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Original Research

Seasonal Trend Indicators and Return Periods of Meteorological Drought in the Northern States of Mexico

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Abstract

Meteorological drought is an atmospheric condition characterized by a deficiency in the amount of precipitation and increased evapotranspiration. We calculated the magnitudes of average annual seasonal trends (June to September) of the following drought indicators for 1970-2011: average temperature (T_{avg}), precipitation (*Prec*), potential evapotranspiration (*PET*), standardized precipitation evapotranspiration index (*SPEI*) on a 24-month scale (*SPEI-24*), and return periods (*RP*) of drought (*SPEI-24*). The indicators were calculated from records of daily T_{avg} and *Prec* obtained from 38 CONAGUA (National Water Commission) weather stations located in the northern states of Sinaloa, Baja California Sur, Durango, Chihuahua, and Sonora. *PET* was calculated by the method of Thornthwaite; drought was calculated by the expression for *SPEI-24* based on the calculation of deciles 1, 2, 3, 7, 8, and 9 of *Prec*; and the *RP* of *SPEI-24* were calculated using the probability distribution function of Gumbel on time scales from 2 to 500 years. The nonparametric Mann-Kendall test was applied. The magnitude of change in the trends was estimated by Sen's method for slopes. *SPEI-24* showed positive and negative trends (-0.066 to 0.082). The results have predicted that there will be severe droughts in 2021 and 2036 in the states of Baja California Sur and Sinaloa.

Keywords: *SPEI-24,* precipitation deciles, return periods

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Introduction

Climate change will lead to changes in regimes on cumulative annual average seasonal precipitation (*Prec*) and evapotranspiration [1], as well as increases in the intensity and number of hurricanes and droughts [2]. [2] collected more than 150 definitions of drought, categorizing them into four main groups: hydrological drought, agricultural drought, socioeconomic drought, and meteorological drought. Meteorological drought is an atmospheric condition characterized by a deficiency in the amount of *Prec* and an increase in evapotranspiration. It is normally defined over a region but can manifest as changes in the environment at the local level, causing considerable economic and environmental losses, particularly in regions where most economic activities such as agriculture and aquaculture, among others, are scheduled according to the season [3-9]. Significant trends (*ST*) in seasonal annual average air temperature (T_{avg}) and *Prec* can cause *ST* in the seasonal annual average potential evapotranspiration (*PET*), and therefore also in the drought of a region [7, 8, 10]. There are various indices that can reliably be used to calculate the meteorological drought of a region. The average annual standardized precipitation

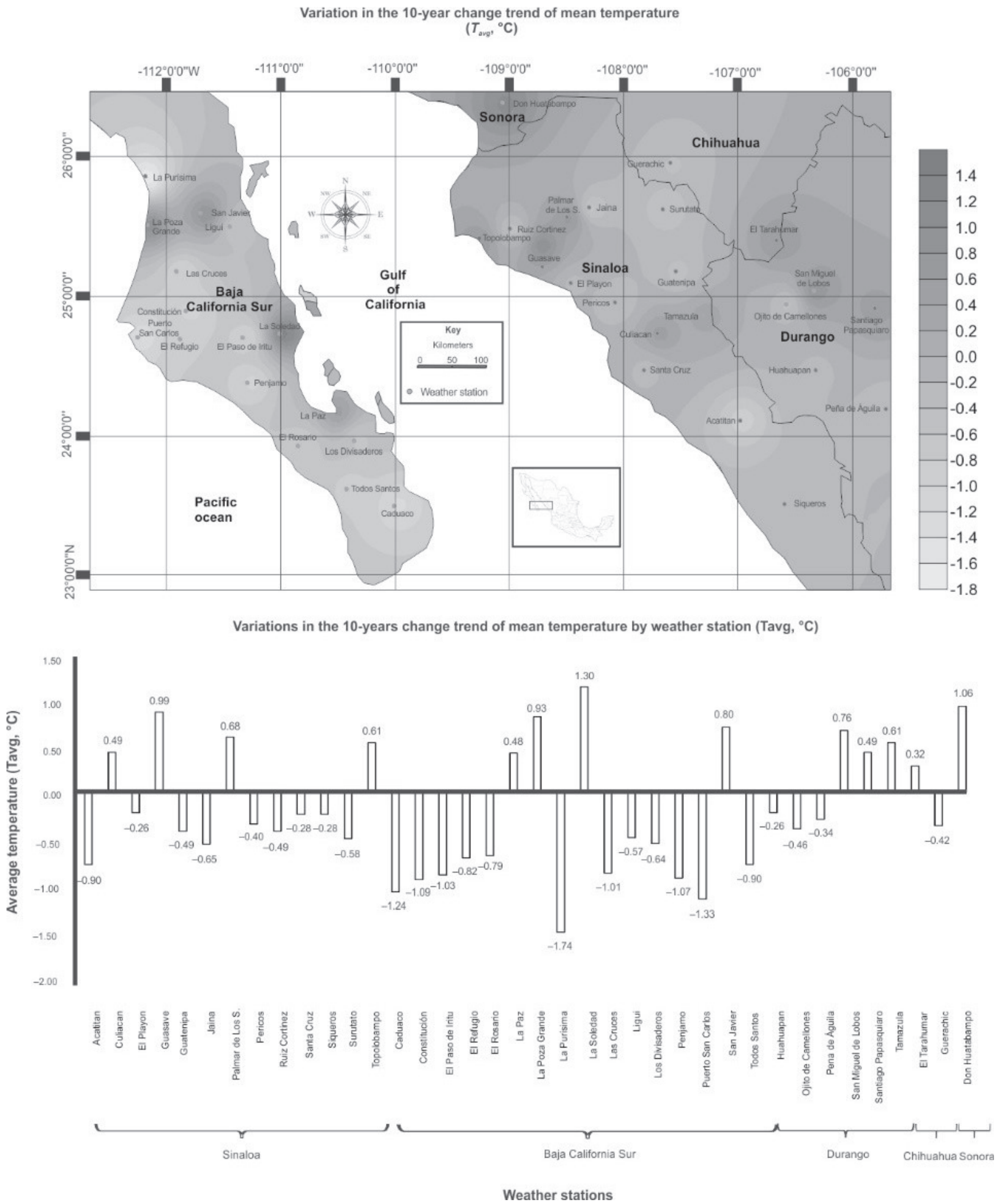


Fig. 1. Magnitude of change trends in T_{avg} in states in northern Mexico (ºC decade^{-1}).

evapotranspiration index (*SPEI*) is the only methodology that jointly takes these two indicators (temperature and precipitation) into account [7-9]. [11] found that for greater fidelity, it is advisable to estimate drought on a 24-month scale, mainly because this has been shown to be a suitable timescale to capture low-frequency variability. Drought events that have occurred in regions with arid and semi-arid climates, such as West Africa [12], northeastern Brazil [13], and North America [10] have caused the greatest natural disasters associated with these events, including frosts, increased arid areas, decreased soil organic matter, and decreased crop yields, among others, leading to hunger, poverty, and unemployment [14]. The occurrence of these events has been reported by the agricultural industry of northern Mexico in the states of Sinaloa (SIN), Baja California Sur (BCS), Durango (DGO), Chihuahua (CHIH), and Sonora (SON) [15-16]. In northern Mexico, seasonal summer rains (June to September) account for about 60% of the cumulative annual average *Prec* (P_a), and the highest temperatures in the year usually fall in summer. [1] has estimated projections for the year 2100, in which T_{avg} could reach values above 2ºC.

To accurately analyze T_{avg}, an *ST* can be divided into positive trends (*PT*) and negative trends (*NT*); where a *PT* indicates an increase in T_{avg} and an *NT* indicates a decrease [17-18]. For example, a *PT* of T_{avg} indicates warming of a region and an *NT* indicates cooling. In northern Mexico, despite the existence of climate models on global and regional scales, which can be an important resource for decision makers taking action to counter the effects of climate change, this information is unrepresentative and therefore unsuitable for timely decision making [18]. Because of the lack of regional data on this important issue, the present study was designed to calculate seasonal estimates (June to September) of the magnitude of average annual trends of the following drought indicators: T_{avg}, *Prec*, *PET*, *SPEI-24*, and return periods (*RP*) of drought (*SPEI-24*). To do so, T_{avg} and *Prec* were calculated using daily data from 38 CONAGUA weather stations from the period 1970-2011. These stations were located in the states of SIN, BCS, DGO, CHIH, and SON. For each station, the *SPEI-24* index and the annual averages of *PET* were calculated using the methods of [7] and [19]. To identify *ST* at a confidence level of 95% ($\alpha = 0.05$) and to generate hypotheses regarding the threats associated with climate change on production systems of the states in the study, the nonparametric Mann-Kendall test was applied to each variable [20]. The magnitude of changes in each variable was calculated using Sen's slope estimator [21]. Representative spatial maps of the variation of the seasonal trend of each variable were constructed using the inverse distance weighting (*IDW*) interpolation method. According to [22], drought is categorized based on knowledge of deciles 1, 2, 3, 7, 8, and 9 (percentiles 10, 20, 30, 70, 80, and 90) of the daily precipitation and variation of *SPEI-24* at each weather station. *RP* of *SPEI-24* were calculated for the study states in northern Mexico on time scales of 2, 5, 10, 25, 50, 100, 200, and 500 years according to the Gumbel probability function distribution [23] and the drought classification scale. It was considered important to measure drought in these states because of their economic role in Mexico.

The Guasave Valley in SIN is the most important agricultural region of Mexico, commonly called the "agricultural heart of Mexico." Protecting this valley is vital to ensuring the food sovereignty of the country [24, 25]. SIN and BCS are distinguished worldwide for their many tourist destinations, including Mazatlán, La Paz, Cabo San Lucas, and San José del Cabo, among others [26], which are sources of foreign exchange and employment. BCS and SIN, because of their climate and environmental richness, are the first and second states respectively with the most Ramsar wetlands in Mexico. DGO contains 12 wetlands of national importance. In the other states in the study, the weather stations have higher elevations (*E*), which means that there are different thermal floors, and multiple agricultural, forestry, and drought problems. CHIH was selected due to its forest wealth, and the high risk of occurrence of drought. SON was selected because of its species richness of flora and fauna, and its agricultural importance in Mexico [27]. Given the issues raised, the goal of this work was to calculate the summer seasonal trend (June-September) and the *RP* of *SPEI-24* for 2, 5, 10, 25, 50, 100, 100, 200, and 500 years in states in northern Mexico.

Material and Methods

Study Area and Data Series

T_{avg} and *Prec* were calculated using daily summer data (June-September) collected from 38 CONAGUA (National Water Commission) weather stations in the study states for the period 1970-2011. Most of the time series had continuity issues such as missing data or outliers, so the data were visually inspected, comparing the values from each station with the values from neighboring stations (≤25 km). The reason for the particular time period and

Table 1 Categorization of seasonal drought according to *SPEI-24* and deciles 1, 2, 3, 7, 8 and 9 of *Prec*.

Category	*SPEI-24*	*Decile*
Extreme drought	$SPEI\text{-}24 \leq -1.5$	$Prec \leq P_{10}$
Severe drought	$-1.5 < SPEI\text{-}24 \leq -1.0$	$P_{10} < Prec \leq P_{20}$
Moderate drought	$-1.0 < SPEI\text{-}24 \leq -0.5$	$P_{20} < Prec \leq P_{30}$
Normal	$-0.5 < SPEI\text{-}24 < 0.5$	$P_{30} < Prec \leq P_{70}$
Moderately wet	$0.5 \leq SPEI\text{-}24 < 1.0$	$P_{70} < Prec \leq P_{80}$
Severely wet	$1.0 \leq SPEI\text{-}24 < 1.5$	$P_{80} < Prec \leq P_{90}$
Extremely wet	$SPEI\text{-}24 \geq 1.5$	$Prec > P_{90}$

Table 2. Detection of ST of drought indicators, applying the Mann-Kendall statistic.

Location				Standardized Z (Z_{std}) with $\alpha = 0.05$. threshold. $Z = \geq /1.96/$ (dimensionless)			
State	Weather station	*E* (masl)	P_a (mm·yr^{-1})	T_{avg}	*Prec*	*PET*	*SPEI-24*
Sinaloa	Acatitan	130	627	**3.38**	1.79	**-3.45**	**3.70**
	Culiacan	40	569	0.18	-0.11	0.34	**3.89**
	El Playon	5	345	**-4.07**	**-3.56**	**-4.28**	**-4.13**
	Guasave	40	341	-0.01	0.62	-1.17	**3.44**
	Guatenipa	18	801	**-5.28**	0.87	**-5.28**	**3.46**
	Jaina	200	703	**-5.33**	0.54	**-5.41**	**2.18**
	Palmar de Los S.	21	489	0.70	-0.91	-0.33	-1.41
	Pericos	11	507	**-2.72**	**2.65**	**-2.70**	**1.98**
	Ruiz Cortinez	15	261	**-4.17**	1.72	**-4.32**	**3.70**
	Santa Cruz	2050	590	**-4.18**	0.96	**-4.23**	**2.40**
	Siqueros	12	537	**-2.75**	1.32	**-2.67**	**-3.44**
	Surutato	1400	765	-0.81	**2.12**	-1.35	**2.16**
	Topolobampo	34	221	**2.55**	0.25	**3.38**	1.86
Baja California Sur	Caduaco	206	333	-1.05	**4.06**	-1.02	1.61
	Constitución	47	101	-1.39	-0.5	-1.31	**-1.96**
	El Paso de Iritu	135	134	-1.04	1.84	-1.14	**-2.02**
	El Refugio	23	40	-1.39	**2.32**	-1.31	**-2.63**
	El Rosario	45	71	**-3.31**	-0.52	**-3.25**	**-4.67**
	La Paz	16	115	0.35	0.78	0.29	**-3.44**
	La Poza Grande	25	24	0.54	0.69	0.44	**-4.19**
	La Purísima	95	57	-1.58	0.41	-1.57	**2.12**
	La Soledad	412	187	0.42	1.25	0.70	**-2.76**
	Las Cruces	40	72	-0.83	0.87	0.90	-1.86
	Ligui	10	143	**-2.05**	1.67	-1.41	**2.46**
	Los Divisaderos	502	316	-0.87	1.69	0.87	**-2.52**
	Penjamo	24	75	-0.45	-0.88	-0.44	**-3.55**
	Puerto San Carlos	10	32	**-3.73**	1.12	**-4.16**	**-2.40**
	San Javier	440	206	1.40	0.90	1.38	**1.98**
	Todos Santos	75	104	**-5.97**	1.13	**-5.83**	1.72
Durango	Huahuapan	1150	608	**-1.97**	0.19	**-2.69**	1.31
	Ojito de Camellones	15	1039	-1.14	**2.34**	-1.16	0.08
	Pena de Águila	1896	438	**-5.13**	0.70	**-5.18**	**2.31**
	San Miguel de Lobos	2300	605	**2.50**	-0.88	**2.49**	**2.12**
	Santiago Papasquiaro	1716	418	**2.80**	**4.17**	**2.76**	0.86
	Tamazula	1580	778	1.17	0.65	1.16	1.94
Chihuahua	El Tarahumar	2435	617	1.24	-0.11	1.23	0.90
	Guerachic	780	125	-0.18	1.69	-0.61	**2.16**
Sonora	Don Huatabampo	50	325	2.00	-1.42	1.15	**2.67**

E = elevation. P_a = cumulative annual average of precipitation. T_{avg} = average seasonal temperature. *Prec* = cumulative annual average seasonal precipitation. *PET* = seasonal potencial evapotranspiration. *SPEI-24* = Standardized Precipitation Evapotranspiratoion Index. Bold = significant trend indicators weather stations chosen for this study was that only these 38 stations out of a total of 56 met the requirement of a minimum percentage of daily data (≥95%) used for calculating T_{avg} and *Prec*. Of the 38 stations, 13 are located in SIN (population 2,767,761), 16 in BCS (637,026), 6 in DGO (1,632,934), 2 in CHIH (3,406,465), and 1 in SON (2,662,480) [28]. The range of *E* among the stations by state was 5 to 2,050 masl for SIN, 10 to 502 masl for BCS, 15 to 2,300 masl for DGO, 780 to 2,435 masl for CHIH, and 50 masl for the single station in SON. With the exception of DGO, the states in the study border mountainous zones (Sierra Madre Occidental) and the Gulf of California [29] (Fig. 1).

Identification and Quantification of *ST*

To detect, estimate, and quantify the trends in the time series of average annual T_{avg}, *Prec*, *PET*, and *SPEI-24*,

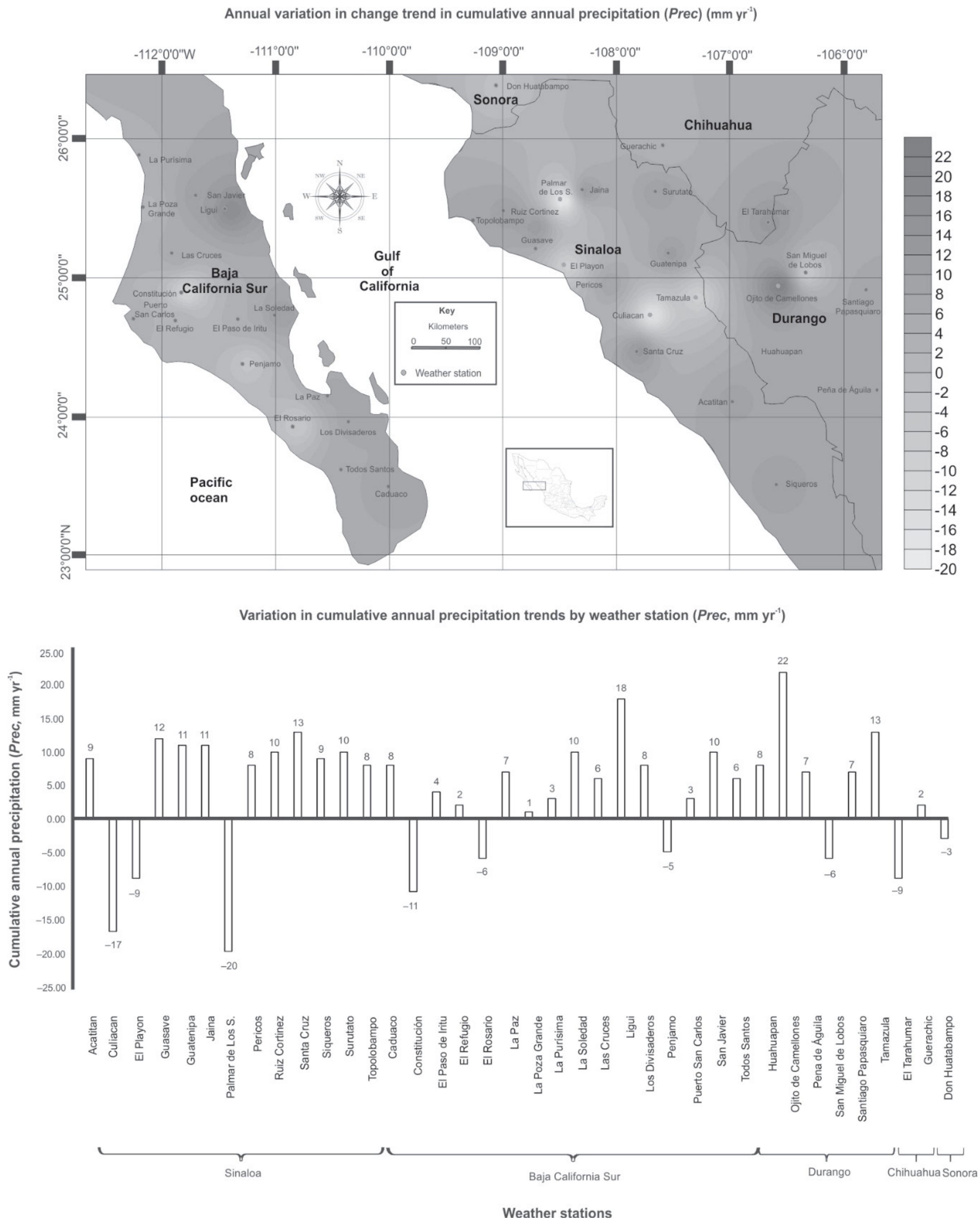


Fig. 2. Magnitude of change trends in *Prec* in states in northern Mexico (mm yr^{-1}).

we used the non-parametric methods of Mann-Kendall [20] and Sen's slope estimate [21]. These methods have been effective for detecting, estimating, and quantifying annual averages in trends in atmospheric data, drinking water quality, agricultural irrigation, and concentration of pollutants in the atmosphere, among others [20, 30]. According to [31], for correct analysis of *ST* in time series of thermopluviographic data, the data must be continuous (≥30 years). The CONAGUA time series data used in this study meet this condition. In order to detect *ST*, the Mann-Kendall test [20, 32-33] was applied. The statistical threshold (Z_{std}) for a 95% confidence interval was ≥ I1.96I. The null hypothesis was rejected at the $\alpha = 0.05$ level of significance. A positive value of Z_{std} indicated a *PT* and a negative value indicated an *NT* in the data [34]. The magnitude of each trend was estimated using Sen's slope estimator [18] from among the possible slopes that can be calculated for a time series [31, 35].

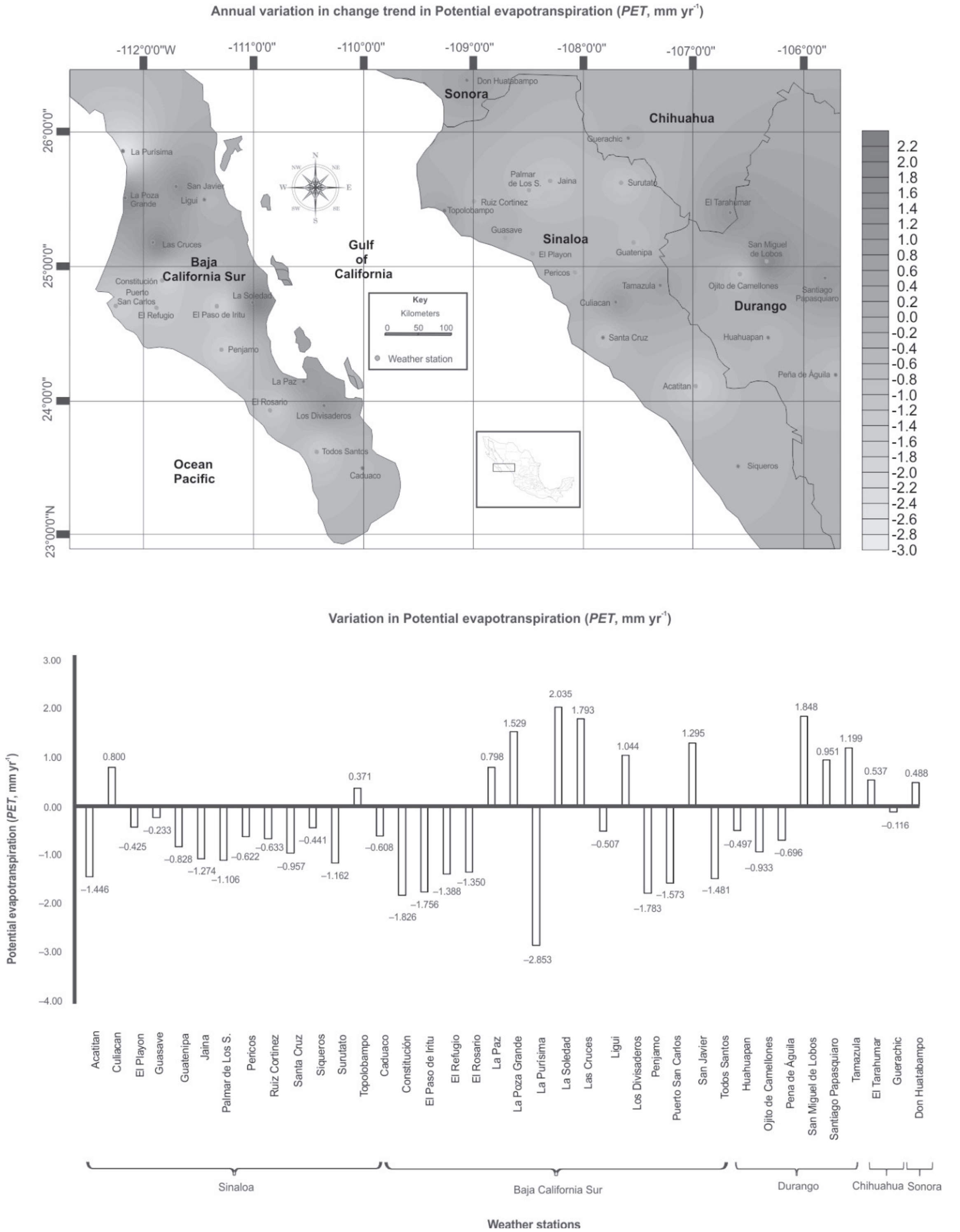


Fig. 3. Magnitude of change trends in *PET* in states in northern Mexico (mm yr^{-1}).

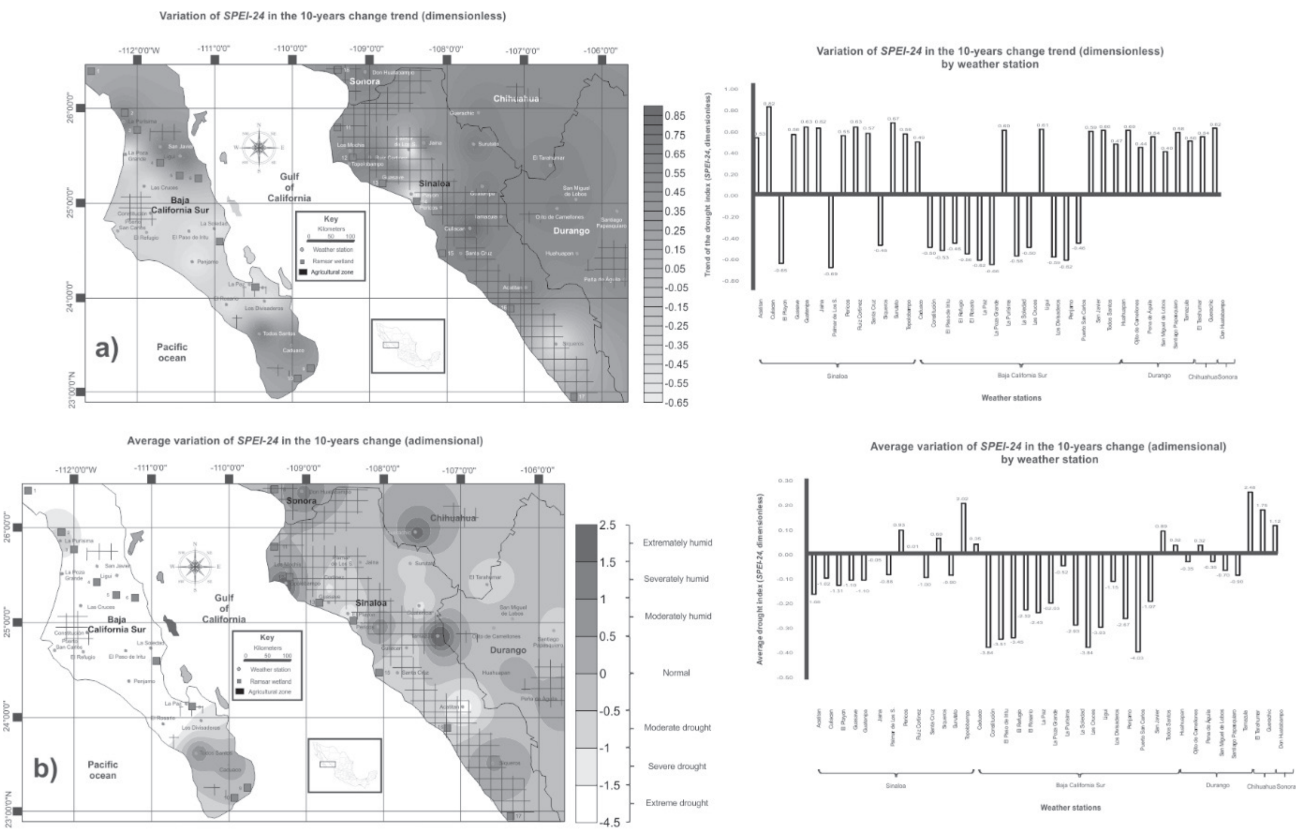
Table 3 Quantification of magnitude of change of ST of drought indicators, using Sen's slope estimator.

Location		Magnitude of change trend indicator			
State	Weather station	T_{avg} (ºC·yr^{-1})	*Prec* (mm·yr^{-1})	*PET* (mm·yr^{-1})	*SPEI-24* (Dimensionless)
Sinaloa	Acatitan	**-0,090**	9	**-1,446**	**0,053**
	Culiacan	0,049	-17	0,800	**0,082**
	El Playon	**-0,026**	**-9**	**-0,425**	**-0,065**
	Guasave	0,099	12	-0,233	**0,056**
	Guatenipa	**-0,049**	11	**-0,828**	**0,063**
	Jaina	**-0,065**	11	**-1,074**	**0,062**
	Palmar de Los S.	0,068	-20	-1,106	-0,069
	Pericos	**-0,040**	8	**-0,622**	**0,055**
	Ruiz Cortinez	**-0,049**	10	**-0,663**	**0,063**
	Santa Cruz	**-0,059**	13	**-0,957**	**0,057**
	Siqueros	**-0,028**	9	**-0,441**	**-0,048**
	Surutato	-0,058	10	-1,162	**0,067**
	Topolobampo	**0,061**	8	**0,371**	0,056
Baja California Sur	Caduaco	-0,124	**8**	-0,608	0,049
	Constitución	-0,109	-11	-1,826	**-0,050**
	El Paso de Iritu	-0,103	4	-1,756	**-0,053**
	El Refugio	-0,082	**2**	-1,388	**-0,046**
	El Rosario	**-0,079**	-6	**-1,350**	**-0,056**
	La Paz	0,048	7	0,798	**-0,062**
	La Poza Grande	0,093	1	1,529	**-0,066**
	La Purísima	-0,174	3	-2,853	**0,060**
	La Soledad	0,130	10	2,035	**-0,058**
	Las Cruces	-0,101	6	1,793	-0,050
	Ligui	**-0,057**	18	-0,507	**0,061**
	Los Divisaderos	-0,064	8	1,044	**-0,059**
	Penjamo	-0,107	-5	-1,783	**-0,062**
	Puerto San Carlos	**-0,133**	3	**-1,573**	**-0,046**
	San Javier	0,080	10	1,295	**0,059**
	Todos Santos	**-0,090**	6	**-1,481**	0,060
Durango	Huahuapan	**-0,026**	8	**-0,497**	0,047
	Ojito de Camellones	-0,046	**22**	–0.933	0,060
	Pena de Águila	**-0,034**	7	**-0,696**	**0,044**
	San Miguel de Lobos	**0,076**	-6	**1,848**	**0,054**
	Santiago Papasquiaro	**0,049**	**7**	**0,951**	0,040
	Tamazula	0,061	13	1,199	0,058
Chihuahua	El Tarahumar	0,032	-9	0,537	0,050
	Guerachic	-0,042	2	-0,116	**0,054**
Sonora	Don Huatabampo	**0,106**	-3	0,488	**0,062**

T_{avg} = average seasonal temperature, *Prec* = cumulative annual average seasonal precipitation, *PET* = seasonal potencial evapotranspiration, *SPEI-24* = Standardized Precipitation Evapotranspiratoion Index, *Bold* = significant trend indicators

Table 4. Time scales of RP of seasonal drought associated with deciles 1, 2, 3, 7, 8 and 9 of Prec in northern Mexico.

Return periods (years)	Probability (dimensionless)	State	P_{10}	P_{20}	P_{30}	P_{70}	P_{80}	P_{90}
2	0.5	Sinaloa	0.93	1.78	2.95	15.50	23.38	32.63
5	0.8	Baja California Sur	1.33	2.55	3.75	15.75	24.26	41.48
10	0.9	Durango	1.80	2.00	3.14	9.46	12.00	19.34
25	0.96	Chihuahua	0.84	1.40	2.30	9.78	14.60	19.48
50	0.98	Sonora	0.50	1.50	2.50	20.00	26.00	52.00
100	0,99							
200	0,995							
500	0,998							



c)

Ramsar wetlands

State	Name	Number on map	Ramsar number
Baja California Sur	Laguna Ojo de Liebre	1	1339
	Laguna de San Ignacio	2	1341
	La Sierra de Guadalupe	3	1815
	Los Comondú	4	1761
	Oasis Sierra de la Giganta	5	1793
	Parque Nacional Bahia de Loreto	6	1358
	Oasis de La Sierra El Pilar	7	1794
	Humedales El Mogote-Ensenada La Paz	8	1816
	Parque Nacional Cabo Pulmo	9	1778
	Sistema Ripario de la Cuenca y Estero de San José del Cabo	10	1827
Sinaloa	Sistema Lagunar Agiabampo - Bacrehuis - Río Fuerte Antiguo	11	1797
	Lagunas de Santa María Topolobampo-Ohuira	12	2025
	Sistema Lagunar San Ignacio Navachiste-Macapule	13	1826
	Ensenada de Pabellones	14	1760
	Laguna Huizache-Caimanero	15	1689
	Laguna Playa Colorada - Santa María La Reforma	16	1327
	Sistema Lagunar Ceuta	17	1824
Sonora	Complejo Lagunar Bahia Guásimas - Estero Lobos	18	1790

Fig. 4. Seasonal variation of *SPEI-24*: a) variation in the 10-year change trend (dimensionless), b) average variation in 10-year change (dimensionless), and c) Ramsar wetlands in northern Mexico.

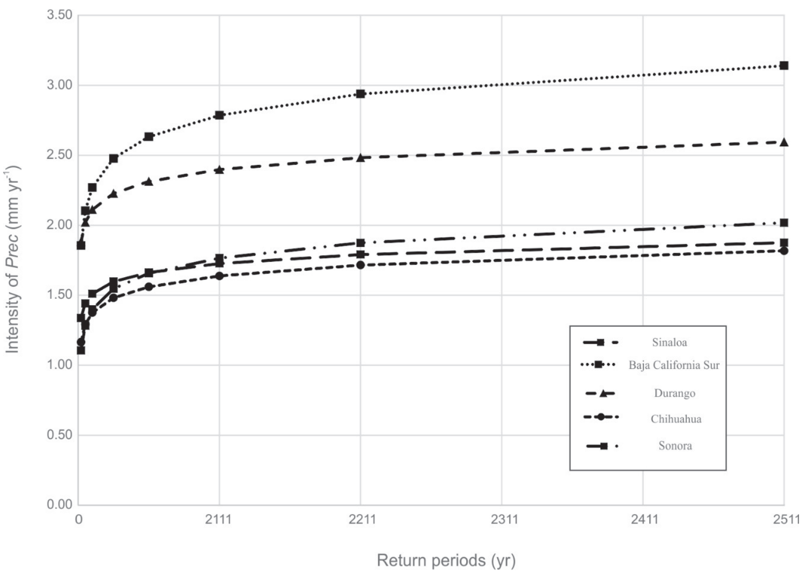


Fig. 5. Intensity of *RP* of droughts in northern Mexico, using time scales of 2, 5, 10, 25, 50, 100, 200 and 500 years.

Calculation of *PET* and the *SPEI-24* Index

To obtain *SPEI*-24 and *PET*, the expression of Serrano [7] and the relationship of Thornthwaite [19], respectively, were applied. The expression for *SPEI-24* calculates drought based on the variation of *Prec* and *PET*. From daily T_{avg} and *Prec* data, monthly and annual time series were constructed for T_{avg}, *Prec*, *PET*, and *SPEI-24*; and the annual series was used to calculate the averages of T_{avg}, *Prec*, *PET*, and *SPEI-24* and the cumulative annual average value for *Prec* (P_a). To classify seasonal drought in northern Mexico we applied the categorization of [22], which relates the variation of *SPEI-24* to deciles 1, 2, 3, 7, 8, and 9 of *Prec* (Table 1, Fig. 3).

Generating Trend Maps

The *IDW* method included in the Surfer 10.0 software was used to interpolate the seasonal magnitudes of *ST* for each weather station. This deterministic interpolation method is one of the most common methods for constructing maps containing spatial information of climate indicators [36]. However, the *IDW* has the disadvantage that it tends to generate closed surfaces around the data when the power coefficient (*P*) is small. To avoid this, in this paper the criterion of [18] for a coefficient of $P = 2$ was used to generate continuous smooth surfaces. The results of the *IDW* interpolation were applied to the urban trace drawn using CorelDRAW X7 (Fig. 1). To visualize important spatial changes in the interpolation maps, the magnitudes of annual spatial variation of *ST* in T_{avg} and *SPEI-24* were multiplied by 10 in order to convert magnitudes of spatial variation of *ST* to a decadal time scale.

Return Periods of Droughts

By means of the seasonal deciles 1, 2, 3, 7, 8, and 9 of *Prec* and the probability distribution function of Gumbel, the *RP* of droughts were calculated for each state in the study on 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year time scales (Tables 1, 4, Fig. 5). According to [23, 37], the Gumbel probability distribution function is the distribution most recommended for frequency analysis against extreme values because of its high statistical reliability in hydrology [38].

Statistical Analysis

Spearman correlation coefficients (*Sr*) were calculated between the trend groups of T_{avg} and *Prec* (T_{avgcal} and $Prec_{avgcal}$) obtained from CONAGUA weather stations, and the data obtained from weather stations (T_{avgobs} and $Prec_{avgobs}$) for 1970-2011 [39]. This method was used because it is the most common method for non-normal data [40]. Before calculating *Sr*, the Shapiro-Wilk normality test was applied to the four groups in the data series. This test statistic was employed mainly because it shows good power for small *n* (n<50) [41]. The PAleontological STatistics (PAST) program (v. 3.14) [42] and Microsoft Excel version 2013 were used for all data processing and calculation of test statistics.

Results and Discussion

Table 2 shows the spatial variation in *ST* of T_{avg}, *Prec*, *PET*, and *SPEI-24*, according to the Mann-Kendall statistic ($\alpha = 0.05$). *ST* for T_{avg} was observed at 18 stations (four with *PT* and 14 with *NT*). The stations with the largest *NT* were Puerto San Carlos (-0.133ºC yr^{-1}) and El Rosario (-0.079ºC yr^{-1}) in BCS. The largest magnitudes of *PT* were observed at Don Huatabampo (0.106ºC yr^{-1}) in SON and San Miguel de Lobos (0.076ºC yr^{-1}) in DGO. Average *NT* was T_{avg} = -0.059ºC yr^{-1} (-0.59ºC $decade^{-1}$) and *PT* T_{avg} = 0.073ºC yr^{-1} (0.73ºC $decade^{-1}$) (Tables 2-3, Fig. 1). Without taking into account the *ST* of *PT*, the average was T_{avg} = 0.073ºC yr^{-1}, which differs from the results obtained

Table 5. Observed and calculated annual trends of T_{avg} (ºC yr⁻¹) and Prec (mm yr⁻¹) at weather stations in northern Mexico.

		Trends			
State	Weather station	T_{avg}		*Prec*	
		Obs	Cal	Obs	Cal
Sinaloa	Acatitan	-0.060	-0.090	12	**9**
	Culiacan	0.071	**0.049**	-15	-17
	El Playon	-0.045	**-0.026**	-5	-9
	Guasave	0.061	**0.099**	15	**12**
	Guatenipa	-0.075	**-0.049**	5	**11**
	Jaina	-0.085	**-0.065**	16	**11**
	Palmar de Los S.	0.029	0.068	-24	-20
	Pericos	-0.040	**-0.040**	4	**8**
	Ruiz Cortinez	-0.084	**-0.049**	10	**10**
	Santa Cruz	-0.091	-0.059	16	**13**
	Siqueros	-0.059	-0.028	13	**9**
	Surutato	-0.080	**-0.058**	9	**10**
	Topolobampo	0.111	0.061	14	8
Baja California Sur	Caduaco	-0.184	-0.124	10	8
	Constitución	-0.108	**-0.109**	-8	**-11**
	El Paso de Iritu	-0.133	**-0.103**	8	**4**
	El Refugio	-0.085	-0.082	9	**2**
	El Rosario	-0.104	**-0.079**	-15	-6
	La Paz	0.060	**0.048**	7	**7**
	La Poza Grande	0.110	**0.093**	6	**1**
	La Purísima	0.142	**0.174**	8	**3**
	La Soledad	0.110	**0.130**	7	10
	Las Cruces	-0.086	-0.101	9	6
	Ligui	-0.039	**-0.057**	15	**18**
	Los Divisaderos	-0.046	-0.064	5	**8**
	Penjamo	-0.079	**-0.107**	-15	-5
	Puerto San Carlos	-0.083	-0.133	8	**3**
	San Javier	0.084	**0.080**	14	10
	Todos Santos	-0.075	-0.090	10	**6**
Durango	Huahuapan	-0.020	-0.026	6	8
	Ojito de Camellones	-0.030	-0.046	26	**22**
	Peña de Águila	-0.015	**-0.034**	12	**7**
	San Miguel de Lobos	0.055	**0.076**	-5	**-6**
	Santiago Papasquiaro	0.050	0.049	10	**7**
	Tamazula	0.038	0.061	11	13
Chihuahua	El Tarahumar	0.056	0.032	-15	-9
	Guerachic	-0.030	**-0.042**	6	2
Sonora	Don Huatabampo	0.141	0.106	-8	**-3**

T_{avg} = average seasonal temperature, *Prec* = cumulative annual average seasonal precipitation, Obs = observed value, Cal = calculated value and bold = significant trends.

by IPCC (2013) over the period 1906-2005, in which the *PT* was T_{avg} = 0.74ºC (0.56-0.92ºC). The *PT* of T_{avg} was associated with an increase in the frequency and intensity of frost, which affected crop and livestock yield and profit, causing considerable economic losses to vegetable, fruit, flower, potato, maize, and feed production. The local population depends on these and other agricultural products for both food and income [43]. Fig. 2 shows the *PT* and *NT* of *Prec*.

The zones with the highest variability are in the north of BCS at the Constitución and Ligui stations. This is attributed to homogeneous climate changes and the high variability of T_{avg}. *ST* were observed at only five stations (four *PT* and one *NT*), of which Ojito de Camellones in DGO (22 mm yr^{-1}) was the station with highest magnitude of *PT* and El Playon in SIN (-9 mm yr^{-1}) the station with the greatest *NT.* The *ST* of *Prec* are less significant than those of temperature. The average *Prec* = 9.75 mm yr^{-1} for *PT,* and the overall average (all trends) of *Prec* = 4.21 mm yr^{-1} (Table 3 and Fig. 2). The *ST* results for *Prec* are very similar to those reported by [1], which report no evident trends in P_a, and that worldwide T_{avg} increased 0.85ºC from 1880 to 2012 [44]. *ST* of *PET* were observed at 16 stations (13 with *NT* and three with *PT*) with an average of -0.29 mm yr^{-1}. The stations with the most extreme *PT* were San Miguel de Lobos (1.848 mm yr^{-1}) and Santiago Papasquiaro (0.951 mm yr^{-1}) in DGO; and the stations with the greatest magnitude of *NT* were in BCS; Puerto San Carlos (-1.573 mm yr^{-1}) and Todos Santos (-1.481 mm yr^{-1}). The results for *PET* are consistent with those reported by [45] in Spain and Portugal in the period 1970-2010, where they state that the annual seasonal *PET* mean was 3.1 mm yr^{-1}. The results of this study also agree with the findings of [46], where the average trend of *PET* in China for the period 1960-2013 was -2.92 mm (10 km)$^{-1}$.

For the *SPEI-24*, *ST* were observed at 28 stations (13 with *NT* and 15 with *PT*). The highest values of *PT* were at Culiacán (0.082) and Surutato (0.067) in SIN, and the greatest magnitudes of *NT* were recorded at La Poza Grande (-0.066) in BCS and El Playon (-0.065) in SIN. Considering only the *ST*, the average of *NT* = -0.056 and *PT* = 0.060. Without taking into consideration α = 0.05, the average was 0.015 (Tables 1-2, Fig. 4). The results of *SPEI-24* agree with [9], who found that the trends of annual *Prec* and *SPEI* in China are related to changes in T_{avg} and *PET* trends. No published records of the *SPEI* index for northern Mexico were found; however, CONAGUA [47] reported variations in the Standardized Precipitation Index (*SPI*), which averaged 0.011 for the period 1970-2011.

Knowledge of *ST* in *SPEI-24* can be used in development of adaptation and mitigation measures such as construction designed to withstand extreme temperatures and precipitation, design of drought-resistant seeds, or water rationing for agriculture, among other measures [39]. The *ST* of T_{avg} and *PET* recorded in Guasave (Fig. 4a) should serve to stimulate actions taken to mitigate and adapt to climate change. These *ST* in Guasave could be the main factor that explains the hysteresis of variability in agricultural production and soil damage due to temperature increase, which affects food security at local and international levels [48]. The areas adjacent to El Playón in SIN are important because they are vulnerable to *NT* in T_{avg}, *Prec*, *PET*, and *SPEI-24*, and this station is located near Ramsar wetlands 13 and 14 (Lagunar San Ignacio Navachiste-Macapule System and Ensenada de Pabellones, respectively). The Siqueros station in SIN and Constitución in BCS showed *ST* in *SPEI-24*; these stations are located near Ramsar wetlands 16, and 4, 5, and 6, respectively (Laguna Playa Colorada-Santa María La Reforma and Los Comondú, Oasis Sierra de La Giganta and Loreto Bay National Park), which are among the most important ecosystems and the most threatened by drought at the worldwide level (Fig. 4) [49]. The observed range in *SPEI-24* showed that the drought category varied from extreme drought to extremely wet, with values from -3.37 (Pericos) to 2.56 (Jaina) in SIN, from -2.25 (La Poza Grande) to 2.31 (Todos Santos) in BCS, from -2.71 (Huahuapan) to 2.23 (Tamazula) in DGO, from -1.67 (Guerachic) to 2.25 (El Tarahumar) in CHIH, and from -1.85 to 2.26 in the only station analyzed in SON (Don Huatabampo) (Fig. 4a). The annual averages for *SPEI-24* were -0.04 in SIN, -0.23 in BCS, -0.028 in DGO, 0.21 in CHIH, and 0.11 in SON (Fig. 4b).

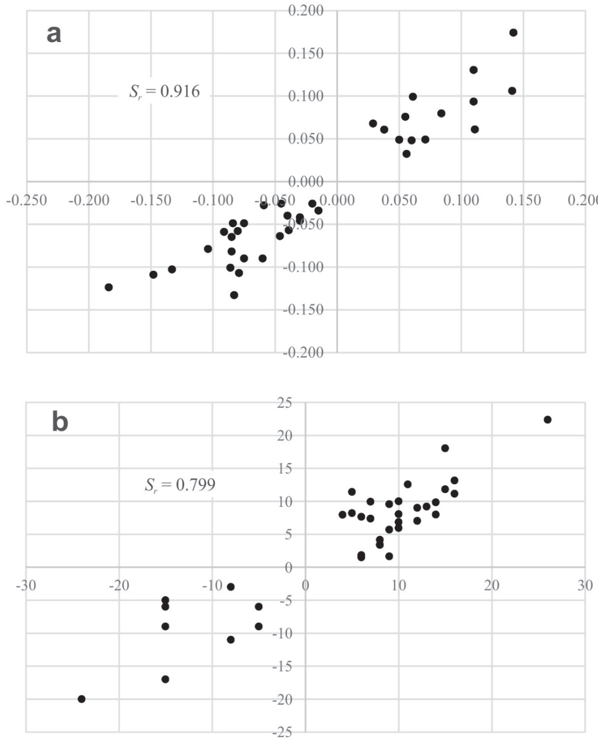


Fig. 6. Dispersion of observed and calculated data of: a) T_{avg} (°C yr^{-1}) and b) *Prec* (mm yr^{-1}) by weather station in northern Mexico.

Return Periods of Droughts

Table 4 and Fig. 5 show the *RP* of drought associated with deciles 1, 2, 3, 7, 8, and 9 in the study area in northern

Mexico. According to the results in BCS and SIN, there will be severe droughts in 2021 and 2036 (Tables 1, 4, Fig. 5). It is important to develop adaptation and mitigation plans prior to the occurrence of severe droughts in order to ensure food sustainability at the national and international levels [50]. The results of this work are similar to those reported for China by [51], who predict that there will be droughts in 2015.6 and 2020.5. Fig. 5 shows the *RP* of drought according to the intervals of variation of deciles 1, 2, 3, 7, 8, and 9 of *Prec* for each study state in northern Mexico. According to Tables 1 and 4, and Fig. 5, the states pf DGO, CHIH, and SON will not experience extreme droughts, although they will experience moderate drought events in 2036, 2061, 2111, 2211, and 2511.

Statistical Analysis

The four groups of data (T_{avgobs}, T_{avgca}l, $Prec_{obs}$, and $Prec_{cal}$) did not show normality: respectively, p (normal) = 0.037, p (normal) = 0.019, p (normal) = 0.001, and p (normal) = 0.012, and W = 0.9385, W = 0.9295, W = 0.8789, and W = 0.9229 (Table 5). The correlation coefficient S_r for T_{avg} was S_r = 0.916; P (uncorr) = 6.91×10^{-16} and for *Prec*, S_r = 0.799; P (uncorr) = 1.82×10^{-9} (Table 5, Figs 6a-b).

Conclusions

An important finding of this study is the behavior of T_{avg} with *ST* at the stations of Topolobampo, Puerto San Carlos, and Todos Santos, which are near international tourism destinations. Tourism strategies for adaptating to climate change must be implemented to avoid respiratory, gastrointestinal or cutaneous diseases due to abrupt changes of T_{avg}. The few *ST* of *Prec* may be associated with tropical cyclones. The core North American monsoon region, constituted by SIN, SON, and CHIH, is vulnerable to the effect of *ST* in *Prec* associated with tropical cyclones [18]. The excess rainfall associated with these events can severely affect soil in the form of water erosion and disaggregation by torrential rains [49].

The *ST* found by this study can help soil management analyses accurately incorporate the impact of tropical storm events on local agriculture. These results require environmental conservation and adaptation of Ramsar wetlands, and tourist and agricultural areas that sustain local and national economies. We recommend reforesting the Ramsar wetlands, which according to [1] play an important role in the capture and storage of atmospheric carbon, which is of global importance and can mitigate the effects of *ST* in *SPEI-24*. The methodology proposed in this paper is an efficient way to predict droughts; that is, quantifying the impacts of climate change at the local level, even when extensive time series (> 50 years) or powerful computing resources are not available. The *ST* of T_{avg} are higher than those of *Prec*. Due to the *ST* of T_{avg}, *PET*, and *SPEI-24*, it is essential to make changes in the way economic activities such as agriculture and aquaculture are scheduled in northern Mexico. It is essential to carry out studies of this nature in regions where the water resources resulting from *Prec* exceed 60% of the annual cumulative total, as is the case in the agricultural sector of northern Mexico.

The methodology proposed in this research to predict droughts can be applied to any region of Mexico and the world simply by using the appropriate T_{avg} and *Prec* indicators. One of the limitations of the IDW interpolation method is that the spatial distribution of the variables depends only on the distances between the weather stations. In order to improve the interpolation on the maps, the number of years of daily data (n > 50) and the number of weather stations would need to be increased and the distance between them (< 25 km) reduced. In the literature, no studies were found that analyzed the *ST* of the *SPEI-24* index or *RP* of droughts in northwest Mexico. Worldwide, no studies were found analyzing the *ST* of *SPEI-24*. The trends calculated for T_{avg} and *Prec* were similar to the results obtained by [39]. The correlation coefficients were 0.916 for T_{avg} and 0.799 for *Prec*, which validates the results of this study.

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