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Analysis of climatic variation in a changing livestock and agricultural area: Misiones, Paraguay

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ABSTRACT

Over recent decades, the Misiones Department, located in southern Paraguay, has shifted from an almost exclusively natural pasture-based traditional livestock production region, to the major rice production area of the country, soybeans maize, and family farm crops are also grown. Producers face production risk due to climate variability and change, and due to a lack of studies and analysis of meteorological variables in the area. The major risk are related to precipitation, including excess, deficiencies, intense events and frosts. We used RClimDex to analyze extreme event trends, specifically precipitation and temperature values; and the Standard Precipitation Index (SPI) to analyze drought. Results show that drought is a recurrent phenomenon and that it alternates with periods of significant rainfall excesses. First frost is June seven, the last frost occurs on August two, and the frost period is on average 57 days. We found significant increases in intense precipitation and on wet days. A negative trend was observed in summer days, monthly maximum value of daily maximum temperature, hot days, cold nights and daytime temperature range. These results properly communicated may help producers avoid and adapt to climate risk.

Introduction

Irrigation has been, throughout history, one of the main adaptive methods to mitigate climate risk in agriculture. The availability of surface water for irrigation is subject to extreme phenomena, which could become more frequent because of climate variability and change and the ENSO phenomenon.

One of the crops that uses water is rice, this in Paraguay is currently increasing in important either for domestic consumption or for export. For the 2013-2014 cropping year, using Landsat 8 satellite images, a cultivated area of approximately 86,000 ha was identified in the Tebicuary River Basin, of which in the middle and lower basin are in the Misiones Department (Mongelós, 2016). This administrative region continues to grow, currently producing slightly over 70% of irrigated rice, or some 105,000 ha in 2020. The Ministry of Agriculture and Livestock (2019) indicates that the same area of the previous harvest will be maintained, but projects reductions of 1.5 % both in yield, which would fall to 6,500 kg / ha, and in production to 1,053,050 tons (FCA UNA, 2019).

The Department of Misiones, located in the South of the Oriental Region of Paraguay, is a traditional livestock production area, here grows some 50,000 ha of soybeans (CAPECO, 2019). There is a cattle herd 466,000 head in the Department (SENACSA, 2018). Finally, over 5,300 family farmers exist in the study area. They depend on crops such as manioc, beans, maize, sugar cane and vegetables for food security (PNUD, 2010).

Previous studies identified intense rain events as increased in Eastern Paraguay. The volume and intensity of precipitation recorded every year is increasing as are the annual number of extreme events defined from the 90th percentile of the historical data. For the decennial changes observed by climatic season, a positive tendency was detected in the volume of accumulated precipitation and in the number of extreme events in spring, summer and autumn (Breuer et al., 2017).

Statistical studies on variation of the volume of precipitation in the region and for Paraguay as a whole exist. These studies indicate an increase of the annual accumulated and an increase in the daily intensity of rainfall through time (Arndt et al., 2010; Haylock et al., 2006; Liebmann et al., 2004).

Paraguay's precipitation patterns are influenced by climatic phenomena, especially due to the El Niño-Southern Oscillation phenomenon (ENSO). Fraisse et al. (2008) showed that this phenomenon, by influencing the rainfall regime influences yields of crops in Paraguay. This study analyzed the relationship between ENSO phenomenon and precipitation patterns during different stages of development of soybeans and concluded that the positive and negative residuals of performance occurred both in the neutral phase as in the warm phase (El Niño), and that in cold phase events (La Niña) the residuals were always negative. The North Atlantic Oscillation (NAO) and the Madden-Julian Oscillation (MJO) potentially influence rainfall patterns in Eastern Paraguay, but studies are lacking.

Recently heavy flooding occurred in Paraguay, Argentina and southern Brazil during the austral summer of 2016/2017. One study attributed these events to "alternating moisture inflow from the South American low-level jet and local convergence associated with baroclinic systems that were conducive to mesoscale convective activity and enhanced precipitation." These circulation patterns were favored by cross-time-scale interactions of a very strong El Niño event, an unusually persistent Madden-Julian Oscillation in phases 4 and 5, and the presence of a dipole SST anomaly in the central southern Atlantic Ocean (Doss-Gollin et al., 2018). Although the 2016/17 flooding study refers to a major event, a trend toward increased intense rainfall patterns in the region has been highlighted in the literature for some time (Grimm & Tedeschi 2009; Skansi et al., 2013).

On the other hand, drought is one of the recurring natural phenomena and presents different time scales. Scientific knowledge and technological advancement have allowed us to improve forecasting techniques for a drought event. It can appear gradually and last from weeks to years. The analysis of the different past drought events is of utmost importance, since this has an impact not only on the meteorological and hydrological sphere, but also in the social and economic aspects. In Paraguay, where agriculture and livestock make a large portion of GNP, drought can cause very important impacts on the economy.

Understanding that precipitation deficits had different impacts on groundwater, reservoir water storage, soil moisture, snowbanks, and river flows led US scientists McKee, Doesken and Kleist to develop the normalized precipitation index (SPI) in 1993.

Another phenomenon of great importance is the frost, as it arouses much interest due to the impacts it has on the agricultural sector. Also, the implementation of different types of models that allow obtaining agroclimatic information on the behavior of frost for a specific region. This type of study helps to know that the region provides for the occurrence of frosts, their causes and their consequences. At present, climate variability generates the majority of inter-annual fluctuations in annual crop yields, which represent a significant proportion of the basic nutrition of the family farm population. It also affects maize, wheat, oats and other winter covers, and soybean plantings in early spring, as well as late sowings of "zafriña" or second cycle maize.

Soybean and rice farmers, livestock breeders, and family production units face potential climate risk from insufficient or excessive rainfall, greater rain event intensity, frosts, changing seasons, extreme temperatures and extreme weather events. Understanding of climate variability and change contributes for greater adaptation and resilience through best management practices. However, as there are few studies for the Misiones department of Paraguay specifically, this document aims to begin to fill the knowledge gap by analyzing a long-term climate record from the main station located at San Juan Bautista, Misiones.

Material and methods

The city of San Juan Bautista capital of the department of Misiones is shown in Figure 1. In this city the conventional meteorological station is located, in addition to an automatic station, belonging to the network of stations of the Directorate of Meteorology and Hydrology. The San Juan Bautista station is located at 26° latitude and 57° longitude with an elevation of 131 m, and there are 53 years of data since 1966.

In the Eastern region of Paraguay, the origin of the prevailing precipitations is of the convective type, and they are produced by isolated storms or by storm lines that start from spring to autumn and in some isolated cases occur in winter. The spatial variation of the average annual precipitation in Paraguay is considerable, the distribution has a southern sense and varies zonally from a minimum of 600 mm in the west of the Chaco and exceeds 1800 mm (Figure 2) in the south of the Eastern region (Grassi et al.,

Figure 1. Location map of Misiones department. Own source.

2005). The precipitations are maximum in the months of October to March and the period of low precipitations goes from April to August.

In Paraguay the average annual temperature ranges from 21°C in the southeast of the Oriental region and above 25°C in the north of the Chaco (Figure 3). In the Oriental region the average temperatures are lower than in the Chaco and the maximum temperatures exceed 40°C in summer, while in the south of the Eastern region the average temperatures are lower than in the Chaco. In winter, frosts are usually registered in much of the country.

To analyze the trends of extreme events, specifically extreme values of precipitation and temperature, we used Rclimdex. The script was carried out in the R statistical package. RClimDex allows calculation of 27 basic extreme climate indices recommended by the expert team of CC1 / CLIVAR for "Climate Change Detection Monitoring and Indices (ETCCDMI)", as well as other temperature (Table 1) and precipitation (Table 2) indices with limits defined according to the user's interest.

Figure 2. Precipitation Normals 1961-1990 (Source: Pasten et al., 2011). Figure 3. Monthly mean temperature 1971-2000 (Source: Pasten et al., 2011).

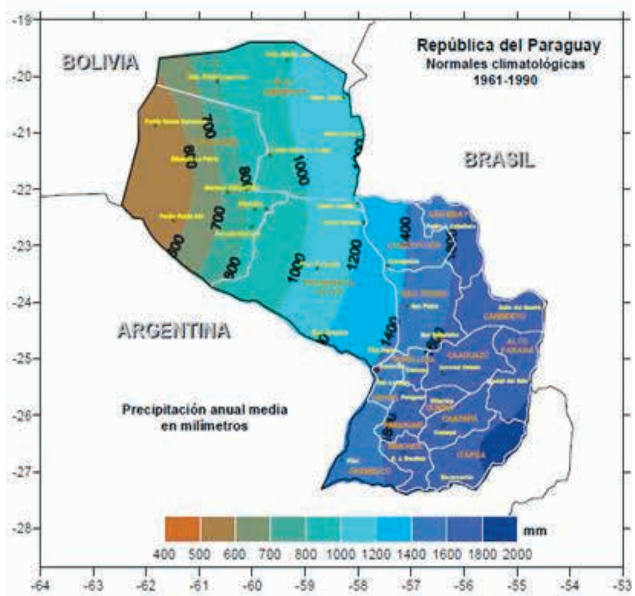
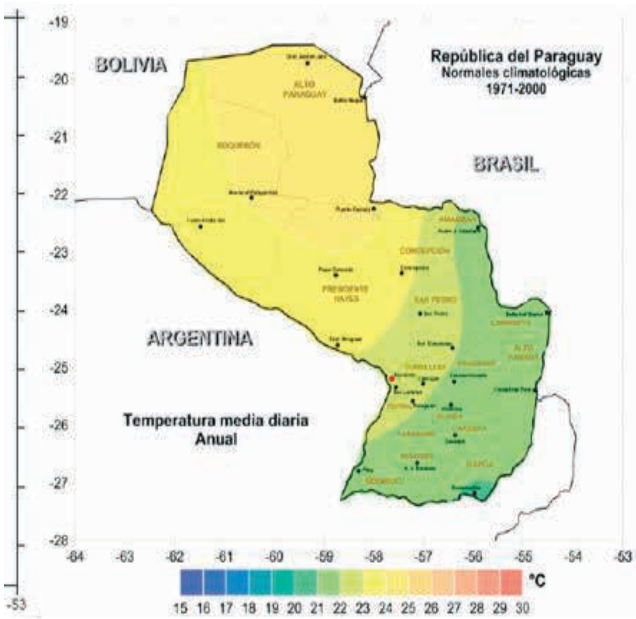


Figure 3. Monthly mean temperature 1971-2000 (Source: Pasten et al., 2011).



In order to calculate these indices of climate extremes and use them for studies of monitoring and detection of climate change, a homogenized database is required. The data is controlled with the RClimTool program and some previous homogenization tests are applied.

According to Heim (2002), there are four types of droughts, which differ in duration, with hydrological drought being the longest in time. These are meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought. Here we refer only to agricultural drought.

Agricultural drought refers to the permanent and

Table 1. List of basic ETCCDMI climatic indexes (Temperature).

ID	Name of indicator	Definition	Unit
FD0	Frost days	Number of days per year when TN (minimum daily) <0°C	Days
SU25	Summer days	Number of days per year when TX (maximum daily) >25°C	Days
ID0	Ice days	Number of days per year when TX(maximum daily) <0°C	Days
TR20	Tropical nights	Number of days per year when TN(minimum daily)>20°C	Days
GSL	Growing season Length	Annual (1 Jul to 30 Jun in SH) shows first period of at least 6 days with TG>5°C and first period after Jan 1 with TG<5°C	Days
TXx	Max Tmax	Monthly maximum value of maximum daily temperature	°C
TNx	Max Tmin	Monthly maximum value of minimum daily temperature	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temperature	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temperature	°C
TN10p	Cool nights	Percentage of days when TN<10th percentile	Days
TX10p	Cool days	Percentage of days when TX<10th percentile	Days
TN90p	Warm nights	Percent of days when TN>90th percentile	Days
TX90p	Warm days	Percent of days when TX>90th percentile	Days
WSDI	Warm spell duration indicador	Annual count of days with at least 6 consecutive days in which TX>90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days in which TN<10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX y TN	°C

Table 2. List of basic ETCCDMI climatic indexes (Precipitation).

RX1day	Max 1-day precipitation amount	Monthly maximum precipitation in one day	mm
RX5day	Max 5-day precipitation amount	Monthly maximum precipitation on 5 consecutive days	mm
SDII	Simple daily intensity index	Total annual precipitation divided by number of wet days (defined by PRCP>=1.0mm) in one year	mm/day
R10	Number of heavy precipitation days	Number of days in one year in which PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Number of days in one year in which PRCP>=20mm	Days
Rnn	Number of days above nnmm	Number of days in one year in which PRCP>=nn mm. nn is a user-defined parameter	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Total annual precipitation in which RR>95 percentile	mm
R99p	Extremely wet days	Total annual precipitation in which RR>99 percentile	mm
PRCPTOT	Annual total wet-day precipitation	Total annual precipitation on wet days RR>=1mm	mm

marked deficit of the amount of rain, which significantly reduces agricultural production in relation to what is normally expected or the average values for a specific region. Agricultural drought is the result that meteorological and / or hydrological droughts have on crop yields (Heim, 2002). This type of drought refers to the deficit of humidity in the root zone to satisfy the needs of a crop in a place at a given time. The amount of water required is different for each crop and may even vary throughout the year. Therefore, it is not possible to establish a single valid agricultural drought threshold even for a geographic area.

For this study we used the SPI, which is the most widely used index at the regional and global level, as well as being easy to apply. For calculation of the SPI, the historical monthly and seasonal precipitation data are used to calculate the probability distribution of the totals; these are then normalized with the inverse normal (Gaussian) function. Although the duration increases with the time scale, the frequency decreases inversely. The standardized precipitation index allows expressing both droughts and wet periods in terms of precipitation deficit, percentage of normal, and probability of non-exceedance.

Among droughts, we can differentiate

Types of drought

Mild drought, which is characterized by having values on the SPI scale from 0 to -0.99 that is, a standard deviation of 0 to 0.99. It occurs first in the evolution of a dry period and is the one that has the most frequency with respect to time, in addition to that, if its duration is not prolonged, it does not pose a danger to the productive sector.

Moderate drought occurs when the values by having values on the SPI scale range from -1 to -1.49, that is, with a standard deviation of 1 to 1.49. The frequency of occurrence is less than mild drought.

Severe drought has a threshold on the SPI scale with values from -1.50 to - 1.99, that is, a standard deviation of up to 1.99. It has a lower frequency than mild and moderate droughts. Severe drought easily turns into extreme drought, due to the negative values it can present.

Extreme drought is in terms of drought category the worst of the former mentioned, with threshold values that exceed -2 on the SPI scale and therefore have a standard deviation that exceeds the value of 2. It is the one with the lowest frequency, and is detrimental to the agricultural and livestock sectors, because the available water is not enough to alleviate the prevailing scarcity.

Drought classification based on SPI

A further classification based on SPI follows.

The 1-month SPI is similar to a map where the percentage of precipitation during the 30-day is defined. In other words, it is the most accurate representation of monthly precipitation, because the distribution has normalized. The 1-month SPI compares the total precipitation for a month in a given year with the precipitation totals for the same month for all the available years. The 1-month SPI reflects short-term conditions, closely related to agricultural drought, which reflects short-term soil moisture and crop stress, especially during the growing season. However, the interpretation of the 1-month SPI can be misleading if the weather is not understood. In regions with low rainfall for a month, such as the Chaco Boreal, large negative or positive SPI values can result even though the mean output is relatively small. The 1-month SPI can also be misleading with less than normal precipitation values in regions with a small normal number of precipitations during a month.

The 3-month SPI compare the precipitation during the 3-month period with the precipitation totals for the same 3-month period for all the years included in the historical records. In other words, a 3-month SPI in late February compares the total precipitation for December-January-February in that particular year with the totals for December-January-February precipitation for all recording years for that location. Values can and will change as the current year compares historically and statistically to all previous years in the observation record.

The 3-month SPI reflects the short and medium term humidity conditions and provides a seasonal estimate of rainfall. It is important to compare the 3 months SPI with longer terms. A relatively normal period or even a wet 3-month period could occur in the midst of a long-term drought that would only be visible for a long period. Looking at longer time frames you can avoid misinterpretations by believing that a drought is over, when in reality it was just a wet period.

The 6-month SPI compares the precipitation for that period with the same 6-month period on the historical record. For example, a 6-month SPI in late September compares the cumulative precipitation for the April-September period, with all the latest totals for that same period. The 6-month SPI indicates the medium-term seasonal trend in precipitation.

The 9-month SPI provides an indication of inter-seasonal precipitation patterns over a median length of time. Droughts usually have a season or more to develop. SPI values below -1.5 for these larger time scales are generally a good indication that dryness is having a significant impact on agriculture and may be affecting other sectors. This period begins to close a period of short-term seasonal drought, leading to long-term droughts that can become hydrological, or multi-year droughts.

Finally, the 12-month SPI reflects long-term precipitation patterns. It is a comparison of the precipitation during the last 12 consecutive months with that recorded in the same 12 consecutive months of all the previous years of the available data. The SPI of these time scales is generally tied to flow rates, reservoir levels, and groundwater levels, even on longer time scales.

For frost analysis, we used the minimum temperature data recorded at the conventional meteorological station for the entire existing data period. From the meteorological point of view, a frost is any thermal decrease equal to less than about 0 Celsius degrees measured in a meteorological shelter. However, this concept varies widely from the point of view of agriculture, which it considers to be susceptible to all thermal downturns capable of causing damage to plant tissues. This varies by species, variety, phenological and sanitary status, and other factors. Surface minimum temperature differs considerably from that observed sheltered areas.

According to studies carried out by Burgos (1963), the agrometeorological level is the decrease in temperature that is equivalent to certain degrees on the surface. Therefore, it defines the temperature as less than 3 degrees Celsius at the meteorological station.

Results and discussion

The quality control of the data from the meteorological station of the department of Misiones (86260) was carried out with the RClimtool program, the OMS Station Code 86260 plot graphics and histograms are shown in Figure 4 while, the boxplots are shown in Figure 5.

The boxplots show the distribution of the data through the quartiles, in addition, they make possible the visualization of outliers. Figure 5 shows the data distribution based on daily records of temperatures in Celsius degree (°C) and precipitation in millimeters (mm).

The dry and wet events recorded in the historical series of the San Juan Bautista station are observed in Figure 6. The colored regions yellow, orange and red correspond to dry periods associated with Niña events (drought). The regions in green and blue correspond to wet periods associated with Niño events (floods, continuous precipitation). The great dry periods correspond to the dates of 1972-1973, 1986-1989, 1995-1996, 2006-2007 and 2012-2013.

The number of times each of the drought categories proposed by Mckee et al. (1993) is shown in Figure 7, with an 6-months SPI for the periods 1971-1980, 1981-1990, 1991-2000, 2001 - 2010 and 2011-2013. We found that for a 6-month SPI there was a higher repetition of mild drought for the period 1981-1990 with the lowest value for the San Pedro station (spe). For moderate, severe and extreme droughts, more repetitions were found for the period 2001-2010. In addition, the periods 1971-1980 and 1991-2000 registered quite low values. San Juan Bautista is one of the municipalities affected by droughts.

In major events livestock slaughter greatly increases after major frosts, as pasture carrying capacity is affected. One storm occurred in August 2013, causing the loss of more than 5,000 cattle and 30% of total wheat production was lost (Diario Hoy, 2013).

Frosts also affect human health due to respiratory illnesses, which affect the farm and ranch labor population. Frosts are a periodic phenomenon and part of the climatic variability in Paraguay. They manifest each year as the polar systems advance, with low temperatures. In the past 10 years of extreme climatic events, such as prolonged drought, floods, frosts, heat waves, etc., there is evidence of the high vulnerability of the productive system to face these situations (ID, 2014).

The amount of damage depends on the sensitivity of cultivation to freezing at the time of producing the event and the time that the temperature is due to the "critical freezing" temperature (Snyder et al., 2010). The critical temperature, at which different plant organisms are affected, differs according to species and variety.

The numerical results of the frosts for the study period shown in Table 3.

The results of the indexes, their tendency and their significance are observed in Table 4 and Table 5. Only 7 indexes show statistical significance; SU25 (Summer days), TXx (Maximum daily value of maximum daily temperature), TX90p (Hot days), TN10p (Cold nights), DTR (daytime temperature range), R10 (Number of days with intense precipitation) and CWD (Consecutive wet days). Climate indexes that are statistically significant in are highlighted in gray.

The results of the indices indicate that on summer days (SU25), the minimum monthly values of the maximum daily temperatures (TXn), percentage of days when the maximum temperature is above the 90th percentile, show a statistically significant increase. On the other hand, the percentage of days with the maximum daily temperature below the 10th percentile (TX10p), and the percentage of days with the minimum daily temperature below the 10th percentile (TN10p) show a statistically significant decrease.

The Precipitation indices number of days with precipitation greater than 10 mm in a year (R10mm) and the maximum number of consecutive days with precipitation greater than 1 mm (CWD), show a significant increase.

Figure 4. Analysis of climate data series from the San Juan Bautista Misiones station.

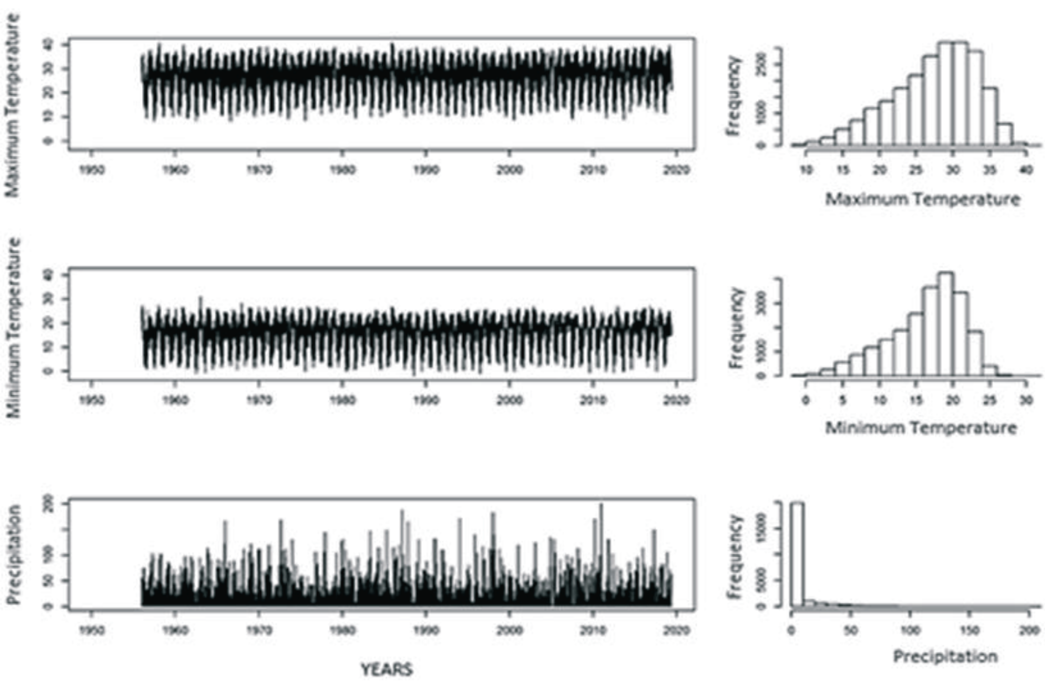


Figure 5. Daily data distribution shown in annual and monthly form from the San Juan Bautista, Misiones station.

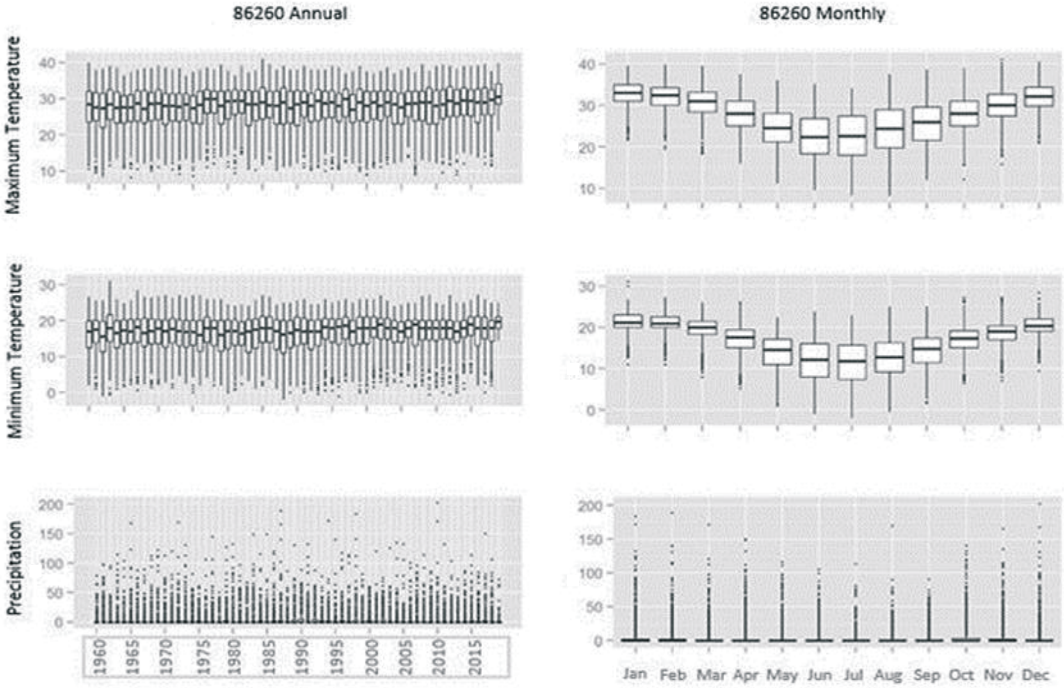
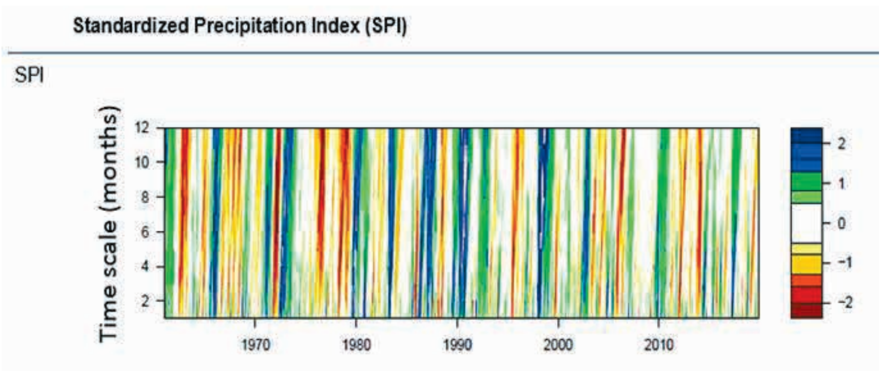


Figure 6. Distribution of monthly data in monthly and annual form for the San Juan Bautista, Misiones station. The colors that define drought go from yellow (slight drought) to red (extreme drought), whereas excesses go from green (excess level) to blue (extreme excess).



Discussion

The analysis of the data of the studied locality covers a length of 53 years, a considerable period for a good analysis of the different climatic events that may occur in that locality and its surroundings.

Drought analysis based on SPI verified that it is a recurrent phenomenon and that it alternates with periods of significant rainfall excesses, normally the rainfall excesses are more related to the “El Niño” phenomenon and that the significant deficits occur in “La Niña” years.

Analysis of minimum temperatures. We consider both meteorological frost (0°C), and minimum temperatures less than or equal to 3 and 5 degrees (agronomic frost) for the period of 1956-2019. The frost period presents different starting dates. Few years show meteorological frosts. Over the period studied, these represented only 6 first frosts and 8 last frosts, and only 10 percent of years with the first frost and 13 percent of the last frost.

Result of the analysis of the different climatic indices

The indices related to temperature show the following. A statistically significant increase in: Number of days per year in which the maximum daily temperature exceeds 25°C (SU25); and monthly minimum value of the maximum daily temperature (TXn), and percentage of days when the minimum daily temperature is above the 90th percentile (Tn90p). A statistically significant negative trend in Maximum monthly value of the minimum daily temperature (TNn), percentage of days for the maximum temperature below the 10th percentile (TX10p), and percentage of days

Figure 7. Distribution of drought categories following Mckee et al. (1993) for the six month scale for various selected locations. The San Juan Bautista Misiones station is marked by a black box.

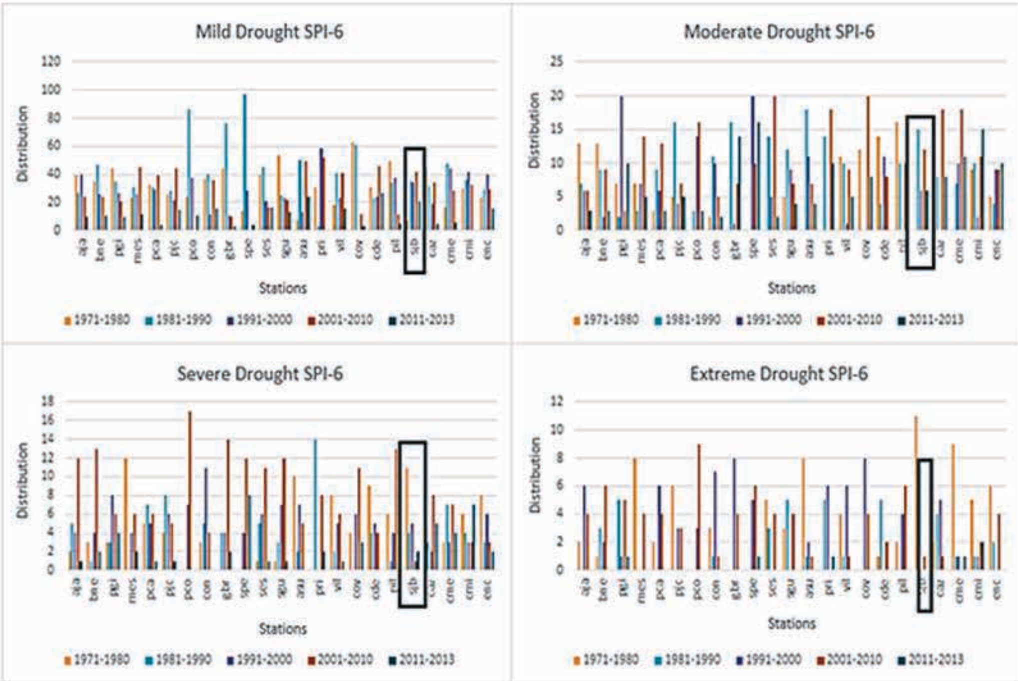


Table 3. Statistical Summary of Frosts in San Juan Bautista.

RESULTS	Tmin ≤ 5°C		Tmin ≤ 3°C		Tmin ≤ 0°C	
	FPH*	FUH**	FPH*	FUH**	FPH*	FUH**
Average dates of all years	05/06	21/08	15/06	09/08	04/07	02/08
Standard deviation	18	19	18	16.3	13.7	14.1
Nº of years with frost	56	56	41	37	6	8
Nº of years without frost	4	4	19	23	54	52
% of years with frost	0.93	0.93	0.683	0.617	0.1	0.133
Average frost date	08/06	19/08	25/06	31/07	14/07	17/07
Average frost date (normal)	07/06	20/08	22/06	01/08	26/07	12/07

*FPH Date of first frost

**FUH Date of last frost

when the minimum daily temperature is less than the 10th percentile (TN10p). This implies that there is an increase in summer days, the minimum temperatures are increasing and with there is a greater frequency of days with minimum temperatures above the 90th percentile. In addition, a decrease in the minimum daily temperature and fewer and fewer days with maximum temperatures and minimize below their 10th percentile.

Indices related to precipitation

A statistically significant increase exists in the number of days in the year in which the precipitation is greater than or equal to 10 mm (R10mm), and maximum number of consecutive days with daily precipitation greater than 1 mm (CWD). This implies that there is an increase in days of intense precipitation and consecutive wet days.

These trends are of value to agricultural and livestock production. A similar transition from low-efficiency cow-calf cattle ranching toward higher value rice and other crop production occurred in Corrientes and Entre Ríos, Argentina, and Rio Grande do Sul, Brazil, decades ago. However, this transition is relatively recent in Paraguay. With greater knowledge of climate history and extremes, this crop production may be undertaken with climate risk management in mind.

For producers, these results may allow adaptation through adoption of best management practices on the part of rice, soybean, livestock, and family farmers. These practices may range from the very simple, such as widening, deepening, and timely clearing of drainage ditches, to water harvesting and storage, and adjusting planting dates to avoid early and late frosts. Fertilizer rates, especially nitrogen top-dressing, subject to runoff from intense rain events, may be divided into smaller applications.

It is expected that the type of results presented here may serve as inputs for climate services in the form of decision support systems (Fraisse et al., 2006; Breuer & Fraisse, 2020; Radin & Matzenauer, 2016). The development of

Table 4. Index results (Temperature).

Indexes	Trend	Trend deviation	P_Value	Description
SU25	0.301	0.123	0.018	Number of days per year when TX (maximum daily) >25°C
ID0	0	0	NaN	Number of days per year when TX(maximum daily) <0°C
TR20	-0.091	0.131	0.492	Number of days per year when TN(minimum daily)>20°C
FD0	0.001	0.003	0.762	Number of days per year when TN (minimum daily) <0°C
TXx	0.004	0.007	0.636	Monthly maximum value of maximum daily temperature
TXn	0.03	0.011	0.009	Monthly minimum value of daily maximum temperature
TNx	-0.018	0.009	0.053	Valor mensual máximo de temperatura mínima diaria
TNn	-0.017	0.011	0.127	Monthly minimum value of daily minimum temperature
TX10p	-0.107	0.021	0	Percentage of days when TX<10th percentile
TX90p	0.077	0.029	0.011	Percent of days when TX>90th percentile
TN10p	-0.122	0.023	0	Percentage of days when TN<10th percentile
TN90p	0.033	0.027	0.231	Percent of days when TN>90th percentile
WSDI	0.074	0.053	0.17	Annual count of days with at least 6 consecutive days in which TX>90th percentile
CSDI	0.002	0.028	0.933	Annual count of days with at least 6 consecutive days in which TN<10th percentile
DTR	0.003	0.004	0.483	Diferencia media mensual entre TX y TN

Table 5. Index results (Precipitation).

Indexes	Trend	Trend deviation	P_Value	Description
RX1day	0.234	0.279	0.406	Monthly maximum precipitation in one day
RX5day	-0.146	0.506	0.775	Monthly maximum precipitation on 5 consecutive days
SDII	-0.034	0.025	0.188	Total annual precipitation divided by number of wet days (defined by PRCP>=1.0mm) in one year
R10mm	0.138	0.067	0.044	Number of days in one year in which PRCP>=10mm
R20mm	0.052	0.052	0.329	Number of days in one year in which PRCP>=20mm
R25mm	0.037	0.046	0.42	Number of days in one year in which PRCP>=25mm
CDD	-0.002	0.041	0.958	Maximum number of consecutive days with RR<1mm
CWD	0.023	0.011	0.031	Maximum number of consecutive days with RR>=1mm
R95p	-0.772	1.836	0.676	Total annual precipitation in which RR>95 percentile
R99p	1.083	1.069	0.316	Total annual precipitation in which RR>99 percentile
PRCPTOT	2.783	2.712	0.309	Total annual precipitation on wet days RR>=1mm

these systems among scientists and producers may lead to improved adaptation and resilience in light of climate variability and change, risk mitigation, and optimization of input use.

Authors contribution

M. PASTEN designed the study and oversaw all statistical analysis. N. BREUER Co-designed the study, integrated agronomic and livestock data, and co-wrote the manuscript. V. D. SCHNEIDER analyzed drought periods using SPI. C. GALEANO controlled RClimtool data outputs and co-wrote the manuscript.

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Análise da variação climática em uma área agrícola e pecuária em mutação: Misiones, Paraguai

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RESUMO

Nas últimas décadas, o Departamento de Misiones (Paraguai), passou de região de produção de gado tradicional, baseada exclusivamente em pastagem natural, para a principal área de produção de arroz do país. Soja, milho e culturas familiares também estão sendo cultivadas. Os produtores enfrentam riscos de produção devido à variabilidade e mudança climática e à falta de estudos e análises de variáveis meteorológicas na área. Os principais riscos estão relacionados às precipitações incluindo excessos, deficiências, eventos intensos e geadas. Para analisar as tendências de eventos extremos, especificamente com os valores extremos de precipitação e temperatura, foi usado o RClimDex e o SPI foi usado para analisar as ocorrências de seca. Os resultados mostram que a seca é um fenômeno recorrente e que se alterna com períodos de excessos significativos de chuvas. A primeira geada acontece em sete de junho, a última ocorre em dois de agosto e o período de geada é, em média, de 57 dias. Encontramos aumento significativo na precipitação intensa e dias chuvosos. Porém, uma tendência negativa foi observada nos dias de verão, nas temperaturas máximas diárias, em dias quentes, em noites frias e na amplitude da temperatura diurna. Esses resultados, comunicados adequadamente, podem ajudar os produtores a evitar e se adaptar ao risco climático.

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