

Original Research

Hot Extremes and Climatological Drought Indicators in the Transitional Semiarid-Subtropical Region of Sinaloa, Northwest Mexico

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Abstract

The main goal of this study was to explore the historical and recent spatial concurrence between the frequency (F), duration (D) and intensity (I) of hot extremes (HEs) and the frequency and evolution of meteorological drought in the region of Sinaloa. Based on the values of daily maximum temperature (Tmax) and precipitation obtained from CLImate COMputing for the interval April–October of a historical period (1963–2000) and a recent period (1982–2014), the HE and the standardized precipitation index (SPI) were calculated on one-month (SPI-1) and four-month (SPI-4) timescales. Spearman rank correlation coefficients (Sr) were used to obtain the significant concurrences (SCs) between HEs and SPI-1, and HEs and SPI-4. El Quelite weather station showed the highest historical SCs between HEs and SPI-1 ($-0.66 \leq Sr \leq -0.57$). Jaina is the only station that showed SCs with all four indicators of HEs and SPI-4 ($-0.47 \leq Sr \leq -0.34$). In this study, the concurrence between HEs and SPI-1, and HEs and SPI-4 was determined for the first time. These are phenomena that can decrease the crop yield, particularly for rainfed crops such as maize, sesame and sorghum in the region commonly known as “the breadbasket of Mexico”.

Keywords: frequency and evolution of meteorological droughts, the breadbasket of Mexico, Sinaloa

Introduction

Worldwide, among the weather phenomena that most affect the agricultural sector are precipitation variability [1-5], intense meteorological droughts [6-10], and hot extremes (HEs) [11-13]. The importance

of studying HEs and meteorological droughts jointly is that HE events can be predicted from knowledge of previous meteorological droughts, mainly due to the fact that dry events can increase the number of hot days in the summer [14]. In addition, several authors have stated that the increase in frequency (F), duration (D) and intensity (I) of HEs in summer may exacerbate both the frequency and the evolution of meteorological drought [7, 15-19], and when HEs and meteorological

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drought show significant concurrence (SC); that is, significant correlation, the damage to agriculture and other economic sectors is worse than that of a single phenomenon [17, 20-23]. In the Mexican region of Sinaloa, a large increase in the F, D and I, and frequency and evolution of meteorological drought is expected; i.e., in the coming years the annual mean temperature in northwestern Mexico will increase significantly (up to 2.5°C) and the mean annual precipitation decrease (up to 20%) [24]. In this study, McKee's equation [25] was used to calculate the standardized precipitation index (SPI) on time scales of 1 (SPI-1) and 4 (SPI-4) months. According to [7], these scales can be used to determine the frequency and evolution of meteorological drought, respectively. The F, D and I of HEs was determined by Li et al.'s methodology [26]. By means of a correlation analysis, concurrences between F, D and I with SPI-1, and F, and D and I with SPI-4 were obtained for two time periods; historical (1963-2000) and recent (1982-2014). The overlapping of years in the study periods (1982-2000) is due to the climatic transition that responds to El Niño and La Niña periods [27, 28] and, where appropriate, to periods of anomalies resulting from microclimatic disturbances or modifications. The strong El Niño eventually induces a significantly low rainfall with a lag time of some months, inducing a water deficit. Under such conditions and overlapping, vapor pressure deficit responds reflecting a significant increase in water demand after El Niño appearance, similar to increasing maximum air temperature and soil temperature [29]. In the overlapping period, 18 years (1982-2000), antagonist events occurred causing confusion in data. The goal was to explore the historical and recent spatial concurrence between the HE indicators and SPI-1, and HE indicators and SPI-4 for the region of Sinaloa, Mexico. This study is the first to establish the spatial concurrence between these indicators in Sinaloa, enabling identification of the presence of weather phenomena that can put at risk

the yield of crops in the region commonly known as "the breadbasket of Mexico" [30].

Material and Methods

Region of Study

This research analyzes the Mexican region of Sinaloa, known as "the breadbasket of Mexico," since it contributes about 30% of the total annual food production of the country [31] and represents about 2.9% of the total area [32]. Within this region Guasave is located, called the "agricultural heart of Mexico" due to its vast cropland area and diversity in production [33]. Sinaloa is located between the longitudes and latitudes 105°23'32" and 109°26'52" N, and 27°02'32" and 22°28'02" W (Fig. 1).

Daily Values of Maximum Temperature (Tmax) and Precipitation

Tmax and daily precipitation at 32 weather stations were obtained from the CLImate COMputing data base at <http://clicom-mex.cicese.mx/mapa.html> [34], for the period 1963-2014. Based on the available information, the data from 13 stations were analyzed to study the historical period 1963-2000 and data from 19 stations for the recent period 1982-2014; see Tables 1 and 2. The overlap between the historical and recent study periods (1982-2000) was due to at least one of the following effects; climate transition corresponding to El Niño and La Niña periods [27, 28], periods of anomalies of disturbances, or agroclimatic modifications [37]. In the overlapping period, antagonist events occurred, causing confusion in the data. The period chosen for the data was April-October because it presents the most intense magnitudes of Tmax and precipitation during the annual cycle [35], which coincides with the summer season

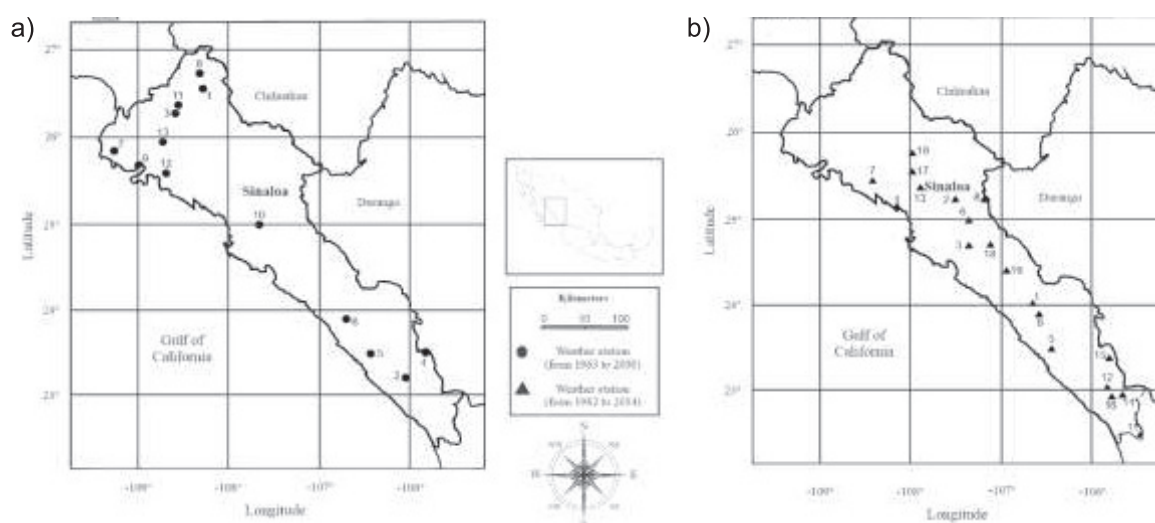


Fig. 1. Locations of weather stations analyzed for the following periods of time: a) historical (1963-2000) and b) recent (1982-2014).

(June–September). At each weather station and for each variable (Tmax and precipitation), 8,132 (historic period) and 7,062 (recent period) daily data points were analyzed. The multiple imputation method [36] was used to fill missing values using XLStat version 2014.

Hot Extreme Indicators

In order to obtain the HE indicators, the methodology described by [26] was used. These authors defined a HE as a period of three or more consecutive days of a given month with Tmax above the 85th percentile (P85). The indicators calculated based on HE data were the frequency of annual occurrence (F), annual average duration (AAD), annual daily duration (ADD), and average daily annual intensity (I). The F was obtained by summing the number of days of each month of each year that exceeded the P85 and 90th percentile (P90), AAD was the average of each value of F for each month of the year, ADD was the sum of HE events in each year, and I was the average of the value of all HE events in each year.

Frequency (SPI-1) and Evolution (SPI-4) of Meteorological Drought

SPI is a probability-based drought index used in all climate regions [36]. Because it uses only precipitation as input variable, it is the most popular meteorological drought analysis tool in the world [39]. Based on the principles of [24] for the analysis of meteorological drought, in this study the SPI values were calculated using the SPI-generator software. This index was chosen since it has been recommended due to its approximation and simplicity of the results [40]. Based on the study conducted by [7], in this work the frequency and evolution of meteorological droughts were calculated using SPI-1 and SPI-4, respectively.

Statistical Analyses: Normality, Concurrence, Hypothesis Testing and Validation

Prior to calculating the concurrences of all the data series, a Z-standardized normalization was generated. To obtain the Z-standardized normalization values, the mean was subtracted from each value in the data series and the result was divided by the standard deviation [41]. To know what type of concurrence to use (parametric correlation or non-parametric correlation), a Shapiro-Wilk normality analysis was conducted on the indicators Tmax, HE indicators, SPI-1, SPI-4 and number of days with precipitation (NDP). Not all the data series showed normality and therefore it was decided to carry out a Spearman rank correlation analysis (Sr). According to [42], Sr equals the Pearson correlation coefficient (Pr), after a data transformation. For spatial correlation, using Surfer 10.0 software, interpolation was applied using the weighted inverse

distance method with a weighting power of two, a smoothing factor of zero, and anisotropy radius and angle of one and zero, respectively. To prepare the final maps, CorelDRAW version 2019 was used.

A hypothesis test was applied to compare Sr with the critical absolute Sr ($Sr_{crit} \leq -0.271$ and $Sr_{crit} \leq -0.291$ for the historical and recent periods, respectively) since, according to [43], this test determines whether Sr is significantly different from zero ($H_0: Sr = 0$; $H_1: Sr \neq 0$).

For the validation, a Pearson and Spearman correlation analysis was applied to the NDP (data with normality) and Tmax data (data with non-normality), respectively. The observed NDP and Tmax data were obtained from [44] for the period 1961–2003 and, due to the data availability, the number of weather stations was 11 for the historical period and 17 for the recent period.

Results and Discussion

Hot Extremes (HE) Indicators

For the historical period, Choix II was the weather station with the highest average magnitudes: AAD = 6.96 day HE⁻¹ year⁻¹, ADD = 20.08 day year⁻¹, and I = 42.23°C year⁻¹. El Palmito station showed F = 3.97 HE year⁻¹, the highest value of frequency (Table 1). The average values of the HE indicators were F = 2.93 HE year⁻¹, AAD = 4.05 day HE⁻¹ year⁻¹, ADD = 15.57 day year⁻¹ and I = 30.19 42.23°C year⁻¹. The stations with the highest annual magnitudes were El Palmito (F = 18 HE year⁻¹ for 1982), Choix II (AAD = 24 day HE⁻¹ year⁻¹ for 1992), El Palmito (ADD = 106 day year⁻¹ for 1982) and Huites (I = 44.13°C year⁻¹ for 1968).

For the recent period, the stations with the highest intensities in the HE indicators were Guasave (F = 3.73 HE year⁻¹), Jaina (AAD = 5.08 day HE⁻¹ year⁻¹), Guatenipa (ADD = 20.94 day year⁻¹) and El Playón (I = 36.49°C year⁻¹). The mean annual values were F = 2.81 HE year⁻¹, AAD = 3.92 day HE⁻¹, ADD = 15.07 day year⁻¹ and I = 30.42°C year⁻¹. The stations with the highest annual intensities were Guasave (15 HE year⁻¹ for 2002), El Playón (AAD = 30 HE⁻¹ year⁻¹ for 1982), Ixpalino and Potrerillos (ADD = 112 day year⁻¹ for 2004 and 2013, respectively), and San Joaquín (I = 43.66°C year⁻¹ for 1982). The results are consistent with those of [2], who argue that for the study period 1952–2013, the highest cyclonic rainfall in northern Mexico was recorded in the years 1982, 1983 and 1984, and according to [45, 46], these events typically occurred in the summer (June–September, for Sinaloa), because they are an important mechanism for atmospheric circulation of warm temperatures on the earth's surface. The accumulated daily effect of HEs in Sinaloa, specifically near the Ixpalino and Potrerillos stations in 2004 and 2013, has led to consequences

Table 1. Annual average values of F, AAD, ADD and I for historical and recent periods.

Historical period					Recent period				
	HE year ⁻¹	day HE ⁻¹ year ⁻¹	day year ⁻¹	°C year ⁻¹		HE year ⁻¹	day HE ⁻¹ year ⁻¹	day year ⁻¹	°C year ⁻¹
Weather station	F	AAD	ADD	I	Weather station	F	AAD	ADD	I
Choix II (1)	3.39	6.96	20.08	42.23	Acatitan (1)	2.76	4.01	15.18	30.12
Concordia (2)	1.97	3.02	10.00	22.66	Badiraguato (2)	3.18	4.30	15.61	35.78
El Fuerte (3)	2.18	4.68	12.03	35.00	Culiacan (3)	3.39	3.28	15.09	28.67
El Palmito (4)	3.97	3.77	19.24	21.91	El Playón (4)	2.94	4.74	13.88	36.49
El Quelite (5)	2.21	2.77	10.37	26.23	El Quemado (5)	1.27	2.22	5.24	21.44
Elota (6)	3.13	3.80	16.42	30.43	El Varejonal (6)	3.42	4.73	19.94	33.92
H. de Zaragoza (7)	2.92	2.92	16.71	22.84	Guasave (7)	3.73	3.56	17.55	32.77
Huites (8)	2.92	4.66	17.42	35.97	Guatenipa (8)	3.33	5.07	20.94	34.41
Los Mochis (9)	3.32	3.43	15.21	31.44	Ixpalino (9)	2.70	3.34	15.73	30.13
Pericos (10)	2.61	4.38	14.71	32.48	Jaina (10)	3.27	5.08	18.85	36.27
Presa M. Hidalgo (11)	2.92	6.27	18.11	39.51	La Concha (11)	1.58	2.72	9.33	20.92
Ruiz Cortines (12)	3.68	2.97	16.34	27.11	Las Tortugas (12)	2.61	3.52	11.76	29.00
San Blas (13)	2.89	3.02	15.79	24.66	Mocorito (13)	2.94	5.00	19.79	32.68
					Otatitan (14)	2.36	3.21	11.61	27.77
					Potreros (15)	2.12	3.75	13.82	21.70
					Rosario (16)	2.91	4.59	17.61	28.36
					San Joaquín (17)	2.94	4.21	16.91	33.11
					Sanalona (18)	2.58	3.74	11.18	34.93
					Santa Cruz de Alaya (19)	3.30	3.33	16.33	29.47

such as, for example, 90% to 100% of the crop area in Sinaloa being sown with improved maize [47], and as a result, more area is now planted with irrigated maize than with rainfed maize, also mainly due to the increasing irregularity of rainfall [48].

Frequency (SPI-1) and Evolution (SPI-4) of Meteorological Drought

SPI-1 of the historical period showed only positive anomalies, and the smallest magnitude was registered in El Palmito (SPI-1 = 0.07; see Table 2). Two negative anomalies of SPI-4 were recorded in El Fuerte (SPI-4 = -0.01) and Elota (SPI-4 = -0.01). The historical negative anomalies with the highest values of SPI-1 and SPI-4 were recorded in El Palmito (SPI-1 = -4.15 in 1979), Huites (SPI-1 = -4.15 in 1977) and Choix II (SPI-4 = -4.77 in 1986).

The recent period only showed positive SPI-1 anomalies and the less intense values were recorded at stations Jaina (SPI-1 = 0.15), Acatitan (SPI-1 = 0.16)

and Santa Cruz de Alaya (SPI-1 = 0.16). SPI-4 showed both positive and negative anomalies, and the less intense values were recorded at Mocorito station (SPI-4 = 0.01) and Jaina station (SPI-4 = 0.01). The highest annual anomalies of SPI-1 and SPI-4 were recorded at Acatitan in 1987 (SPI-1 = -2.95 and SPI-4 = -3.13). According to the classification of [49], in this study meteorological droughts (negative anomalies of the SPI-1 and SPI-4) ranged between normal (from 0.49 to -0.49) and extreme (≤ -2.00). Particularly in the El Palmito, Huites, Choix II and Acatitan stations, the municipal governments of Concordia, Choix and San Ignacio, respectively, should continuously monitor for meteorological drought through various indices using total and effective precipitation with different reference periods and time frames [49]. In this way they can determine which index is the most sensitive to dry events in each microregion, and thus avoid significant reductions in the yields of the most important rainfed crops in these municipalities, such as maize, sesame and sorghum [50].

Table 2. SPI-1 and SPI-4 values for historical and recent periods.

Historical period			Recent period		
	Dimensionless			Dimensionless	
Weather station	SPI-1	SPI-4	Weather station	SPI-1	SPI-4
Choix II (1)	0.21	0.01	Acatitan (1)	0.16	0.02
Concordia (2)	0.22	0.02	Badiraguato (2)	0.18	0.00
El Fuerte (3)	0.21	-0.01	Culiacan (3)	0.37	0.07
El Palmito (4)	0.07	0.00	El Playón (4)	0.42	0.09
El Quelite (5)	0.19	0.01	El Quemado (5)	0.26	0.06
Elota (6)	0.18	-0.01	El Varejonal (6)	0.19	0.02
H. de Zaragoza (7)	0.51	0.03	Guasave (7)	0.40	0.07
Huites (8)	0.23	0.00	Guatenipa (8)	0.17	0.01
Los Mochis (9)	0.37	0.02	Ixpalino (9)	0.27	0.04
Pericos (10)	0.23	0.03	Jaina (10)	0.15	0.01
Presa M. Hidalgo (11)	0.21	0.01	La Concha (11)	0.36	0.07
Ruiz Cortines (12)	0.44	0.05	Las Tortugas (12)	0.30	0.04
San Blas (13)	0.27	0.01	Mocorito (13)	0.24	-0.02
			Otatitan (14)	0.41	0.13
			Potrerrillos (15)	0.18	0.03
			Rosario (16)	0.42	0.07
			San Joaquín (17)	0.27	0.02
			Sanalona (18)	0.29	0.03
			Santa Cruz de Alaya (19)	0.16	0.03

Historical Spatial Concurrences and Hypothesis Testing of Hot-Extreme (HE) Indicators and the Frequency (SPI-1) of Meteorological Drought

The El Quelite station showed the highest values of historical concurrences ($F = -0.64$, $AAD = -0.66$, $ADD = -0.65$ and $I = -0.57$; see Fig. 2). The stations with SC in F and ADD were Concordia, El Palmito, El Quelite and Elota; in AAD , Concordia and El Quelite. In I , the stations with SC were Concordia, El Palmito and El Quelite (see Table 1 and Fig. 2). The SCs with F were recorded in El Quelite (-0.65), Elota (-0.36), Concordia (-0.35) and El Palmito (-0.33); to AAD in El Quelite (-0.66) and Concordia (-0.37); with ADD in El Quelite (-0.65), Concordia (-0.34), El Palmito (-0.32) and Elota (-0.258); and with I in El Quelite (-0.57), El Palmito (-0.36) and Concordia (-0.31), see Table 1 and Fig. 2. The mean values were $F = 2.21$, $AAD = 2.27$, $ADD = 10.37$ and $I = 26.23$. Although El Quelite is the station with the highest SCs between HE indicators and SPI-1, the Concordia and El Palmito stations also presented this concurrence in the four HE indicators (F , AAD , ADD and I). This highlights the importance

of establishing urgent measures for early identification of lack of moisture in agricultural soil, which tends to degrade it and reduce the health of the vegetation in southern Sinaloa [51]. A clear example of these urgent measures is the use of oceanic teleconnections such as the indices of El Niño Southern Oscillation, Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation, which on the whole according to [48, 49] are significantly correlated in magnitude and period of occurrence with meteorological droughts [48] and air temperatures [52].

Historical Spatial Concurrences and Hypothesis Testing of Hot-Extreme (HE) Indicators and the Evolution (SPI-4) of Meteorological Drought

SC were recorded in F (-0.32) and ADD (-0.40) at the Higuera de Zaragoza and Los Mochis stations for the historical period (Table 1 and Fig. 3). In summary, SCs in F , AAD , ADD and I were recorded at the El Palmito and El Quelite stations, where SCs in ADD (El Quelite = -0.54) and I (El Palmito = -0.59) were the most significant. These results should be used

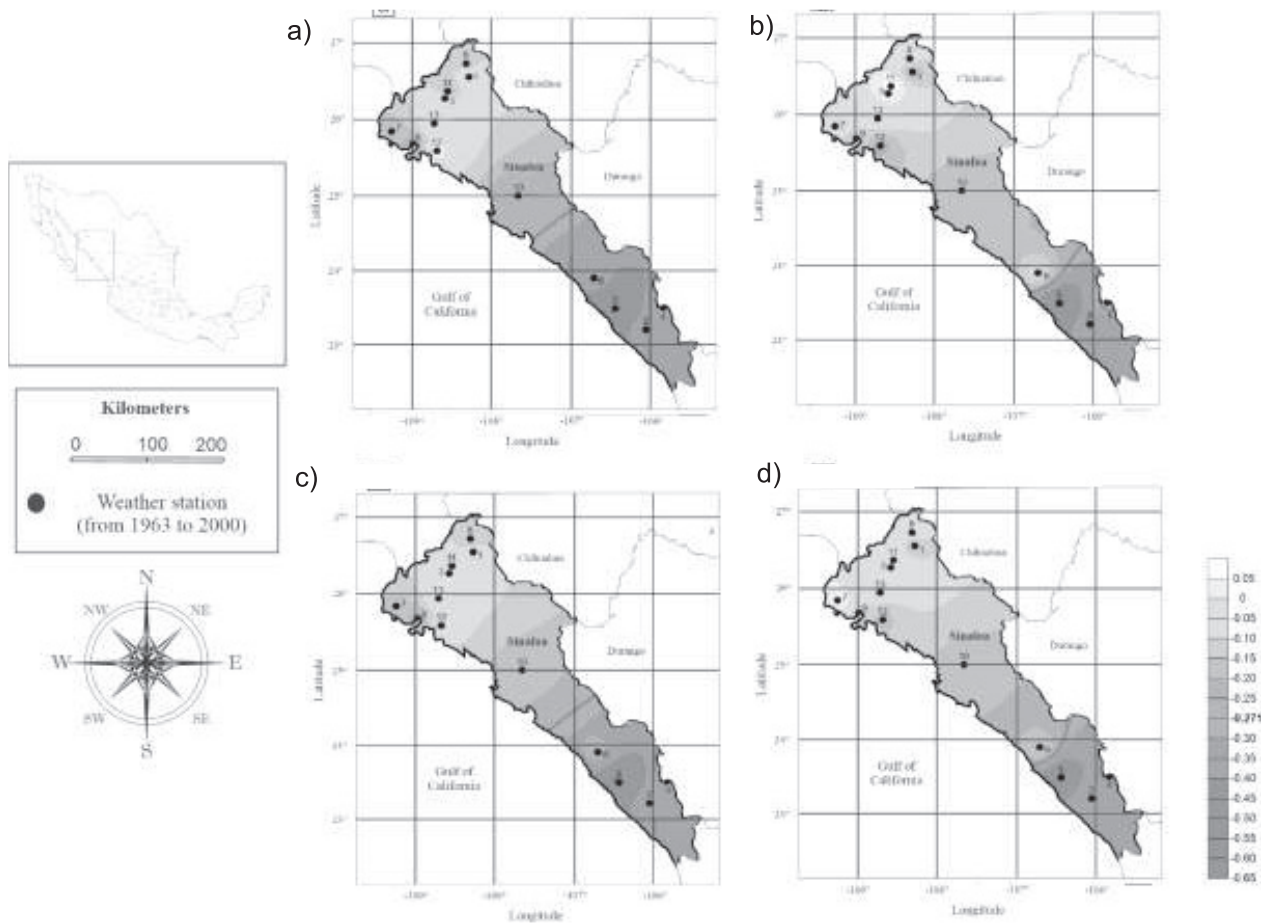


Fig. 2. Historical spatial concurrences and hypothesis testing: a) F vs SPI-1, b) AAD vs SPI-1, c) ADD vs SPI-1 and d) I vs SPI-1. The gray line is the boundary for SC.

to guide policies that would supply the nearby areas (Concordia, El Palmito and El Quelite stations are the zones with most SCs, for the four HE indicators and SPI-4) with more water resources and subsidies, since these actions significantly reduce the harm produced by meteorological drought. Some examples are adapting crops to lower water requirements to improve water and soil conservation, reestablishing the design factors of construction projects aimed at capturing water resources under current conditions of climate change, and generating conditions to regulate the better use and consumption of groundwater to reduce or at least not increase irrigated area, compensating it with crops associated with better commercial and economic production [53-55].

Recent Spatial Concurrences and Hypothesis Testing of Hot-Extreme (HE) Indicators and Frequency (SPI-1) of Meteorological Drought

The stations that showed SC in F for the recent period were Acatitan (-0.38), Guatenipa (-0.33), La Concha (-0.39) and Las Tortugas; in AAD and ADD Acatitan (-0.35), Jaina (-0.41) and La Concha (-0.35); in ADD Acatitan (-0.39), Jaina (-0.33) and La

Concha (-0.39); and in I El Playon (-0.31) and Jaina (-0.33). See Table 2 and Fig. 4. The mean values were $F = -0.20$, $AAD = -0.13$, $ADD = -0.19$ and $I = -0.07$. Stations Acatitan, Jaina and La Concha showed three of the four HE indicators, which indicates that in the area surrounding these stations, the agricultural sector could be at risk. Although the variation in SC is more concentrated for the recent period, 26.32% of the meteorological stations (Acatitan, Guatenipa, Jaina, La Concha and Las Tortugas) presented SCs for which emerging management plans should be prioritized in their respective regions in the face of climate change. These plans should include: 1) creation and development of formal and informal education campaigns focused on water rationing, use, consumption, exploitation, overexploitation and recycling; 2) generation of economic investment in infrastructure for irrigation wells and human consumption, and design for water storage in places where precipitation has increased substantially due to climate change in recent years; and 3) development of new alternative technologies for agricultural production such as hydroponics, greenhouses, and vegetables in controlled climates [53-56].

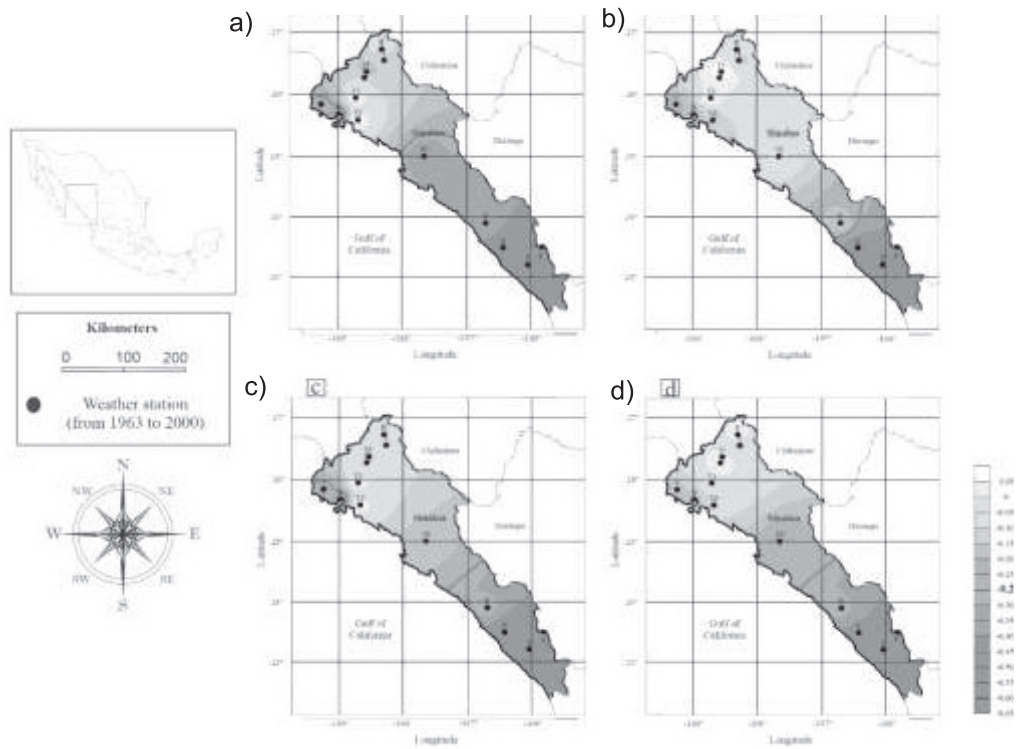


Fig. 3. Historical spatial concurrences and hypothesis testing: a) F vs SPI-4, b) AAD vs SPI-4 and d) I vs SPI-4. The gray line is the boundary for SC.

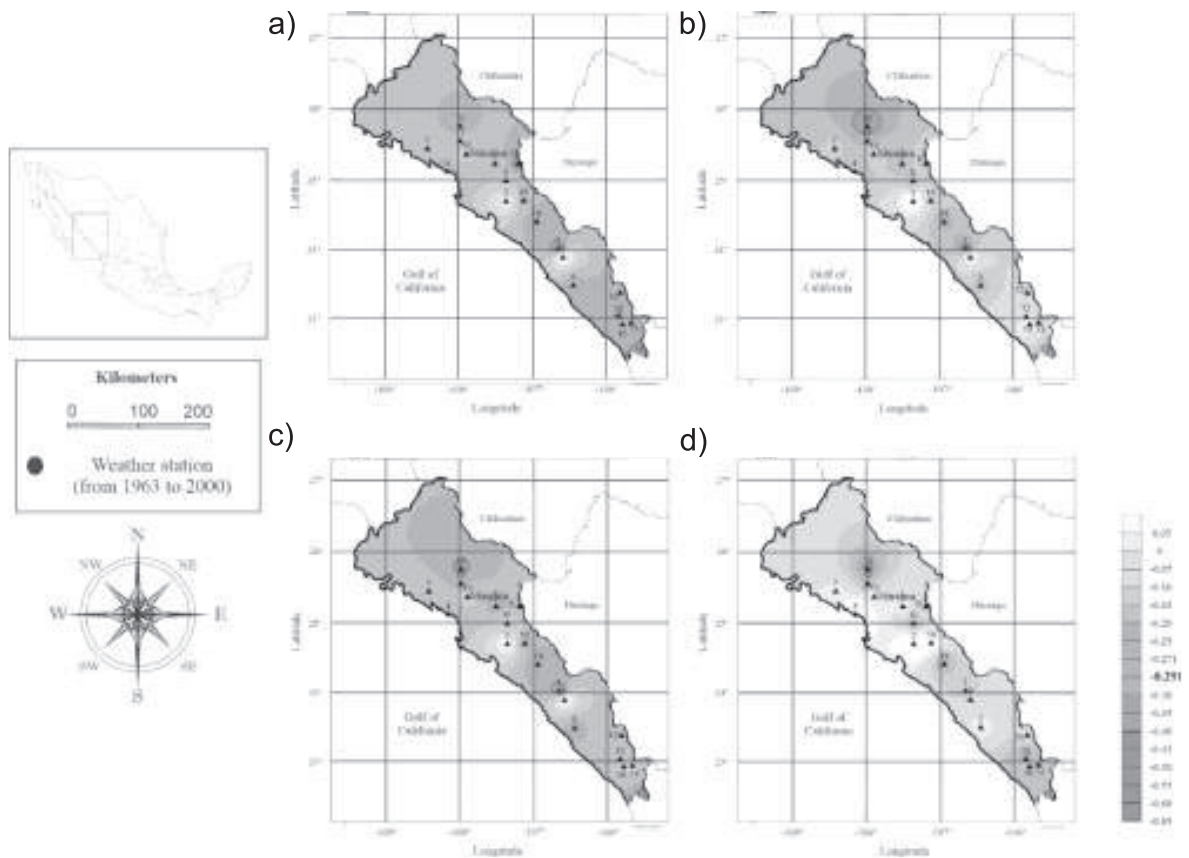


Fig. 4. Recent spatial concurrences and hypothesis testing: a) F vs SPI-1, b) AAD vs SPI-1, c) ADD vs SPI-1 and d) I vs SPI-1. The gray line is the boundary for SC.

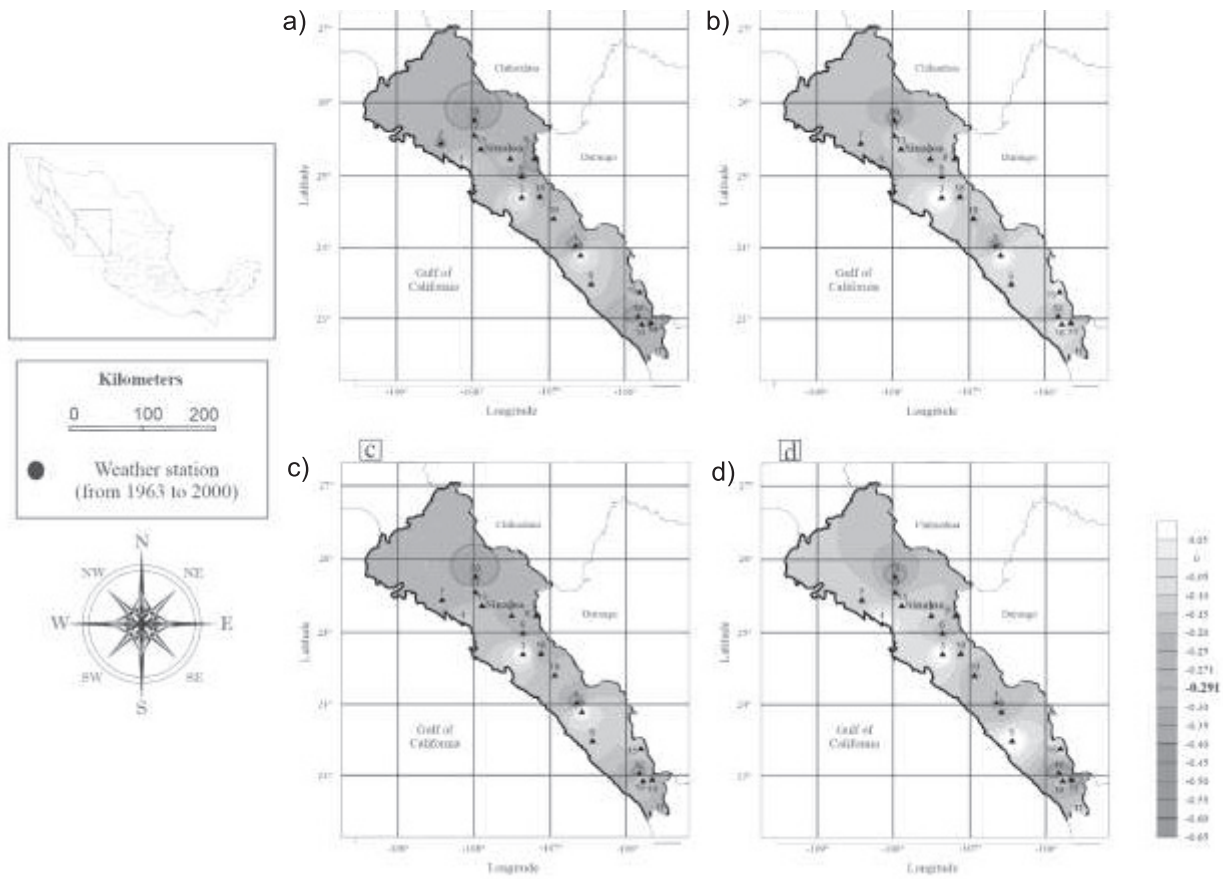


Fig. 5. Recent spatial concurrences and hypothesis testing: a) F vs SPI-4, b) AAD vs SPI-4, c) ADD vs SPI-4 and d) I vs SPI-4. The gray line is the boundary for SC.

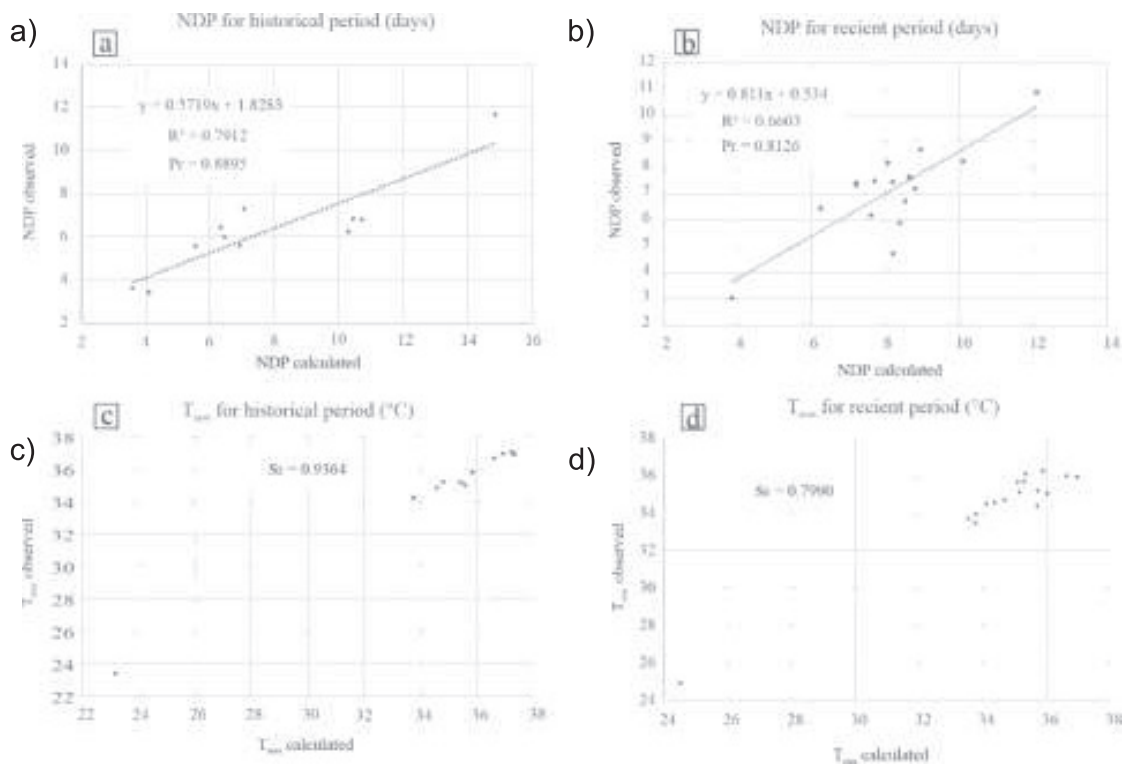


Fig. 6. Correlation coefficients between calculated and observed values of: a-b) NDP for the historical and recent periods, respectively (data with normality) and c-d) T_{max} for the historical and recent periods, respectively (data with non-normality).

Recent Spatial Concurrences and Hypothesis Testing of Hot-Extreme (HE) Indicators and Evolution (SPI-4) of Meteorological Drought

SCs in F for the recent period were recorded at stations Acatitan (−0.40), El Varejonal (−0.30), Guasave (−0.30), Guatenipa (−0.41), Jaina (−0.47), Las Tortugas (−0.40) and Otatitan (−0.34); in AAD for Acatitan (−0.36), Jaina (−0.34) and Las Tortugas (−0.31); in ADD for Acatitan (−0.40), Jaina (−0.47), Las Tortugas (−0.37) and Sanalona (−0.30); and in I for Jaina (−0.39), Las Tortugas (−0.44) and Otatitán (−0.36). See Table 2 and Fig. 5. The mean values were $F = -0.22$, $AAD = -0.12$, $ADD = -0.20$ and $I = -0.14$. The Jaina weather station is the only one with SCs in the four indicators of HEs. Indicator F showed the highest number of SCs (in seven meteorological stations; 36.84%), which shows that government authorities must provide farmers and anyone affected with the skills and knowledge required to be able to adapt to the effects of regional climate change [57], particularly at Jaina station, where the affected area is much larger than around the other six stations that presented SCs, which could be due to the microscale variability of Sinaloa which was indicated by [37]. This is a factor that should always be examined when studying climate indicators of precipitation and temperature [58].

Data Validation

After a normality test of observed and calculated NDP for the historical and recent periods, the following results were obtained: $W = 0.9214$, $p(\text{normal}) = 0.3308$; $W = 0.8574$, $p(\text{normal}) = 0.0533$; $W = 0.9059$, $p(\text{normal}) = 0.0855$ and $W = 0.9315$, $p(\text{normal}) = 0.2306$, respectively. The Tmax data did not show normality since the results were the following: $W = 0.6183$, $p(\text{normal}) = 4.296 \times 10^{-5}$; $W = 0.5806$, $p(\text{normal}) = 1.462 \times 10^{-5}$; $W = 0.6115$, $p(\text{normal}) = 1.348 \times 10^{-5}$ and $W = 0.5742$, $p(\text{normal}) = 5.915 \times 10^{-6}$, respectively. The NDP for the historical and recent periods showed $Pr = 0.8895$ and $Pr = 0.8126$, respectively (Fig. 6a-6b). Tmax showed $Sr = 0.9364$ and $Sr = 0.7990$ for the historical and recent period, respectively (Fig. 6c-6d).

Conclusions

In general, the historical period showed a higher number of SCs in the frequency and evolution of drought events (SPI-1 = 13 events and SPI-4 = 20 events), which can be attributed to the longer duration of the historical period (5 years longer). The weather stations El Palmito and El Quelite showed the most SCs; at these stations higher magnitudes were found in intensity (I, up to −0.59). In all stations, the annual average, annual minimum and annual maximum values were: for SPI-1 in the historical period were 0.26, 0.07

and 0.51, respectively; for the SPI-4 for the historical period were 0.01, −0.01 and 0.05, respectively; for the SPI-1 for the recent period were 0.27, 0.15 and 0.42, respectively and for the SPI-4 for the recent period were 0.04, −0.02 and 0.09, respectively. The highest historical SCs of SPI-1 were found at El Quelite station. In SPI-1 of the historical period, F showed the most SCs (4 stations), which means that the local government in Sinaloa should take actions to characterize and preserve water resources, such as: 1) creation and development of formal and informal education campaigns focused on water rationing, use, consumption, exploitation, overexploitation and recycling; and 2) generation of economic investment in infrastructure for irrigation wells and human consumption, and designs for storage in places where precipitation has increased substantially due to climate change in recent years. In the recent period, Jaina station was the only one with SCs between SPI-4 and the four HE indicators, which means that reductions in crop yield may occur. For this reason, urgent measures should be taken in the area surrounding this station, such as shifting the planting time, especially of rainfed crops such as maize, sesame and sorghum, and propose development of new alternative technologies for agricultural production such as hydroponics, greenhouses, vegetables for controlled climates and changing to crops with greater commercial value and economic production. After SPI-4 of the recent period was analyzed, F showed SCs in a higher number of stations (7 stations), which can be helpful for a reliable understanding of the phenomenon of meteorological drought evolution in Sinaloa. The most important HE's and those that were most significantly correlated with meteorological droughts were F, ADD and I for the historical period. These HE's were useful to identify the most vulnerable stations (Concordia, El Palmito, El Quelite and Elota) to the frequency and evolution (historical period) of meteorological droughts. This study gives new knowledge about the concurrency between HE indicators and SPI-1 and SPI-4, which could be the basis for the local government to make specific plans to avoid risk and damage to the agricultural sector, on which a large part of the local and national population depends economically, and for food supply, which depends principally on agroclimatology at the microscale, which is very variable.

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Conflict of Interest

The authors declare no conflict of interest.

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