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Climate change and its effect on the soil water balance of Lages, Santa Catarina

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A B S T R A C T

Undertaken activities in agricultural, industrial and urban productions emit gases that increase the greenhouse effect and change both air temperature and precipitation. These changes damage the environment and agricultural production alike, as well as life on Earth. In light of this, the present study has as its objective to understand the climate regime in Lages/SC, a municipality located in southern Brazil, and analyze the effects of climate change on air temperature, precipitation, consecutive dry days and the soil water balance. To that end, historical series corresponding from 1948 to 2020 were used for maximum, average and minimum air temperatures, while the series from 1961 to 2020 were used for precipitation. In order to have the water balance calculated, precipitation and air temperature were considered as input data for the method of Thornthwaite and Mather (1955). As for potential evapotranspiration, soil water storage and available water capacity, they were calculated considering a Humic Dystrudept, classified according to the Soil Taxonomy. Temporal analyses regarding air temperature, precipitation, evapotranspiration, consecutive dry days, intense rains and water balance were conducted by using the Mann-Kendall trend test (0.05). A positive and increasing trend was observed for maximum, average and minimum air temperatures, as well as for the precipitation over the years. Although rainfall volume has increased over time, periods with fifteen consecutive dry days have been increasingly frequent. Despite the changes in temperature, precipitation and rainfall distribution, there were no changes observed in evapotranspiration, occurrence of intense rains or in the soil water balance.

Keywords: Humic Dystrudept, air temperature, precipitation, evapotranspiration, water storage, greenhouse effect, Cambisols.

Mudanças climáticas e seu efeito no balanço hídrico do solo de Lages, Santa Catarina.

As atividades desenvolvidas nas produções agrícolas, industriais e urbanas emitem gases que aumentam o efeito estufa e alteram tanto a temperatura do ar quanto a precipitação. Essas mudanças prejudicam o meio ambiente e a produção agrícola, bem como a vida na Terra. Diante disso, o presente estudo tem como objetivo compreender o regime climático em Lages/SC, município localizado no sul do Brasil, e analisar os efeitos das mudanças climáticas na temperatura do ar, precipitação, dias secos consecutivos e balanço hídrico do solo. Para tanto, foram utilizadas séries históricas correspondentes de 1948 a 2020 para temperaturas máximas, médias e mínimas do ar, enquanto as séries de 1961 a 2020 foram utilizadas para precipitação. Para o cálculo do balanço hídrico, a precipitação e a temperatura do ar foram consideradas como dados de entrada para o método de Thornthwaite e Mather (1955). Quanto à evapotranspiração potencial, armazenamento de água no solo e capacidade hídrica disponível, foram calculados considerando um Distrudado Húmico, classificado de acordo com a Taxonomia do Solo. As análises temporais referentes à temperatura do ar, precipitação, evapotranspiração, dias secos consecutivos, chuvas intensas e balanço hídrico foram realizadas por meio do teste de tendência de Mann-Kendall (0,05). Foi observada uma tendência positiva e crescente para as temperaturas máximas, médias e mínimas do ar, bem como para a precipitação ao longo dos anos. Embora o volume de chuvas tenha aumentado ao longo do tempo, períodos com quinze dias secos consecutivos têm sido cada vez mais frequentes. Apesar das mudanças na temperatura, precipitação e distribuição das chuvas, não foram observadas alterações na evapotranspiração, ocorrência de chuvas intensas ou no balanço hídrico do solo.

Palavras-chave: Disstrução Húmica, temperatura do ar, precipitação, evapotranspiração, armazenamento de água, efeito estufa, Cambissolos.

Introduction

Climate change effects and impacts are visible worldwide on natural ecosystems, agriculture and water resources, having global, regional and local scales. Climate change is one of the greatest challenges of our time. Its impacts affect everything from food production to the rising sea levels, which have been destabilizing both society and the environment alike in a global and unprecedented manner (Medeiros et al., 2020).

Climate changes projected by models presented at the Intergovernmental Panel on Climate Change (IPCC, 2021) are expected to reflect in all areas of society, including agriculture (Ray, 2019; Malhi et al, 2021; Bhardwaj et al, 2022).

Climate and weather patterns have a direct influence on agriculture in terms of food security, sustainability of the soil that having profound effect on human health (Kumar et al., 2022). According to Corwin (2020) changes in climate patterns are dramatically influencing some agricultural areas, particularly in arid regions. A wide variety of climate change has been observed in Latin America, which may be not only from natural climate variability but also from human interference in the system. Mainly, variations can be observed in the average air temperature and in the hydrological cycle (IPCC, 2021; Burger, 2020).

Analyzing the variability of precipitation and air temperature in a given region is necessary to understand climate change and find ways to diminish its consequences. According to Konapala (2020) this analysis makes it possible to know the changes occurring over time in order to prevent problems, be them current or future ones.

Salviano et al. (2016) analyzed behavior changes in the average air temperature over the years (1961-2011) and found a significant positive trend in an area corresponding to between 36 and 78% of the Brazilian territory. Some reflections of global climate change on a regional scale are evidenced by Mendonça (2006), with particular emphasis on southern Brazil, in which thermal changes (over a 0.7°C rise in temperature with changes mainly in minimum temperatures) and increased annual rainfall totals (humidification with tendency of rain concentration) were identified in recent decades. As Tollefson (2021) said that Earth is warmer than it's been in 125.000 years, Ávila and Campos (2017) indicated the warmest years ever recorded in the municipality of Lages, in Santa Catarina, were all in the last decade.

In agriculture, water scarcity is an increasingly common problem for rural producers worldwide, including those from Santa Catarina, which have been suffering significant and increasingly recurrent losses. Analyzing changes in the water balance contribute to understanding water availability for crops (Luo et al., 2022).

Water balance is a climatological indicator of water availability in a region (Bao et al., 2019), and is also a tool that indicates the best areas and planting times. Hence, based on this information, it is possible to scale better the crop treatments and to choose crops and varieties, management system and sowing times, so as to avoid periods of a greater demand for evapotranspiration and less water availability in the soil, aiming at soil and water conservation as well as enhancing the agricultural production. Studies that analyze soil water are especially important for soils that have less water available for crops (Costa et al., 2013a; Reichert at al., 2020).

According Kemp et al. (2022) is necessary to stablish a research agenda for catastrophic climate change that focuses on: understanding extreme climate change dynamics and impacts in the long term; exploring climate-triggered pathways to mass morbidity and mortality; investigating social fragility; and synthesizing the research findings into "integrated catastrophe assessments".

The hypothesis is the existence of climate change in the municipality of Lages-SC, observed by increased air temperature and evapotranspiration in the location. Hence, this also means changes in the precipitation distribution and water balance, with reduced water availability in the soil, as Bao et al. (2019) studied in China.

However, the general objective of this study was to analyze if climate change, reported at global level, alter meteorological conditions (air temperature extremes and precipitation) and the water balance of a Humic Dystrudept of Lages SC.

Materials and methods

Study area

The study was conducted in the municipality of Lages, located in the Southern Plateau (27º49`S and 50º40`W) of the Santa Catarina state, having height above mean sea level of between 884 and 1260 m. According to Wrege et al. (2012) in the Climatic Atlas of the Southern States of Brazil and to the Köppen-Geiger classification, the climate type is "*Cfb*" (temperate climate, with mild summer). It characterizes regions of proper temperate climate, as they are always wet and having no dry season. The municipality in question has an average air temperature of 16°C. Its climate is cold during winter, with temperatures reaching up to -4°C and apparent temperature of -10°C. Strong frosts usually happen in this region; yet in summer, the climate varies from pleasant to hot, with temperatures that can go over the 30°C mark.

Data Analysis

Data used to analyze the climate change trend in Lages region and to calculate the water balance were obtained from the daily records of the network of meteorological stations owned by the Company of Agricultural Research and Rural Extension of Santa Catarina (Epagri, 2020), part of the Information Center for Hydrometeorology and Environmental Resources of Santa Catarina (CIRAM). Used historical series correspond to the period from 1948 to 2020 for maximum, average and minimum air temperatures, and from 1961 to 2020 for precipitation.

Descriptive statistical analyzes were also applied in this study, which express in a compact form the general characteristics of the observations, including mean and absolute values on monthly and annual scales.

Data on soil field capacity, needed in order to calculate the water balance, were obtained from a database (Costa, 2013b) of the Soil Physics laboratory at Santa Catarina State University. Samples were collected in Lages municipality on a Humic Dystrudept (United States, 2014), at coordinates 27°48′57″S, 50°19′33″W, altitude of 930 mals, derived from sedimentary rocks (Siltstones); A_1, A_2, AB and Bi are the main horizons. Up to a 50-cm depth, the average available water content (AW) is 0.18 cm^3 cm^{-3}, which results in a 90-mm storage capacity (AWC). Extreme precipitation indexes indicated by the ETCCDI (Expert team on climate change detection and indices) were also calculated, specifying the number of days in the year in which precipitations were greater than or equal to 50 mm (P50) and greater than or equal to 100 mm (P100). Then, the monthly probability of an extreme event occurring was calculated. Furthermore, the number of consecutive dry days (CDD) in each year of the historical series was obtained. A dry day is considered when a day has a rainfall less than 1 mm, it quantifies the number of CDD intervals, namely when one or more days without rain are recorded, in order to observe the monthly representation.

Based on meteorological elements presented, the following parameters were tabulated and obtained:

a) Maximum temperature (TMax) of the air at 2 m - monthly and annual (ºC)
b) Average temperature (TAve) of the air at 2 m - monthly and annual (ºC)
c) Minimum temperature (TMin) of the air at 2 m - monthly and annual (ºC)
d) Accumulated precipitation - monthly and annual (mm)
e) Potential evapotranspiration - monthly and annual (mm)
f) Precipitation minus evapotranspiration (P-Etp) - monthly and annual (mm)
g) Number of days with occurrence of a P50 extreme event - annual
h) Number of days with occurrence of a P100 extreme event - annual
i) Consecutive dry days CDD5, CDD10 and CDD15 - Number of consecutive dry days (5, 10, and 15) without rain - annual
j) Water deficit - monthly and annual (mm)
k) Water surplus - monthly and annual (mm).

Afterwards, these parameters were subjected to trend analysis by using the RStudio software with the Trend package add-on (Pohlert, 2020). Statistical analyzes of the historical series were subjected to the non-parametric Mann-Kendall test at 5% significance, to verify if there is a temporal trend of reduction, stability or increase of each analyzed parameter.

During the study second phase, these data were used to calculate the climatological water balance for a Humic Dystrudept, the most representative in the study region. To that end, the following parameters were used: monthly averages of air temperature and monthly total precipitation (from 1961 to 2020); geographic coordinates; and the soil available water capacity (AWC) for the 0-50 cm layer. With this information, the water balance calculates monthly water deficit and surplus, by using a "macro" developed in the Excel software, according to the Thornthwaite and Mather (1955) method, employing the 16-step rule proposed by Santos (2010). Water balance has precipitation and potential evapotranspiration as its basic input variables, and water storage, actual evapotranspiration, water surplus and deficit as its output variables. This method considers the soil a rainwater storage, as it occurs in the environment. Soil offers some resistance to water loss to atmosphere, and this resistance increases with reduced soil-stored water, a process depending on variations in the soil water potential, which is in turn composed of gravitational, pressure and matric potentials. When there is a positive balance between precipitation and potential evapotranspiration during the considered period, this balance is incorporated into the soil, replenishing it. When the soil reaches its maximum storage capacity, this balance is considered as excess.

Results

Air temperature

The average annual temperature is 15.9ºC. Minimum temperatures are higher during summer (16.1ºC in January and 16.3ºC in February) while the coldest months are during winter (7.5°C in June and 7.1ºC in July). The average annual minimum temperature is 11.8ºC. Maximum air temperature is higher in January and February (26.5ºC and 26.2ºC, respectively), characterizing them as the hottest summer months. July and June are when maximum air temperatures are at their lowest (17.1 and 17.2ºC, respectively). The annual average of maximum air temperatures is 21.8ºC, and these temperatures normally are recorded in the afternoon; they also favor the formation of convective rains, widely common during summer months (Monteiro, 2001). Considering the highest average temperature was in January (20.4ºC) and the lowest in July (11.0ºC), the amplitude is 9.4ºC.

The analysis of absolute temperatures indicated 35.3°C as the absolute maximum in January 1949, while the absolute minimum was −3.3°C in June 2016. With absolute temperature data, it is possible to observe large thermal amplitude throughout the year, in other words, a large difference between the absolute maximums and minimums during the monthly analysis (Figure 1).

The temporal trend analysis applied to the daily series of maximum, average and minimum air temperatures indicated a significant trend ($p<0.05$) with increasing temperatures (Table 1). Increased minimum and average air temperatures are more pronounced than increased maximum temperatures (Z = +4.5 for maximum temperatures, +7.2 for average temperatures, and +7.7 for minimum temperatures). A decreasing thermal amplitude is also observed, when considering the minimum temperature is increasing more than the maximum. Figure 2 illustrates this greater increase in the series of minimum and average temperatures over time.

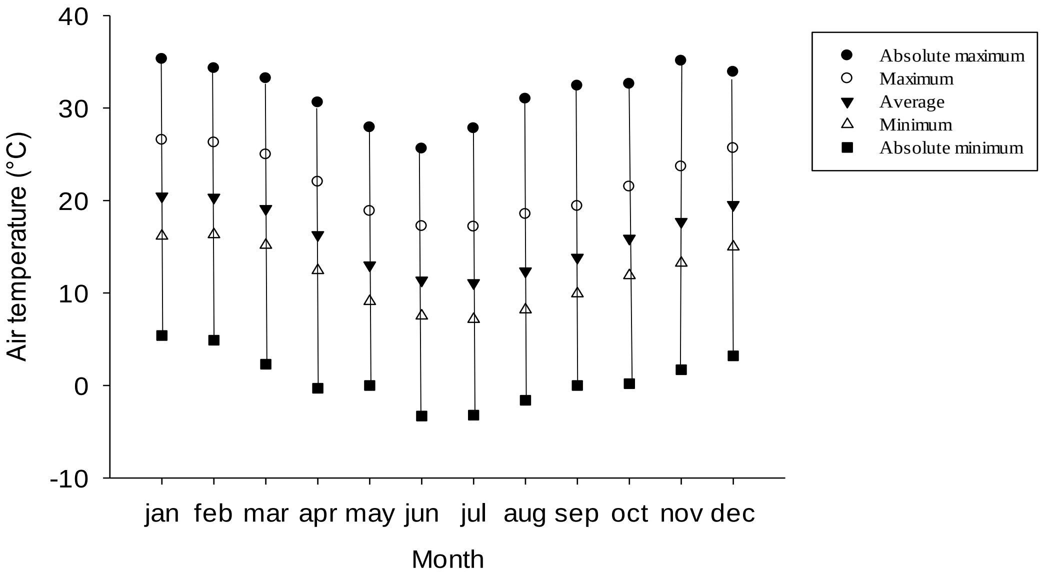

Figure 1. Absolute maximum and minimum temperatures, maximum, average and minimum monthly temperatures for the municipality of Lages from 1948 to 2020.

Table 1 Mann-Kendall test for daily historical series from 1948 to 2020, of maximum (TMax), average (TAve) and minimum (TMin) air temperatures, and annual series from 1961 to 2020 of precipitation (P), evapotranspiration (Etp), precipitation minus evapotranspiration (P-Etp), number of consecutive dry days (CDD), water surplus and deficit for the municipality of Lages, SC.

Variable	p-value (5% significance)	Z value
Daily series		
TMax	<0.01	+4.5
TAve	<0.01	+7.2
TMin	<0.01	+7.7
Precipitation	<0.01	+8.4
Annual series		
Evapotranspiration	0.887	+0.2
P-Etp	0.049	+2.0
CDD5	0.635	-0.5
CDD10	0.127	-1.5
CDD15	0.025	+2.2
Water surplus	0.053	+1.9
Water deficit	0.079	-1.8

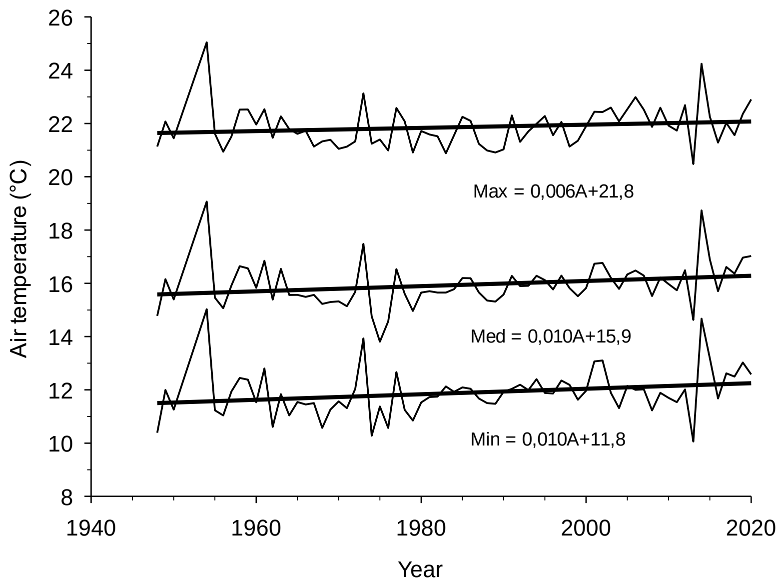

Figure 2. Annual variation of maximum (TMax), average (TAve) and minimum (TMin) air temperatures for the municipality of Lages, from 1948 to 2020. *In the equation, 1948 is considered as year 1.

For a better understanding, months in which temperatures are changing were analyzed. To that end, the trend analysis was applied to monthly averages of TMax, TAve and TMin, with climate changes found indicated in Table 2. Regarding TMax, there are warming trends for April, May, August and December, but most months are stable in terms of maximum air temperatures, or in other words, close to the climate averages. In relation to TAve, an increasing trend is found in January, April, June, October, November and December. For TMin monthly averages, an upward trend is observed in January, February, April, May, October, November and December. No trend in the series is demonstrated by the other months. Therefore, increasing trends stand out in April and December, while in March, July and September no warming up was recorded. No month had a reducing trend on their maximum, average or minimum air temperatures.

Table 2. Monthly change trend in maximum, average and minimum air temperatures (history series from 1948 to 2020), and precipitation (P), evapotranspiration (Etp), precipitation minus evapotranspiration (P-Etp) (history series from 1961 to 2020), for the municipality of Lages, SC.

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMax	ns	ns	ns	+	+	ns	ns	+	ns	ns	ns	+
TAve	+	ns	ns	+	ns	+	ns	ns	ns	+	+	+
TMin	+	+	ns	+	+	ns	ns	ns	ns	+	+	+
P	ns	ns	ns	+	+	+	+	ns	ns	+	+	+
Etp	ns	ns	ns	ns	ns	ns	ns	ns	+	ns	+	ns
P-Etp	ns	ns	ns	ns	ns	ns	+	ns	ns	ns	ns	ns

Positive (+) or negative (-) trends ($p<0.05$); ns = non-significant ($p>0.05$).

Precipitation and evapotranspiration

Analyzing historical averages of precipitation between 1961 and 2020, rainfall is higher in October (179 mm) and lower in April (102 mm) (Figure 3). The average annual rainfall is 1650 mm. February 1981 had the highest precipitation accumulated in a single month, 361 mm (data not shown).

A positive temporal trend is observed when analyzing daily rainfall throughout the historical series, meaning they are increasingly voluminous (Z = +8.4; $p<0.01$). In addition, annual precipitation averages are also increasing (Z = +2.8; $p<0.01$) over the years (Table 1 and Figure 4). When temporal analysis is applied to each month separately, increased precipitation (Z value +) is observed in April, May, June, July, October, November and December, while it remains stable for the other months. The highest rainfall volume in the entire historical series was in 2011, of 2,267 mm, while 1984 had the lowest one, of 500 mm.

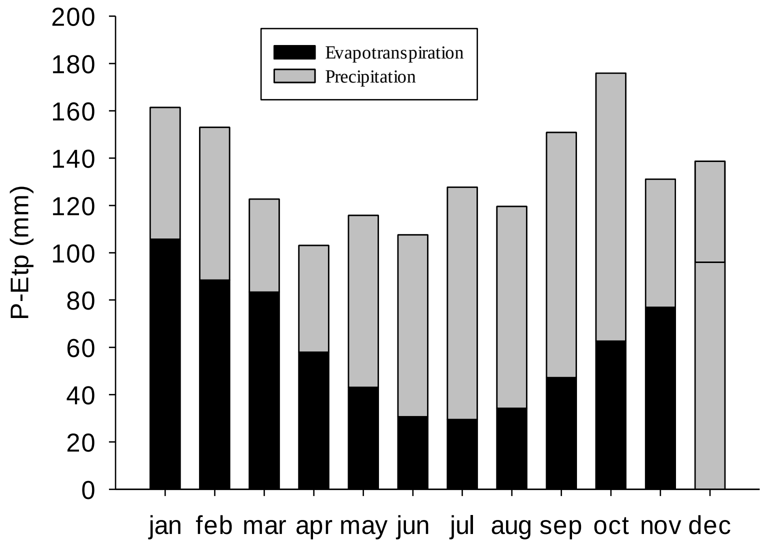

Fig. 3. Relation between precipitation and evapotranspiration in the municipality of Lages, SC, for the historical series from 1961 to 2020.

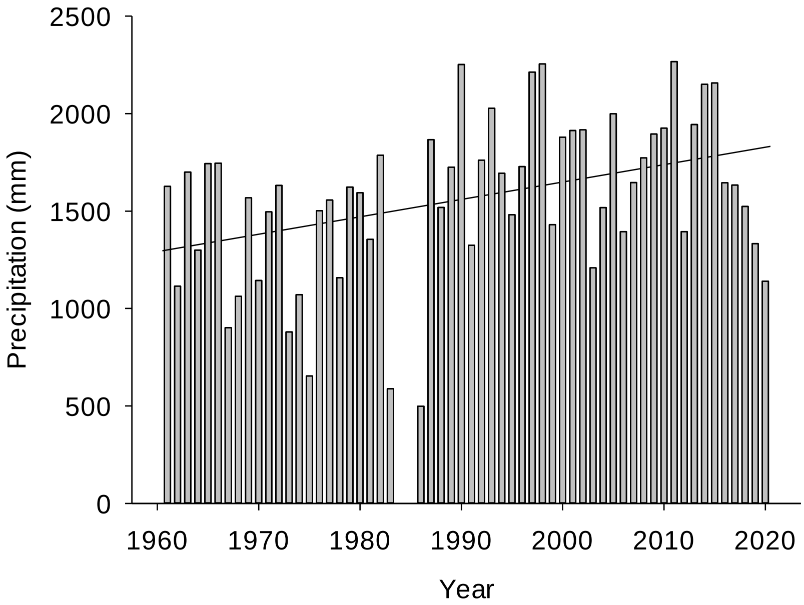

Fig. 4. Annual total accumulated precipitation (1961-2020). History series tendency is represented by the line (Z = +2.8; p<0.01).

The average annual evapotranspiration was 750 mm and the monthly evapotranspiration was higher in January (105 mm) and December (96 mm), coinciding with the hottest summer months; yet they were lower in June and July, with 30 and 29 mm, respectively. No trend of annual evapotranspiration variation was found during the historical series (p=0.88). However, the average monthly evapotranspiration was higher in September and November (Table 2), which may be due to the higher air temperature caused by climate change. In the other months, evapotranspiration remained stable.

Precipitation minus evapotranspiration (P-Etp) ranged from 39 to 113 mm, thus reflecting the water availability, since it calculates water surpluses and deficits. Greater water availability occurs in September (103 mm) and October (113 mm), as these were the months with most rainfall (Figure 3). March, April and December had the lowest water availability, respectively with 39, 45 and 42 mm (Figure 3). The annual average of water availability is 846 mm.

The test indicated increased water availability between 1961 and 2020 (Z = +2.0; p=0.049) (Table 1), possibly due to the increased annual precipitation volume, while evapotranspiration remained as constant. Temporal analysis of calculated P-Etp, for each month, indicated an increase in July (Table 2), which may be related to the greater precipitation observed on it.

Extreme events

The number of days in the year with precipitation above 1 mm were 107, on average, with 82.5% having rainfall between 1 and 25 mm; 13.8% with rainfall between 25 and 50 mm; and 2.7% with rainfall between 50 and 75 mm (Figure 5). Days with more extreme events (>50mm) account for only 3.5%; most of them with rainfall between 50-75 mm, and only 0.8% with rainfall above 75 mm. In spite of their lower frequency, extreme events cause soil degradation, inundations and flooding in rural and urban areas, especially when they take place during periods with consecutive days of rain.

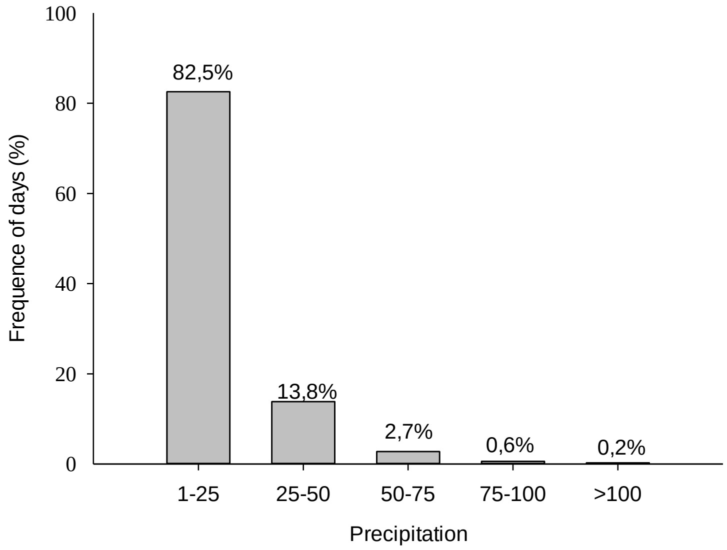

Fig. 5. Daily precipitation frequency with volumes between 1 and 25, 25 and 50, 50 and 75, 75 and 100 and over 100 mm for the municipality of Lages/SC.

When analyzing extreme precipitation events (days of rainfall over 50 mm - P50, and over 100 mm - P100), no significant upward trend between 1961 and 2020 was found. More days with events above 50 mm occurred in 1997 and 2005, nine each year (Figure 6).

The monthly probability of extreme events occurring (Figure 7) was higher in May (49%), September (47%), October (45%) and November (45%), corroborating the study by Monteiro (2001), which indicated spring as the most favorable season for these occurrences in the region. On the other hand, March is the least likely month for rain events above 50 mm (18%). In February, August and October, less than 6%t was the monthly probability of extreme events over 100 mm occurring. The largest event recorded during the analyzed period was in October 2001, of 177 mm in 24 hours.

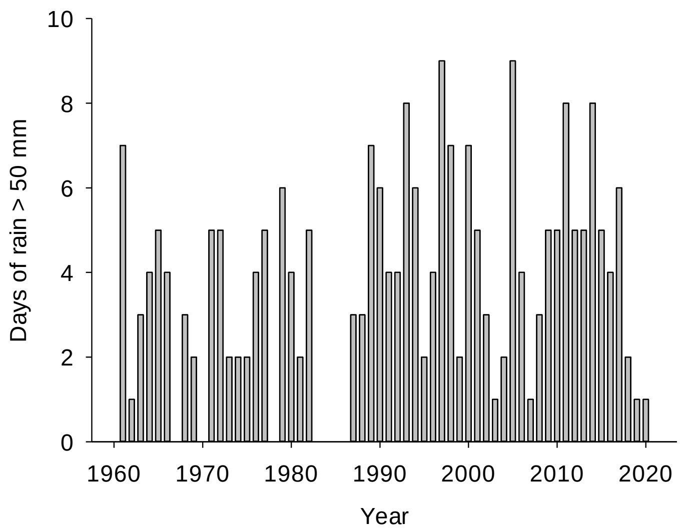

Fig. 6. Number of days in the year with precipitation over 50 mm, for the municipality of Lages, SC, regarding the history series from 1961 to 2020.

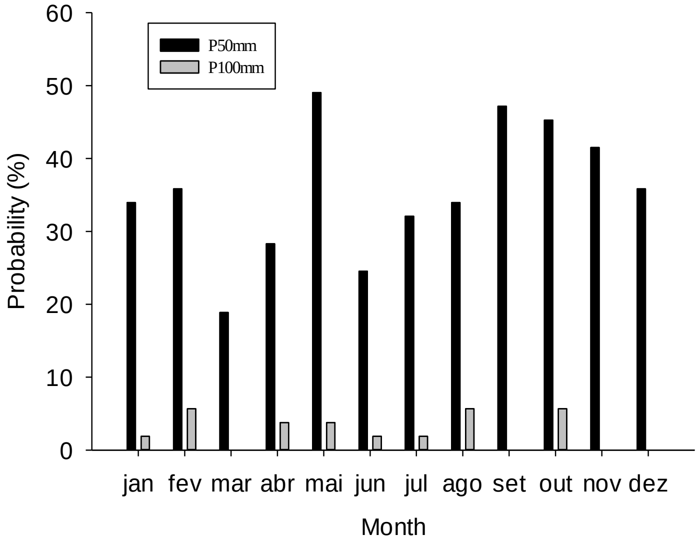

Fig. 7. Monthly probability of an extreme event over 50 mm (P50) and 100 mm (P100) occurring in the series from 1961 to 2020.

In most months, on average, there are over 20 days without rain, with January and February the ones that had less than 20 days without rain (Figure 8).

In order to analyze the consecutive dry days, it was necessary to count the number of days without rain until a rainy day happened. For this, the days were separated at intervals of 5, 10 and 15 consecutive dry days (CDD5, CDD10 and CDD15). The analysis indicates no trend of temporal alteration of CDD5 and CDD10 (p=0.635 and 0.127, respectively) (Table 1); However, CDD15 is increasing over time (p=0.025, and *Z* value = +2.2). These results indicate a poor rain distribution, since consecutive dry days are more frequent and interspersed with periods of more extreme rains.

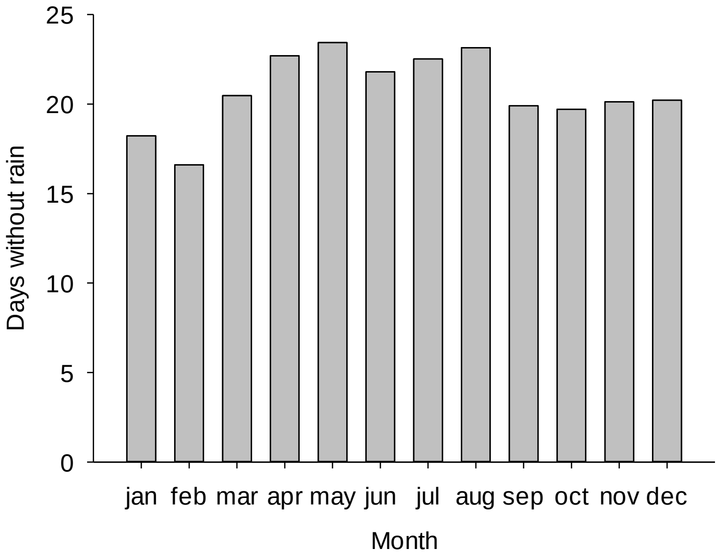

Fig. 8. Number of days without rain for each month in Lages, SC.

Water balance

Water deficit and surplus were calculated for analyzing the soil water balance, with December as the month with the greatest deficit, averaging 3 mm, and October as the one with the greatest surplus, of 115 mm (Figure 9). October also had the highest rainfall volume (Figure 3). There was no water deficit in June, July, August, September and October. No increasing or decreasing trends of soil water availability were recorded (p=0.053 and 0.079) (Table 1). Figures 10 and 11 illustrate occurrence probabilities of water deficit and surplus, respectively. March and April are the months with the highest water deficit, with probability of 27% and 31%, respectively; On the other hand, June, July and September have a lower probability, less than 4%. Altogether, all months of evaluated years have a water surplus probability above 65%, with those from June to October as the most likely to have this occurrence (>80%).

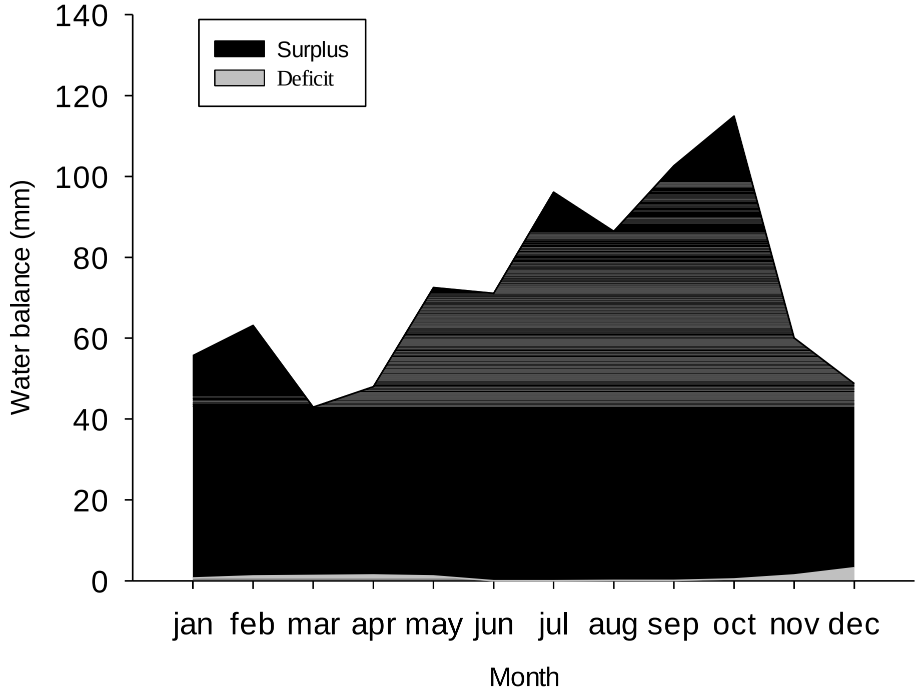

Fig. 9. Monthly average of water deficit and surplus for the Humic Dystrudept of Lages, SC.

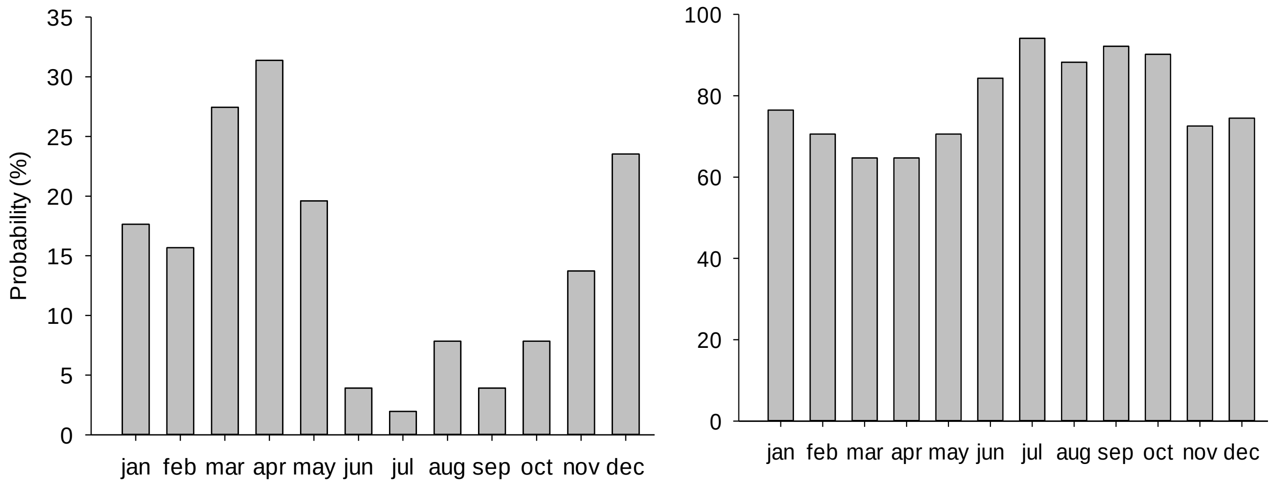

Fig. 10. Monthly occurrence probability of water deficit (left) or surplus (right), for a Humic Dystrudept of Lages, SC.

Climate change main effects on Lages municipality (Table 3) demonstrate an increasing trend regarding the parameters of maximum, average and minimum air temperature, as well as precipitation, P-Etp and CDD15 consecutive dry days. The other analyzed parameters had no trend (evapotranspiration, number of days with P50 and P100, soil water deficit and surplus).

Table 3. Climate change main effects in the municipality of Lages/SC, with data from the historical series from 1948 to 2020 for temperature and from 1961 to 2020 for precipitation.

Analyzed parameters	Trend	Main results
Maximum air temperature	Increase	Warming up trend in April, May, August and December.
Average air temperature	Increase	Warming up trend in January, April, May, June, October, November and December.
Minimum air temperature	Increase	Warming up trend in January, February, April, May, October, November and December.
Precipitation	Increase	Trend of more rains in April, May, June, July, October, November and December.
Evapotranspiration	Stability	Annual series does not have trend, but an increase has been occurring in September and November.
P-Etp	Increase	Increasing trend in July over the years.
Number of days with P50 and P100	Stability	As much as rains are increasing, analyzed series still did not show significant trends for wet extreme events indexes.
CDD15 consecutive dry days	Increase	Increasingly frequent, i.e., rains are not well distributed over time as they once were.
Water deficit and surplus in the soil	Stability	Despite the average annual precipitation volume being greater and the occurrence of more consecutive dry days, trends were not significant considering the average monthly values of water deficit or surplus.

Discussion

Analyzes indicated the averages of TAve and TMax are as what is expected during summer. Winter months, such as June and July, are the coldest ones due to air masses from polar origin, favoring sharp drops in air temperature, as well as recordings of phenomena as snow and frost (Monteiro, 2001).

The temporal analysis of the daily series concerning TMax, TAve and TMin confirms temperatures are increasing, corroborating the hypothesis of this study of climate changes in the municipality of Lages-SC, observed by increased air temperature. It also corroborates the study by Ávila (2017), who reported the occurrence, in the last decade, of the hottest years ever recorded in the municipality of Lages, in Santa Catarina. Warmer winters may be favorable in reducing frost episodes, thus mitigating their impacts on agricultural activities (Reichert et al., 2011). However, it can also have a negative aspect when considering the reduced number of hours of cold, a highly relevant factor in the cycle of fruit species in temperate climates such as plums, persimmons, figs, kiwis, apples, peach and grapes, among others (Monteiro, 2013). According to Wrege et al. (2012), having negative temperatures during winter months is common, as it can be seen by absolute minimum temperatures in the central Santa Catarina state, thus demonstrating the need in developing frost-tolerant cultivars, protected cultivation and proper sowing timing.

Historical knowledge of climatic conditions is important when planning cultivation and management systems to be used during crop cycle, carefully observing the thermal variability and its intensity. Furthermore, when conducting studies on land use and management, it is important to consider sowing time, crop cycle estimation and population well-being, among other activities (Oliveira et al., 2002; Pellegrino et al., 2007; Kumar et al., 2022).

According to IPCC report (IPCC, 2021), limiting warming to 1.5ºC, compared to the pre-industrial period, may already be impossible, as described in the Paris Agreement (Souza and Corazza, 2017). To fulfill this objective, reduced greenhouse gas emissions are recommended to be effective immediately, fast acting and on a large scale.

Regarding the rain, one of its characteristics is its distribution throughout the year. However, there is an indication of the daily rain distribution not being uniform for different months and years. There are regions of Brazil where rains are seasonally, namely only at a certain time of the year, as it happens in the Northeast, thus establishing a dry (winter) and a rainy (summer) season. Such situation requires water storage strategies that are more efficient for crops and for consumption by animals and humans alike.

On the other hand, rains tend to be well distributed throughout the year in southern Brazil. In this region, records of dry periods and even drought are established under influence of other phenomena, such as La Niña and El Niño (Monteiro, 2001), causing interannual variability; Moreover, such periods can be caused by long-term changes in regional climate patterns. During summer, increased cloud coverage and occurrence of intense rains are related to formation of the South Atlantic Convergence Zone (ZCAS) and frontal systems (Reboita et al., 2010). As for the winter, rains are from low to medium intensity and resulting from cold fronts (Mendonça and Bonatti, 2008).

Schick et al. (2014) calculated the erosivity index of rains from 1989 to 2012 in Lages, SC, where 83% were erosive, with the annual average characterized as possessing medium erosive potential. The period from September to February was most critical concerning this potential, concentrating 66% of annual erosivity.

Results from trend analysis by the statistical test are in accordance with the Intergovernmental Panel on Climate Change report (IPCC, 2021), which states that rainfall tends to increase in the region over time, mainly due to the occurrence of extreme events (Moura et al., 2020).

Analyzing the temporal series, both air temperature as well as precipitation indicate an increase over the years, as Doll and Schmied (2012) studied. However, no trend of significant change of monthly evapotranspiration is found; that is, even though air temperature is increasing, it may not be interfering significantly in annual average evapotranspiration. A similar behavior is reported for the northern region of Rio Grande do Sul, having abundant rainfall and low evapotranspiration (Wrege et al., 2012). Air temperature and precipitation trends were calculated based on daily series, while monthly series were considered for calculating Etp trends.

Annual distribution and water surplus in Lages are favorable, from the water availability standpoint, especially for plant vegetative development. This distribution is more irregular due to the number of 15 consecutive dry days (CDD15) occurring more frequently, which is in turn harmful to crops.

Analyzes of wet and dry extreme events corroborate the results of the Intergovernmental Panel on Climate Change report (IPCC, 2021), which states rains are not as well distributed over time as they were in the past. Increased annual precipitation was reported; however, periods with 15 consecutive dry days (CDD15) also increased. As much as the annual rainfall volume is increasing, the surge in extreme precipitation events was not significant (P50 and P100).

Temperature, precipitation and increased carbon dioxide levels in the atmosphere are hence considered the three major driving forces that influence soil properties (physical, chemical, biological) and its process which are soil organic matter decomposition, nitrogen mineralization, nitrification and denitrification, nutrient acquisition, erosion, soil salinity and acidity (Kumar et al., 2022).

There are no doubt human activities cause the climate change, with more extreme climate events such as heat waves, heavy rains, and droughts occurring with greater severity and frequency (IPCC, 2021; Burger, 2020).

As presented in the study, Lages municipality have demonstrated increased water availability over the years, yet even this increase was not enough to increase water surplus in the soil, since it can act as rainwater storage. This storage, in turn, is responsible for gradually transferring water by percolation to reservoirs (wetlands, ponds, streams and rivers).

The climate change is already affecting all regions of the Earth; in many ways, some of these changes are irreversible (Malhi, 2021; Ray, 2019; Nobre, 2020). Nevertheless, other changes can be delayed and some even stopped if anthropogenic actions and impacts on the environment are limited, such as the case with greenhouse gas emissions from burning fossil fuels, deforestation and fires. Even though it is possible, recommendations made by scientists currently are not even considered in government action plans, since land degradation, wildfires and removal of native forests have increased in recent years (IPCC, 2021). This process is worrisome, as there are indications of it reaching a point of no return; in other words, climate and environmental changes could no longer be reversed (IPCC, 2021; Bao et al., 2019).

Conclusions

a) O Trend analyses ascertain increased air temperatures since 1948, as well as precipitation and number of consecutive dry days (CDD15) since 1961, which in turn confirms the existence of climatic changes in the municipality of Lages-Santa Catarina.

b) In spite of the changes in temperature, precipitation and rain distribution, no significant change was observed on evapotranspiration, intense rains (P50 e P100), nor on soil water balance.

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