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Note

Statistical analysis of the occurrence of annual meteorological droughts according to climate type in the state of San Luis Potosi, Mexico

Análisis estadístico de la ocurrencia de sequías meteorológicas anuales según tipo de clima del estado de San Luis Potosí, México

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Abstract

Droughts are a regional and recurrent natural phenomenon, which is governed by local climatic parameters. Since the annual average precipitation is the fundamental quantity defining the climate, in this study it is used for the classification and the identification of the *occurrence* of meteorological droughts. Thirty-two complete annual rainfall records were processed from the state of San Luis Potosi, Mexico, whose amplitudes ranged from 45 to 55 years. These annual series define four climates, and an extremely simple model to detect and estimate the severity of droughts was applied to them. Two representative values of each climate were obtained: drought occurrence percentage (%O) and average intensity (*AI*). In the arid climate, the representative %O was 26.9, with a 0.446 *AI*. For the semiarid climate the %O decreased to 22.2 with an *AI* of 0.379. In the subhumid climate, both indicators fell, to 18.5 and 0.336, respectively. Lastly, in the humid climate the %O decreased to 16.4, but the *AI* increased slightly to 0.344. The analysis of the occurrences of droughts in the years analyzed enables drawing conclusions about their *temporal distribution*, yearly and spatially, within the state of San Luis Potosi, Mexico. Conducting these analyses in other regions of the country is recommended, due to the importance of those estimations in order to understand the behavior of meteorological droughts in a region or state.

Keywords: Annual precipitation, climate spectrum, statistical tests, percentage of occurrences, drought severity, relative precipitation deficit, drought years.

Resumen

Las *sequías* son un fenómeno natural recurrente y regional, gobernado por los parámetros climáticos locales. Siendo la precipitación media anual la magnitud fundamental que define al clima, en este estudio se emplea para su clasificación y para identificar la *ocurrencia* de las sequías meteorológicas. Se procesaron 32 registros completos de precipitación anual del estado de San Luis Potosí, México, cuyas amplitudes variaron de 45 a 55 años. Tales series anuales definen cuatro climas y en ellas se aplica un modelo extremadamente simple de detección y estimación de la severidad de las sequías. Se obtienen los valores representativos por climas del porcentaje de ocurrencia de sequías (% *O*) y de su intensidad media (*IM*). En el clima árido, el % *O* representativo es de 26.9, con una *IM* de 0.446. En el clima semiárido, el % *O* baja a 22.2, con una *IM* de 0.379; en el clima subhúmedo, ambos indicadores descienden a 18.5 y 0.336. Por último, en el clima húmedo, el % *O* se reduce hasta 16.4, pero la *IM* aumenta ligeramente a 0.344. El análisis de las ocurrencias de las sequías en los años analizados permite formular conclusiones sobre su *distribución temporal*, por años y *espacial*, dentro del estado de San Luis Potosí, México. Dada la importancia de las estimaciones citadas, para entender el comportamiento de las sequías meteorológicas de una región o estado se recomienda realizar estos análisis en otras regiones del país.

Palabras clave: precipitación anual, espectro climático, pruebas estadísticas, porcentaje de ocurrencias, severidad de sequías, déficit relativo de precipitación, años de sequía.

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Introduction

Droughts are a natural, cyclical, and regional phenomenon that occurs in all localities of the world. Their occurrence and severity are related to regional climatic parameters, the most impacting ones being *mean annual precipitation (MAP)* and *mean annual potential evapotranspiration (ETp)*. *MAP* depends mainly on eight geographic characteristics: latitude, orographic factors, mesoscale ocean currents, atmospheric wind circulation, proximity to oceans and large lakes, atmospheric pressure, color and texture of the earth's surface, and natural and human-induced atmospheric determinants. In contrast, the *ETp* depends predominantly on four atmospheric and physical characteristics: net solar radiation, vapor-pressure deficit, surface roughness, and leaf area index (Ponce, Pandey & Ercan, 2000).

A *meteorological drought* in a locality or region is the span of months or years during which precipitation is less than normal. Droughts in semiarid and subhumid regions are the best documented, because those climates have the largest human populations, and therefore, water demands are high and more affected by droughts. The opposite occurs in humid climates, where water availability is higher than demand, and because of this, droughts do not have strong negative impacts (Ponce et al., 2000; Mishra & Singh, 2010).

The aim of this study was to quantify the number of droughts and their average severity in each of the four climates that exist in the state of San Luis Potosí, Mexico. For this, 32 annual precipitation (*AP*) records were processed, which were complete and covered a long time period, ranging from 45 to 55 data each. The simplest model that defines the *occurrence* of annual meteorological droughts was applied, specifically, when *AP* does not exceed 75% of its annual average value (*MAP*) and the estimate of its *severity* is based on the relative precipitation deficit, i.e. (*MAP*-*AP*)/*MAP.* Results are analyzed and discussed and conclusions are formulated.

Data processing and applied methods

Selection of annual precipitation records

Based on the Excel file of the climatological information available in the state of San Luis Potosí, provided to the author by the local office of the National Water Commission (CONAGUA), the chronological series of *total monthly precipitation* that did not have missing years and had extensive records were selected. Given these restrictions, 32 weather stations were identified, with a number of years of records, ranging from 45 to 55 data. Their names and general characteristics are shown in Table 1 and their geographical location in the state is shown in Figure 1.

Table 1. General and statistical characteristics of the annual precipitation (*AP*) series from the 32 weather stations with complete records and more than 45 data from the state of San Luis Potosí, Mexico.

No.	Name:	Coordinates[1]			Record		*AP* (mm)		Statistics[3]					Climatic group (according to *MAP*)
		Lat.	Long.	Alt.	Period	n^2	Minimum	Maximum	*MAP*	*Median*	*SD*	*Cv*	r_1	
1	Vanegas	23° 53′	101° 57′	1746	1964–2015	52	52.5	713.7	287.6	279.4	124.4	0.432	0.253	Arid
2	Santa María del Refugio	23° 44′	101° 13′	2068	1964–2015	52	38.7	886.8	299.0	298.3	151.1	0.505	0.125	Arid
3	Reforma	22° 45′	101° 39′	2043	1965–2012	48	111.5	1041.31	347.3	322.4	162.8	0.469	0.009	Arid
4	Col. Álvaro Obregó	22° 15	99°	11	1961–201	5			348.	349.	145	0.4	0.2	Arid

	n	′	40′	46	4	4	83.0	752.0	3	7	.9	19	31	
5	La Maroma	23°28′	100°29′	1900	1965–2015	51	95.0	687.0	366.6	359.8	117.6	0.321	−0.077	Arid
6	Ojo Caliente	21°53′	100°49′	1789	1967–2015	49	191.4	816.9	378.2	347.9	124.9	0.330	−0.081	Arid
7	Los Filtros (SLP)	22°09′	101°01′	1904	1950–2014	65	169.6	657.2	384.6	378.9	111.5	0.290	0.018	Arid
8	El Peaje	22°05′	101°07′	2101	1963–2011	49	195.2	702.7	414.4	394.0	112.9	0.272	−0.027	Semiarid
9	El Grito	22°40′	101°08′	1850	1969–2013	45	178.6	672.1	424.5	423.3	131.8	0.310	−0.054	Semiarid
10	Charcas	23°07′	101°06′	2126	1962–2015	54	119.0	987.0	463.7	441.3	198.0	0.427	0.035	Semiarid
11	Ciudad del Maíz	22°24′	99°27′	1248	1969–2015	47	188.0	2232.1	595.8	514.3	395.1	0.663	0.385	Semiarid
12	Villa Juárez	22°20′	100°16′	1144	1963–2014	52	286.0	1017.2	605.6	598.0	169.1	0.279	0.067	Semiarid
13	Nogal Oscuro	22°02′	100°11′	1045	1965–2014	50	360.1	991.1	632.0	625.9	173.3	0.274	0.121	Semiarid
14	Rayón	22°01′	99°38′	1258	1961–2015	55	206.2	1177.9	634.6	616.5	198.4	0.313	0.145	Semiarid
15	Cerritos	22°26′	100°17′	1178	1965–2015	51	232.3	1161.5	694.4	698.1	180.5	0.260	−0.018	Semiarid
16	San Juan del Meco	22°37′	99°37′	1278	1961–2014	54	255.6	1289.8	794.4	769.4	235.0	0.296	0.010	Semiarid

17	Ébano	22° 13′	98° 22′	40	1961–2015	55	259.5	1318.3	861.9	850.0	228.8	0.265	0.114	Subhumid
18	El Tigre	22° 18′	99° 09′	183	1961–2014	54	588.0	1894.5	1099.2	1061.4	287.4	0.261	–0.004	Subhumid
19	Santa Rosa	22° 01′	99° 04′	96	1961–2014	54	620.5	2276.0	1266.4	1233.6	353.0	0.279	0.330	Subhumid
20	El Pujal	21° 51′	98° 56′	51	1961–204	54	747.2	2507.0	1341.3	1312.5	372.7	0.278	0.249	Subhumid
21	Micos	22° 07′	99° 10′	210	1961–2014	54	804.3	2506.3	1490.5	1427.4	367.4	0.246	0.223	Subhumid
22	Ballesmi	21° 45′	98° 58′	43	1961–2014	54	918.9	2955.3	1508.6	1436.0	423.9	0.281	0.247	Subhumid
23	Damián Carmona	22° 06′	98° 18′	342	1961–2014	54	826.6	2532.5	1554.9	1565.9	366.1	0.235	0.128	Subhumid
24	Gallinas	21° 54′	99° 15′	283	1961–2015	55	907.2	3013.6	1706.0	1646.8	460.3	0.270	0.194	Humid
25	Santa Cruz	21° 42′	99° 03′	67	1961–2015	55	1151.0	3020.6	1865.8	1835.0	467.8	0.251	0.240	Humid
26	Tierra Blanca	21° 15′	98° 52′	168	1961–2015	55	888.2	2828.0	1918.6	1914.5	451.4	0.235	0.098	Humid
27	Temamatla	21° 14′	98° 45′	120	1961–2015	55	1115.9	2998.0	1957.0	1877.7	445.8	0.228	–0.050	Humid
28	Requetemu	21° 25′	98° 53′	126	1961–2015	55	1299.0	3441.1	2099.8	2073.0	454.3	0.216	0.151	Humid
29	Tancuilín	21° 34	99°	10	1961–201	55	1248.9	3555.8	2145.2	2085.7	539.4	0.251	0.3	Humid

		′	07′	0	5								35	
30	Aquismón	21° 37′	99° 01′	68	1961–2015	55	959.2	3562.1	2270.7	2178.3	608.4	0.268	0.183	Humid
31	Xilitla	21° 23′	98° 59′	630	1964–2014	51	1554.5	3764.8	2691.4	2715.4	584.8	0.217	–0.031	Humid
32	Tamapatz	21° 34′	99° 05′	885	1966–2015	50	1837.0	4352.3	2813.4	2806.1	629.3	0.224	0.017	Humid

Symbology:

[1] North Latitude and West Longitude of Greenwich in degrees and minutes; Altitude m.a.s.l. *SD* standard deviation of the series, in millimeters.

[2] number of processed data (sometimes equal to the number of years) *Cv* coefficient of variation (*Cv* = *MAP/SD*), dimensionless.

[3] *MAP* mean annual precipitation of the series, in millimeters. r_1 coefficient of correlation of first-order series, dimensionless.

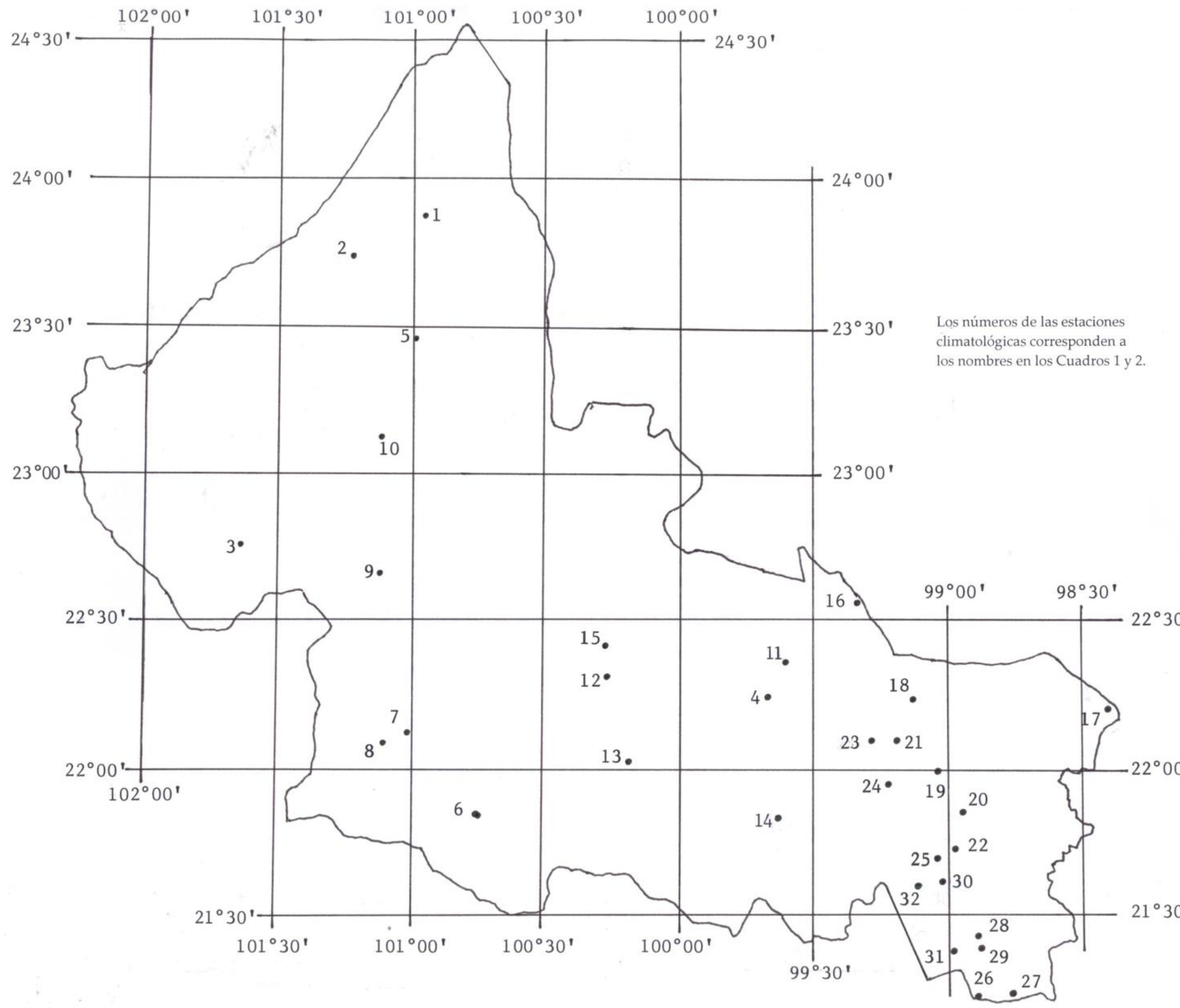

Figure 1. Geographic location of the 32 weather stations processed, from the state of San Luis Potosí, Mexico.

For each record and based on their monthly values, the *medians* of the sample were obtained, with which the few incomplete years (generally less than three) were completed. Annual precipitation (*AP*) values were then obtained. The median was adopted because it is not affected by the extreme values in the series. The arithmetic mean of the *AP* values is the *mean annual precipitation* (*MAP*), which is the basic parameter for classifying the 32 records to be processed, whose statistical values are shown in Table 1 in order of increasing MAP size.

Statistical tests applied

In a study about the occurrence of *annual meteorological droughts*, the statistical tests should look for changes in the mean, which return to the non-homogenous *AP record*. It is also important to identify trends in the series and look for their physical causes. In a study of droughts, the occurrence of *persistence* or autocorrelation in the record does not make it difficult or inconvenient to process, since that component is an intrinsic part of the chronological series.

In this study of meteorological droughts, seven statistical tests were applied. These included one general test against deterministic un-specified components (Von Neumann test) and six specific tests: two of persistence (Anderson and Sneyers), two of trends (Kendall and Spearman), one of change in the mean (Cramer) and one of variability (Bartlett). These tests can be consulted in WMO (1971), Machiwal and Jha (2008), and Campos-Aranda (2015).

Climatic spectrum

Ponce, Pandey, and Ercan (2000) classified climates into eight types, based exclusively on the quotient of *mean annual precipitation* (*MAP*) and *annual global terrestrial precipitation* (*AGTP*). To estimate the latter, they indicated that the amount of moisture stored in the atmosphere is a function of latitude and climate, ranging from 2 to 15 millimeters in polar and arid regions and 45 to 50 mm in humid regions. An average value of 24 mm was adopted for the estimation of the *AGTP*, also considering that the atmospheric moisture is recycled every 11 days on average, which is why 33 cycles occur per year, and then the *AGTP* is on the order of the 800 mm. The quotient of *MAP* and *AGTP* is designated by *CP,* and the eight types of climates and their numerical limits are indicated in Figure 2.

Ponce *et al*. (2000) also established limits for the quotient (*CE*) between mean annual potential evapotranspiration (*ETp*) and *MAP* for the eight groups of climates, and defined these exclusively based on the *MAP*, as shown in Figure 2. Moreover, they indicated *the durations of the wet season* (*DWS*) in months. Based on the *MAP* value in Table 1, the climatic group of each processed weather station is indicated in the final column.

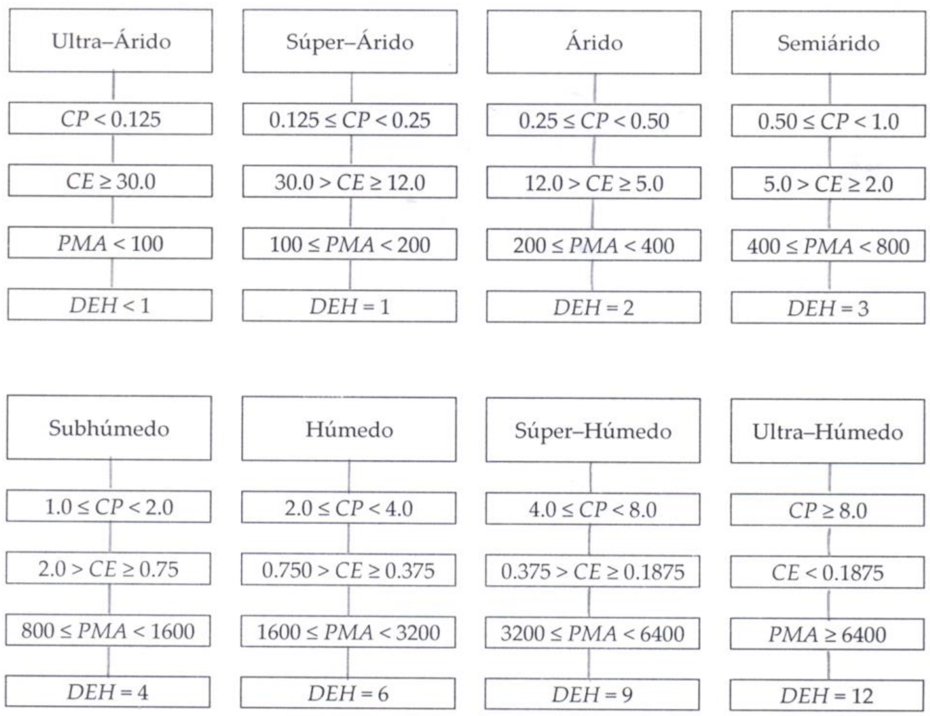

Figure 2. Groups on the climatic spectrum and their classification limits (Ponce *et al*., 2000; Pandey & Ramasastri, 2001; Pandey & Ramasastri, 2002).

Basic technique for drought detection

According to Pandey and Ramasastri (2001, 2002), in a year when precipitation (*AP*) is less than 75% of the mean annual precipitation (*MAP),* a drought has occurred. Then, L1 = 0.75·*MAP*, establishes the upper limit of moderate droughts and the lower one will be L2 = 0.625·*MAP*. A final limit, L3 = 0.375·*MAP*, defines the lower threshold of severe droughts and is also the upper limit of extreme droughts. This tries to fulfill the drought conditions occurring with *AP* < L1 and with their types, which according to Ponce *et al*. (2000) establish that moderate droughts have an *AP/MAP* = 0.75, the severe ones an *AP/MAP* = 0.50, and the extreme ones an *AP/MAP* = 0.25.

Indicators of occurrence and severity of droughts

The number of annual droughts (*NS*) (*AP*< L1) divided by the size (*n*) of the *AP series* and expressed as a percentage, is its *probability of occurrence* (%O), since it is the quotient between the number of favorable cases to the number of possible cases, that is:

$$\%O = \frac{NS}{n}100 \quad (1)$$

Pandey and Ramasastri (2001, 2002) used the reciprocal (*n/NS*) and designated that the *average return period* (*ARP*) of droughts, in years. The indicator of drought severity is its *average intensity* (*AI*), defined (Ponce *et al*., 2000) as the average relative deficit, that is:

$$AI = \frac{1}{NS}\sum_{i=1}^{NS}\frac{\left(MAP - AP_i\right)}{MAP} \quad (2)$$

Analysis and discussion of results

Results of statistical tests

Ten *AP* records did not result fully homogeneous. In the Reforma and Ciudad del Maíz weather stations, excessive variability was detected with the Bartlett test, given its extreme maximum value. Nine *AP* records were non-random, according to the Von Neumann test, and with persistence in the respective tests. These were from the stations: Vanegas, Col. Álvaro Obregón, Ciudad del Maíz, Santa Rosa, El Pujal, Micos, Ballesmi, Santa Cruz, and Tancuilín. Lastly, a downward trend was detected only in the Ciudad del Maíz station, with no change in the mean, according to Cramer's test. There was no evidence of change in mean or loss of homogeneity, except for persistence, and therefore the 32 *AP* records were considered acceptable for the study of annual meteorological droughts.

Occurrence of droughts (number and average intensity per climate)

The following assertions, in general, were formulated based on the *median values* of the results, shown in Table 2. In the arid climate, the representative percentage of occurrences (%O) was 26.9, with an average intensity (*AI*) of 0.446. In the semi-arid climate the %O dropped to 22.2 with an *AI* of 0.379. In the sub-humid climate, both indicators fell, to 18.5 and 0.336, respectively. Lastly, in the humid climate, the %O decreased to 16.4, but the *AI* slightly increased to 0.344.

Extreme droughts occur only in arid and semi-arid climates. In the arid climate, the %O and its *AI* for moderate, severe, and extreme droughts were: 41.2 with 0.307, 50.0 with 0.483, and 11.8 with 0.736, respectively. These same indicators in the semi-arid climate were: 58.3 with 0.308, 36.4 with 0.472, and 8.3 with 0.678, respectively. Lastly, in the sub-humid climate the %O and its *AI* for moderate and severe droughts were: 75.0 with 0.292 and 25.0 with 0.429, respectively. And for the humid climate: 70.0 with 0.310 and 30.0 with 0.405, respectively.

The %O of droughts for each climate were equivalent to the following average return periods: in the arid climate *ARP* = 3.8 years; in the semi-arid *ARP* = 4.3 years; in the sub-humid *ARP* = 5.5 years; and finally in the humid climate *ARP* = 6.2 years. Pandey and Ramasastri (2001, 2002) reported that for India, by processing 95 weather stations with records ranging from 65 to 89 years, in the arid climate the *ARP* ranged from 2 to 3 years, in the semi-arid climate the *ARP* ranged from 3 to 5 years, and in the sub-humid climate it ranged from 5 to 8 years. Thus, the results for the occurrence of droughts obtained in the state of San Luis Potosí, Mexico, coincide approximately with those obtained in India.

Table 2. Limits adopted for annual meteorological droughts, their types, and their indicators of occurrence, in the 32 processed weather stations in the state of San Luis Potosí, Mexico.

No.	Name	Droughts (*AP* < L1 = 0.75·*MAP*)				Moderate (L1 > *AP* > L2 = 0.625·*MAP*)				Severe (L2 > *AP* > L3 = 0.375·*MAP*)				Extreme (*AP* < L3)		
		L1	No.	%O	*IM*	L2	No.	%O	*IM*	L3	No.	%O	*IM*	No.	%O	*IM*
1	Vanegas	215.7	14	26.9	0.499	179.8	3	21.4	0.346	107.9	8	57.1	0.473	3	21.4	0.721
2	Santa María del Refugio	224.3	16	30.8	0.532	186.9	1	6.2	0.254	112.1	11	68.8	0.484	4	25.0	0.736
3	Reforma	260.4	14	29.2	0.446	217.0	7	50.0	0.314	130.2	4	28.6	0.516	3	21.4	0.661
4	Col. Álvaro Obregón	261.2	17	31.5	0.461	217.7	7	41.2	0.317	130.6	8	47.1	0.512	2	11.8	0.757
5	La Maroma	275.0	10	19.6	0.439	229.1	4	40.0	0.307	137.5	5	50.0	0.483	1	10.0	0.741
6	Ojo Caliente	283.7	12	24.5	0.339	236.4	8	66.7	0.296	141.8	4	33.3	0.424	0	0.0	–

7	Los Filtros (SLP)	288.4	14	21.5	0.381	240.4	7	50.0	0.302	144.2	7	50.0	0.460	0	0.0	–
Valor mediano		–	–	26.9	0.446	–	–	41.2	0.307	–	–	50.0	0.483	–	11.8	0.736
8	El Peaje	310.8	10	20.4	0.330	259.0	9	90.0	0.308	155.4	1	10.0	0.529	0	0.0	–
9	El Grito	318.4	12	26.7	0.390	265.3	7	58.3	0.329	159.2	5	41.7	0.476	0	0.0	–
10	Charcas	347.8	18	33.3	0.447	289.8	8	44.4	0.306	173.9	7	38.9	0.508	3	16.7	0.678
11	Ciudad del Maíz	446.9	15	31.9	0.435	372.4	6	40.0	0.300	223.4	7	46.7	0.479	2	13.3	0.683
12	Villa Juárez	454.2	9	17.3	0.402	378.5	4	44.4	0.314	227.1	5	55.6	0.472	0	0.0	–
13	Nogal Oscuro	474.0	11	22.0	0.325	395.0	8	72.7	0.295	237.0	3	27.3	0.404	0	0.0	–
14	Rayón	476.0	11	20.0	0.379	396.6	6	54.5	0.287	238.0	4	36.4	0.442	1	9.1	0.675
15	Cerritos	520.8	8	15.7	0.379	434.0	5	62.5	0.313	260.4	2	25.0	0.401	1	12.5	0.665
16	San Juan del Meco	595.8	12	22.2	0.365	496.5	9	75.0	0.315	297.9	2	16.7	0.430	1	8.3	0.678
Valor mediano		–	–	22.0	0.379	–	–	58.3	0.308	–	–	36.4	0.472	–	8.3	0.678
17	Ébano	646.4	10	18.2	0.382	538.7	6	60.0	0.315	323.2	3	30.0	0.408	1	10.0	0.699
18	El Tigre	824.4	8	14.8	0.357	687.0	6	75.0	0.325	412.2	2	25.0	0.451	0	0.0	–
19	Santa Rosa	949.8	11	20.4	0.341	791.5	7	63.6	0.292	474.9	4	36.4	0.427	0	0.0	–
20	El Pujal	1006.0	10	18.5	0.336	838.3	8	80.0	0.313	503.0	2	20.0	0.429	0	0.0	–

21	Micos	1117.9	9	16.7	0.311	931.6	8	88.9	0.292	559.0	1	11.1	0.460	0	0.0	–
22	Ballesmi	1131.4	11	20.4	0.309	942.8	8	72.7	0.280	565.7	3	27.3	0.387	0	0.0	–
23	Damián Carmona	1166.2	10	18.5	0.323	971.8	8	80.0	0.288	583.1	2	20.0	0.461	0	0.0	–
Valor mediano		–	–	18.5	0.336	–	–	75.0	0.292	–	–	25.0	0.429	–	0.0	–
24	Gallinas	1279.5	11	20.0	0.347	1066.2	7	63.6	0.310	639.7	4	36.4	0.411	0	0.0	–
25	Santa Cruz	1399.4	11	20.0	0.317	1166.1	10	90.9	0.310	699.7	1	9.1	0.383	0	0.0	–
26	Tierra Blanca	1439.0	9	16.4	0.349	1199.1	7	77.8	0.312	719.5	2	22.2	0.477	0	0.0	–
27	Temamatla	1467.8	6	10.9	0.347	1223.1	4	66.7	0.313	733.9	2	33.3	0.414	0	0.0	–
28	Requetemu	1574.9	8	14.5	0.306	1312.4	7	87.5	0.296	787.4	1	12.5	0.381	0	0.0	–
29	Tancuilín	1608.9	9	16.4	0.344	1340.8	6	66.7	0.317	804.5	3	33.3	0.399	0	0.0	–
30	Aquismón	1703.0	9	16.4	0.354	1419.2	6	66.7	0.289	851.5	3	33.3	0.484	0	0.0	–
31	Xilitla	2018.6	10	19.6	0.320	1682.1	7	70.0	0.288	1009.3	3	30.0	0.394	0	0.0	–
32	Tamapatz	2110.0	6	12.0	0.296	1758.4	6	100.0	0.296	1055.0	0	0.0	–	0	0.0	–
Valor mediano		–	–	16.4	0.344	–	–	70.0	0.310	–	–	30.0	0.405	–	0.0	–

It was observed that the *ARP* for the humid climate of San Luis Potosí, Mexico fell in the range reported by Pandey and Ramasastri (2001, 2002) for the sub-humid climate in India. Nevertheless, it should be greater. This anomaly is probably due to the more regular precipitation in humid climates in India, caused by the monsoon.

Evaluation of the severity of droughts with the *MAP*

In Figure 3, the 32 average intensity (*AI*) values of the droughts, taken from column 6 of Table 2, were plotted on the vertical axis against their respective *MAP* on the horizontal axis, in millimeters, obtained from column 10 of Table 1. As can be seen, three points (stations 6, 8, and 13) deviate from the general hyperbolic type of behavior, and therefore they were removed. Those points correspond to the Ojo Caliente, El Peaje, and Nogal Oscuro weather stations.

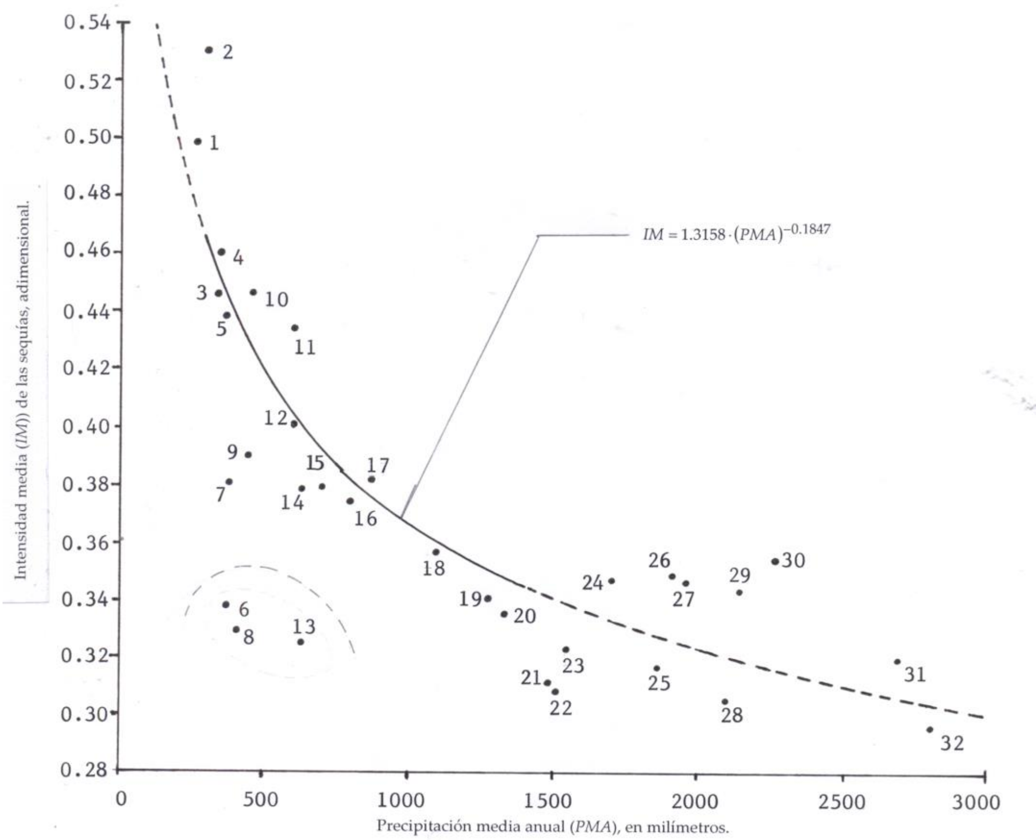

Figure 3. Evolution of the average intensity (*AI*) of the droughts with the mean annual precipitation (*MAP*) in the 32 processed weather stations in the state of San Luis Potosí, México.

The least-squares fitting of residuals results in the equation shown in Figure 3, whose linear correlation coefficient was 0.8947, with a standard error of the estimate of 0.0696. The hyperbolic curve is considered representative of the *MAP* range of 300 to 1 400 millimeters, and therefore its ends are represented by a dotted line.

Occurrence of droughts (types per year)

Table 3a indicates the occurrence of each type of drought, per year, during the first half of the analysis period (years 1961 to 1988), in the 32 processed weather stations. Table 3b shows the occurrences of the types of droughts in the second half of the period (years 1989 to 2015). It is notable that there are a total of 160 drought occurrences in the first period, covering 28 years, and 188 in the second half, which covers 27 years. Therefore, it is concluded from this analysis that the occurrence of droughts has increased over recent decades in the state of San Luis Potosí, Mexico. Having processed 32 weather stations, the years with 20 drought occurrences corresponded to years with widespread drought in the state, primarily 1980, 1982 and 2011, and to a lesser extent to the years 1977, 1979, 1996, 2000, and 2006.

Meanwhile, the years with widespread droughts in the arid and semi-arid climates of the Potosino high plains and central zone were: 1974, 1983, 1989, 1999, and 2011. Lastly, the years with widespread droughts in the sub-humid and humid climates, in the Huasteca region, were: 1962, 1963, 1980, 1982, 1997, 2002, and 2006.

Conclusions

This study showed that greater variability in annual precipitation leads to a greater occurrence of droughts and a higher average intensity, according to the results in Table 2. The decrease in the variability of annual precipitation is shown by its coefficient of variation (*Cv*) in column 13 of Table 1.

In Figure 3, an estimate of the *average intensity* (*AI*) of the annual meteorological droughts can be obtained as a result of this study and exclusively with the mean annual precipitation value of a locality in the state of San Luis Potosí, Mexico. As a complement to Table 2, the representative (*median*) values of the percentage of drought occurrences and their *AI* are shown for the climates in the state.

Table 3a. Types of droughts for the period 1961 to 1988 based on the 32 processed weather stations in the state of San Luis Potosí, Mexico.

Station:	28 years of 1 900:																											
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
Vanegas				↦										SE	SS		SS											
Santa M. del Refugio				↦					SS					SE	SS		SS		SM								SS	SE
Reforma					↦				SM					SM			SM		SM				SM			SM		
Col. Álvaro Obregón	↦	SM	SS	SE													SM	SE	SS		SS	SS	SS	SS	SS	SS		
La Marom					↦				SM	SS				SE									SM					

a																												
Ojo Caliente							↦							SM						SS		SM	SM					
Los Filtros (SLP)	↦	SM												SS						SM			SM					
El Peaje			SS											SM			SM			SM		SM	SM					
El Grito									SS					SM				SM	SM	SM								
Charcas		SM		SM	SM				SE					SS	SM		SS		SS	SM		SE	SS					
Ciudad del Maíz									↦											SM							SS	
Villa Juárez			↦	SS	SS								SM	SS											SM			
Nogal Oscuro					↦						SM								SS		SM							SM
Rayón	↦	SS	SE																			SM			SM	SM		
Cerritos					SE									SM						SM								
San Juan del Meco	↦																			SM		SS					SE	
Ébano	↦		SM	SS													SS			SM		SS						
El Tigre	↦	SM		SM																SS		SM						
Santa	↦	S																	S	S		S					S	S

Rosa		S																	M	S		S					M	M
El Pujal	↦	SS	SM	SM															SM			SS					SM	
Micos	↦		SM																SM	SS							SM	SM
Ballesmi	↦	SS	SM	SM															SM	SM		SM					SS	
Damián Carmona	↦	SM	SM																SM	SM		SS	SS					
Gallinas	↦	SM															SS		SM	SS		SS					SM	
Santa Cruz	↦	SM	SM	SM													SM		SM			SM					SM	
Tierra Blanca	↦	SM															SM			SM		SS						
Tamamatla	↦																SS			SM		SM						
Requetemu	↦		SM														SS					SM					SM	
Tancuilín	↦																SM					SS						
Aquismón	↦	SS	SS																SM			SM					SM	
Xilitla				SM													SS			SM		SM						
Tamapatz						↦														SM		SM						
Annual	0	1	1	9	3	0	0	0	5	1	1	0	1	1	3	0	1	2	1	1	2	2	8	1	3	3	1	4

sums		3	1										1			4		4	9		1					1	

Legend:

↦ start of registry. SM moderate drought. SS severe drought. SE extreme drought.

Table 3b. Types of droughts in the period 1989 to 2015 based on the 32 processed weather stations in the state of San Luis Potosí, Mexico.

Station:	27 years of 1 900 and of 2 000																										
	89	90	91	92	93	94	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Vanegas	SS				SM	SE	SE	SS		SM	SM	SS	SS										SS	SS			
Santa M. del Refugio	SS									SS	SS		SS				SS	SS	SE				SE	SS			
Reforma	SS							SE			SE	SE	SM				SS					SS	SS				
Col. Álvaro Obregón				SM			SM									SM	SM						SM				
La Maroma	SS				SM			SS		SM	SS												SS				
Ojo Caliente	SS				SM			SM			SS	SS	SM				SM						SM				
Los Filtros (SLP)	SS						SM	SM				SS	SM										SS	SS			
El Peaje	SM											SM					SM						SM				

El Grito	SS									SS		SS	SM				SM			SM			SS				
Charcas	SM					SS	SE				SS	SM											SM	SS			
Ciudad del Maíz	SS					SS	SM	SM			SE	SS	SM	SS				SM			SS	SE	SM	SS			
Villa Juárez	SM						SS																	SM		SS	
Nogal Oscuro						SM						SM		SM		SM				SM		SS	SS				
Rayón						SM	SS							SM				SS			SM			SS			
Cerritos							SS				SS	SM					SM							SM			
San Juan del Meco	SM			SM		SS				SM	SM							SM			SM			SM	SM		
Ébano								SM	SM	SM			SM										SE				
El Tigre	SM					SM												SM			SS						
Santa Rosa											SM	SM		SM			SM	SS									
El Pujal							SM					SM						SM					SM				
Micos											SM							SM			SM		SM				
Ballesmi							SM	SM	SM								SS										
Damián Carmon									SM								SM				SM		SM				

a																											
Gallinas	SS					SM		SM	SM									SM									
Santa Cruz		SM							SS			SM		SM													
Tierra Blanca									SS			SM		SM	SM			SM									
Temamatla									SM					SS				SM									
Requetemu												SM		SM				SM					SM				
Tancuilín								SM			SM	SS		SM	SS			SM					SM				
Aquismón								SM	SM									SM					SS				
Xilitla								SM	SM			SM		SM				SS					SS				
Tamapatz								SM	SM				SM														SM
Annual sums	14	1	0	2	3	8	10	13	10	6	12	17	9	10	2	2	10	15	1	2	6	3	20	9	1	1	1

Legend:

↦ start of registry. SM moderate drought. SS severe drought. SE extreme drought.

The occurrence of *droughts* in the years analyzed made it possible to formulate conclusions about their *temporal distribution*, yearly and spatial, in the state of San Luis Potosí, Mexico. From Table 3 it was concluded that more droughts occurred over recent decades, and that the years with widespread drought were primarily 1980, 1982, and 2011, and to a lesser extent 1977, 1979, 1996, 2000, and 2006.

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