-tecnica. Acesso em: 17 jul. 2020.

Sistema Web para Estimativa de Evapotranspiração Potencial. (2020). **Estimativa de ETo & Separação de Escoamento.** Disponível em: https://siambiental.ucs.br/intermediador/. Acesso em: 13 jul. 2020.

Seneviratne, S.I., Rogelj, J., Séférian, R., Wartenburger, R., Allen, M. R, Cain, M., Moillar, R. J., Ebi, K. L., Ellis, N. Hoegh-Guldberg, O., Payne, A., Schleussner, C., Tschakert, P., & Warren, R. F. (2018). The many possible climates from the Paris Agreement's aim of 1.5 °C warming. **Nature**, 558, 41–49. DOI: https://doi.org/10.1038/s41586-018-0181-4.

Sousa, R. M., Viola, M. R., Chou, S. C., Alves, M. V, G., & Avanzi, J. C. (2019). Projeções climáticas regionalizadas para o estado do Tocantins, Brasil, nos cenários RCP 4.5 E RCP 8.5. **Revista Brasileira de Climatologia**. 24, 330-347. DOI: http://dx.doi.org/10.5380/abclima.v24i0.57052.

Tong, S., & Ebi, K. Preventing and mitigating health risks of climate change. (2019). **Enviromental Research**, 174, 9-13. DOI: https://doi.org/10.1016/j.envres.2019.04.012.

Torres, F. T. P., & Machado, P. J. de O. (2011). Introdução a climatologia. **Revista Cengage Learning**. São Paulo. 2011. ISBN 978-85-221-1.

Thornthwaite, C.W. (1948). Na approach toward a rational classification of climate. **Geographical Review**, 38: 55-94.

Vieira S. A., Osorio, D. M. M., Quevedo, D. M., Adam, K. M., & Pereiria, M. A. F. (2018). Metodologia de imputação de dados hidrometeorológicos para análise de séries históricas – bacia do rio dos Sinos, RS, Brasil. **Revista Brasileira de Climatologia**. 24, 189-204. DOI: http://dx.doi.org/10.5380/abclima.v23i0.56219.