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Notes

The contrast of the monthly EDI (Effective Drought Index) as a simple method for monitoring meteorological droughts

Contraste del EDI (Effective Drought Index) mensual como método simple para el monitoreo de sequías meteorológicas

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Abstract

Drought indices are used to detect and monitor the drought conditions of an area or region. Various drought indices have been proposed since the mid-sixties, some of them were developed for a specific region or climate and therefore, comparison studies of various drought indices under different climates are always useful and build confidence in such indices, when their results are similar. This study describes in detail the operating procedure of the EDI (Effective Drought Index), applied to monthly precipitation data. The EDI was originally exposed by Byun and Wilhite (1999) to process daily rains, but due to the difficulty of having such records, its monthly version was developed. The three EDI contrasts described in this study are carried out for a drought duration of 12 months: 1) with the SPI (Standardized Precipitation Index) of the climatological station Río Verde, San Luis Potosí, Mexico; 2) with the SPEI (Standardized Precipitation-Evapotranspiration Index) of the climatological station Zacatecas, Zacatecas, Mexico, and 3) with the SPDI (Standardized Palmer Drought Index) of the climatological station Xilitla, San Luis Potosí, Mexico. The evolution graphs of each contrasted index showed great similarity with the *unique* EDI graphs, but the latter define in more detail the changes of monthly precipitation. Based on the analysis of the results, the systematic application of the monthly EDI, in the monitoring of meteorological droughts and the comparison studies of indexes, is recommended because it has a simple operating procedure, it does not require the definition of the duration of drought, and it is derived from a one-step calculation.

Keywords: Meteorological droughts, Effective Drought Index (EDI), SPI, SPEI, SPDI, drought evolution graphs.

Resumen

Los índices de sequías se utilizan para detectar y dar seguimiento a las condiciones de sequía de una zona o región. Diversos índices de sequías han sido propuestos desde mediados de la década de 1970, algunos de ellos fueron desarrollados para una región o clima específicos y, por ello, los estudios de comparación de varios índices de sequía bajo climas diferentes son siempre útiles y se genera confianza en tales índices cuando sus resultados son semejantes. En este estudio se describe con detalle el procedimiento operativo del EDI (Effective Drought Index), aplicado a datos de precipitación mensual. El EDI fue expuesto originalmente por Byun y Wilhite (1999) para procesar lluvias diarias, pero debido a la dificultad que existe para disponer de tales registros, se desarrolló su versión mensual. Los tres contrastes del EDI descritos en este estudio se realizan para una duración de sequía de 12 meses: 1) con el SPI (Standardized Precipitation Index) de la estación climatológica Río Verde, en San Luis Potosí, México; 2) con el SPEI (Standardized Precipitation-Evapotranspiration Index) de la estación climatológica Zacatecas, Zacatecas, México, y 3) con el SPDI (Standardized Palmer Drought Index) de la estación climatológica Xilitla, San Luis Potosí, México. Las gráficas de evolución de cada índice contrastado mostraron una gran similitud con las gráficas *únicas* del EDI; pero estas últimas definen un mayor detalle respecto a los cambios de la precipitación mensual. Con base en el análisis de los resultados, se recomienda la aplicación sistemática del EDI mensual en el monitoreo de sequías meteorológicas y en los estudios de comparación de índices debido a que tiene un procedimiento operativo bastante simple, y a que no requiere la definición de la duración de la sequía, lo cual conduce a un único cálculo de tal índice.

Palabras clave: sequías meteorológicas, Índice Efectivo de Sequías (EDI), SPI, SPEI, SPDI, gráficas de evolución de las sequías.

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Introduction

The planning, selection, and implementation of preventive and reactive measures against the negative effects of Droughts are based on information regarding their territorial extension, severity, and duration (Dogan, Berktay, & Singh, 2012; Jain, Pandey, Jain, & Byun, 2015). Such information is obtained through the detection, monitoring (Mishra & Singh, 2010; Hao & Singh, 2015) and forecast (Mishra & Singh, 2011) of droughts, which is carried out relying on the so-called *drought indices*, which are procedures that calculate a continuous random variable based on one or more meteorological variables, such as precipitation, temperature, soil moisture and potential evapotranspiration (Fuchs, Svoboda, Wilhite, & Hayes, 2014

Most of the available and common drought indices were developed for specific regions and therefore, have limitations of use in different climatic conditions, due to the inherent complexity of the drought phenomenon (Fuchs *et al*., 2014; Jain *et al*., 2015). For example, the

PDSI (Palmer Drought Severity Index) was developed and applied in the plains of the USA (Palmer, 1965), the Gibbs and Maher decile index (WMO, 1975) was generated and applied in Australia, the *Z* index of China is used in that country (Wu, Hayes, Weiss, & Hu, 2001) and the SPI (Standardized Precipitation Index) exhibited in USA (McKee, Doesken, & Kleist, 1993), which has achieved universality due to the efficient use of monthly rainfall information and consistency of results.

Another index that has shown universality is the EDI (Effective Drought Index), which was originally proposed to process daily precipitation information (Byun & Wilhite, 1999), but due to the difficulties in having easy access to records of this climatic variable, the procedure has been transformed and adapted to monthly records and subsequently contrasted with other drought indices (Smakhtin & Hughes, 2004; Smakhtin & Hughes, 2007; Morid, Smakhtin, & Moghaddasi, 2006; Pandey, Dash, Mishra, & Singh, 2008; Dogan *et al.*, 2012; Jain *et al*., 2015). Kim, Byun, and Choi (2009) have modified and complemented the original EDI, to improve its performance.

The monthly EDI has a calculation as simple as the *Z* and *Z* indices of China (Campos–Aranda, 2017), as it is a standardized value of its main variable called *effective precipitation* (*EP*), which is obtained through a weighting function of the current monthly precipitation and the preceding month of the analysis. This calculation is simpler than in the SPI, based on moving sums of a certain duration and their probabilistic handling to convert them into standard normal variables.

The *objectives* of this study are: first, to explain the operating procedure of the monthly EDI and second, to contrast its results against those obtained with other monthly indices of more complicated calculation, which have already been applied in several locations in Mexico, with different climates. Such is the case of the following: 1) the SPI (McKee *et al*., 1993; Campos-Aranda, 2017); 2) the SPEI (Vicente-Serrano, Beguería, & López-Moreno, 2010; Beguería, Vicente-Serrano, Reig, & Latorre, 2014; Campos-Aranda, 2018a), and 3) the SPDI (Ma *et al*., 2014; Campos-Aranda, 2018b).

Operating procedure

The EDI was proposed by Byun and Wilhite (1999) to monitor the duration and severity of meteorological droughts. It is based on a new concept called effective precipitation (*EP*), which takes into account the monthly rainfall of the month under analysis and the weighting of previous rains, based on a time-dependent reduction function. EDI is calculated based on the so-called *PRN* or precipitation required to return to normal conditions. The *PRN* is estimated based on the deviation of the *EP* concerning its monthly average value, designated *DEP*. Finally, the *PRN* is standardized to obtain the EDI.

The first step in calculating the EDI is to estimate the *EP*. If P_i is the precipitation in the $m-1$ months before month j in analysis and N is the duration of such preceding period, then the *PE* of each month will be:

$$EP_j = \sum_{m=1}^{N} \left[\frac{1}{m}\left(\sum_{i=1}^{m} P_i\right)\right] \quad (1)$$

For example, if $N = 4$, we have: $EP = P_1 + (P_1 + P_2)/2 + (P_1 + P_2 + P_3)/3 + (P_1 + P_2 + P_3 + P_4)/4$; where, P_1, P_2, P_3 and P_4 are the rains during the month in analysis (j), the previous, second and third months before, respectively. The mean of the *EP* values for each month is designated $\overline{EP}_{nm}$, with *nm* varying from 1 to 12; With this value, the deviations of the *EP* are estimated, according to the equation:

$$DEP_j = EP_j - \overline{EP}_{nm} \quad (2)$$

The *PRN* values are calculated with the following expression:

$$PRN_j = \frac{DEP_j}{\sum_{i=1}^{N}(1/i)} \quad (3)$$

When $N = 4$ the denominator will be equal to the sum of 1/1 + 1/2 + 1/3 + 1/4 = 2.08333. Finally, the value of the EDI will be equal to:

$$EDI_j = \frac{PRN_j}{\sigma_{PRN}^{nm}} \quad (4)$$

in which, σ_{PRN}^{nm} is the standard deviation of the *PRN* values in the number of months (*nm*) corresponding to the month under analysis (j).

Regarding the duration *N* used in the reduction function (equation 1), it has varied from a duration of 3 months, apparently used by Smakhtin and Hughes (2004, 2007) and by Jain *et al*. (2015), to a duration of 48 months suggested by Pandey *et al*. (2008). In this study, a duration of 12 months was considered, as used by Dogan *et al*. (2012). For this case, the denominator of equation 3 is 3.103211. Equations 1 to 4 of the above operating procedure corresponds to numbers 2, 4, 3, and 9 of Byun and Wilhite (1999), respectively.

As previously indicated, the EDI, as the SPI, are standardized values, which makes it possible to compare the severity of meteorological droughts in locations with different climates. EDI threshold values indicate humidity ranges from extremely dry to extremely wet. The intervals for droughts are (Smakhtin & Hughes, 2007; Dogan *et al*., 2012; Jain *et al*., 2015): when the EDI < −2.00 there are extreme droughts, when it varies from −1.50 > EDI > −2.00 they are severe, when it fluctuates from −1.00 > EDI > −1.50 moderate droughts are defined and when it varies from −1.00 < EDI < 1.00 there is a normal condition. In this study, when the EDI ranged from zero to −1.00, mild or light droughts were considered.

Byun and Wilhite (1999) state that equation 1 represents a reduction function with exponential decay, dependent on the size *N* adopted, and therefore, the EDI procedure will tend to increase its positive values and reduce its negative magnitudes, depending on whether the values of the initial months are large or small, respectively.

Contrasts performed

Dates of droughts occurrence

The SPI, SPEI, and SPDI indices are applied with different *durations* (k) of meteorological drought, through moving sums that generate several data (n_d) based on the number of years (NA) of the available record and the duration k, according to the equation (McKee *et al*., 1993; Vicente-Serrano *et al*., 2010; Ma *et al*., 2014; Campos-Aranda, 2017):

$$n_d = 12 \cdot NA - k + 1 \tag{5}$$

In the graph of SPI, SPEI, or SPDI values of each analyzed duration k, the sequence numbers or data (n_d) of the beginning and end of the studied drought are obtained, and based on the previous expression, NA

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is cleared, whose entire portion indicates the number of years since the beginning of the record and its decimal part is the respective month; with which, the dates sought are obtained.

In the *single* EDI graph, the number of the analyzed month (*j*) corresponding to the beginning and end of the drought studied is obtained, and with a complete tabulation, as shown in Table 1, the respective date is obtained directly. The first column of Table 1 corresponds to the years of the historical record.

Table 1. Evolution of the number of the month (j) analyzed according to the years of registration.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	13	14	15	16	17	18	19	20	21	22	23	24
10	109	110	111	112	113	114	115	116	117	118	119	120
20	229	230	231	232	233	234	235	236	237	238	239	240
30	349	350	351	352	353	354	355	356	357	358	359	360
40	469	470	471	472	473	474	475	476	477	478	479	480
50	589	590	591	592	593	594	595	596	597	598	599	600
60	709	710	711	712	713	714	715	716	717	718	719	720
70	829	830	831	832	833	834	835	836	837	838	839	840
80	949	950	951	952	953	954	955	956	957	958	959	960

The single graph of the EDI begins in a month (*j*) 13 because the monthly rainfall, from December to February, of the initial year of the record, is used in equation 1, to define the first value of the effective precipitation (EP_1), since in this study a value of N = 12 was adopted.

EDI at Río Verde station, San Luis Potosí

Campos–Aranda (2017) shows the graph of the SPI with k = 12 months in the Río Verde climatological station with a temperate climate and with a record of 54 years (1961–2014). The percentages of extreme, severe, moderate, and mild droughts defined by the SPI are 2.2, 2.4, 11.0, and 35.5, whose sum is 51.1 %. On the other hand, with the EDI the obtained percentages were: 0.0, 2.0, 10.5, and 46.2, whose sum is 58.7 %. Table 2 shows part of the data and results of the application of the EDI in the Río Verde climatological station in the state of San Luis Potosí, Mexico.

Table 2. Data and partial results of the calculation of the EDI in the registry of the climatological station Río Verde, S.L.P., Mexico.

Year	Jan	Mar	Apr	May	Jul	Aug	Sep	Nov	Dec
Monthly precipitation (P_i), in millimeters									
1961	19.6	0.0	17.2	0.0	81.8	11.9	63.7	20.4	0.0
1962	0.0	0.0	65.0	0.0	9.5	12.7	23.0	43.8	13.9

1963	0.0	7.8	1.2	40.7	49.5	17.8	59.5	2.6	27.4
2013	0.9	0.5	0.0	15.1	7.8	151.9	242.7	76.9	64.2
2014	12.2	0.0	2.7	50.7	106.3	73.5	201.8	18.4	11.7
Effective Precipitation (*PE*), in millimeters									
1962	298.4	174.3	326.1	217.9	279.0	248.2	257.8	329.5	286.6
1963	217.4	155.0	116.6	212.9	522.7	439.5	519.0	394.9	394.2
2014	748.2	461.9	367.5	434.1	717.1	725.2	1145.7	802.5	659.4
Monthly averages of effective precipitation, in millimeters									
$\overline{EP}_{nm}$	435.8	310.4	332.0	350.9	632.0	677.4	818.8	612.9	517.2
Precipitation necessary to return to normal conditions (*PRN*), in mm									
1962	−44.3	−43.9	−1.9	−42.9	−113.7	−138.3	−180.8	−91.3	−74.3
1963	−70.4	−50.1	−69.4	−44.5	−35.2	−76.6	−96.6	−70.2	−39.7
2014	100.7	48.8	11.5	26.8	27.4	15.4	105.3	61.1	45.8
Monthly standard deviations of the *PRN*, in millimeters									
σ_{PRN}^{nm}	45.2	35.8	60.1	59.0	108.9	87.3	100.1	62.8	53.2
Monthly values of the effective drought index (EDI), dimensionless									
1962	−0.98	−1.23	−0.03	−0.73	−1.04	−1.58	−1.81	−1.45	−1.40
1963	−1.56	−1.40	−1.15	−0.75	−0.32	−0.88	−0.96	−1.12	−0.75
2014	2.23	1.36	0.19	0.45	0.25	0.18	1.05	0.97	0.86

The EDI graph shown in Figure 1 has a great similarity to the one mentioned for the SPI. It also shows that a significant drought due to its duration and severity was the first on the record. This drought reached month 61, that is, January 1966, with its minimum of −1.96 in October 1962 (j = 22).

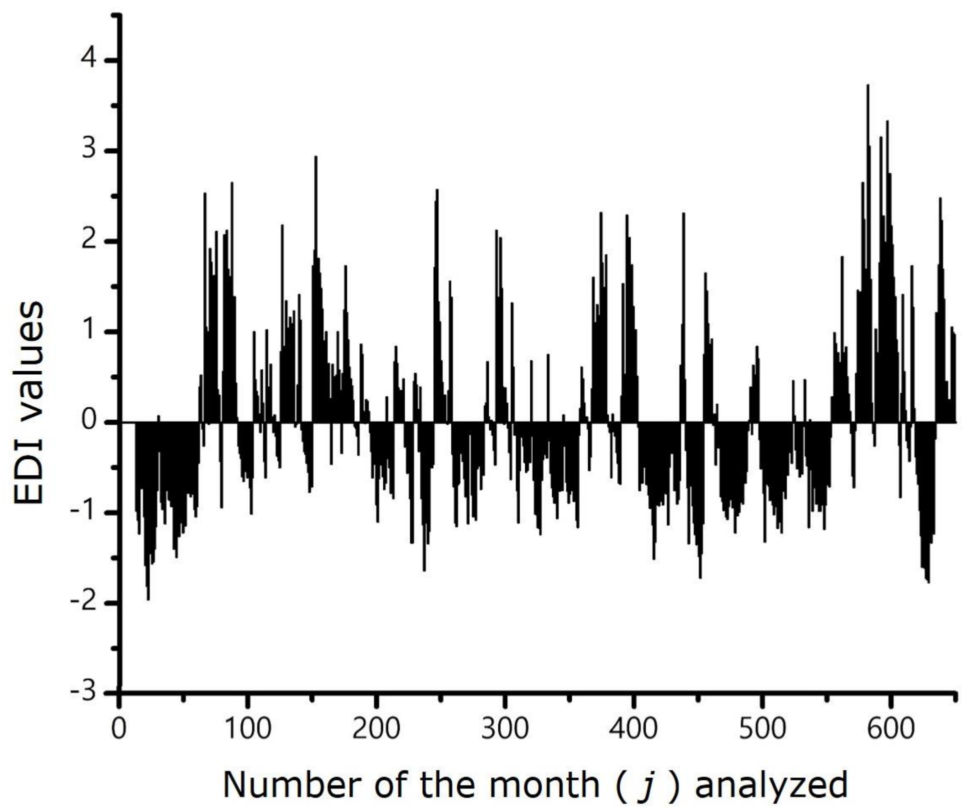

Figure 1. Evolution of the monthly EDI in the climatological station Río Verde, San Luis Potosí, Mexico.

EDI at Zacatecas station, Zac.

Campos–Aranda (2018a) shows the SPEI graph with k = 12 months in the Zacatecas climatological station with a semi-arid climate and with a record of 86 years (1930–2015). The percentages of extreme, severe, moderate, and mild droughts defined by the SPEI are 1.3, 4.8, 11.8, and 32.8, the sum of which is 50.8 %. On the other hand, with the EDI the following are obtained: 0.5, 2.0, 11.0, and 43.7, whose sum is 57.2 %. Table 3 shows a part of the data and results of the application of EDI in the Zacatecas climatological station in the state of Zacatecas, Mexico.

Table 3. Data and partial results of the EDI calculation in the record of the Zacatecas climatological station, Zacatecas, Mexico.

Year	Jan	Feb	Apr	Jun	Jul	Aug	Sep	Oct	Dec
Monthly precipitation (P_i), in millimeters									
1930	1.0	10.5	19.5	67.0	121.4	53.0	21.8	113.0	14.6
1931	79.3	19.9	2.5	52.4	90.0	81.1	41.2	5.0	11.5
1932	0.0	29.8	0.0	18.0	76.2	98.4	102.2	11.1	0.0
2014	10.8	0.0	0.0	78.8	66.6	107.8	111.4	8.6	22.0
2015	24.1	51.1	25.3	245.5	155.8	66.6	134.2	115.1	18.7
Effective Precipitation (PE), in millimeters									
1931	889.8	734.6	446.1	514.5	647.2	713.6	642.5	486.0	321.8
1932	245.0	282.2	159.1	145.0	332.6	532.8	696.0	542.2	343.9
1933	354.5	332.4	192.4	275.6	517.3	782.7	1002.1	1062.3	623.9

Monthly averages of effective precipitation, in millimeters									
$\overline{EP}_{nm}$	423.4	356.5	240.1	404.2	589.9	718.2	786.5	690.4	477.4
Precipitation necessary to return to normal conditions (*PRN*), in mm.									
1931	150.3	121.8	66.4	35.5	18.5	−1.5	−46.4	−65.9	−50.1
1932	−57.5	−23.9	−26.1	−83.5	−82.9	−59.8	−29.2	−47.8	−43.0
1933	−22.2	−7.7	−15.4	−41.4	−23.4	20.8	69.5	119.8	47.2
Monthly standard deviations of the *PRN*, in millimeters									
σ_{PRN}^{nm}	47.8	42.0	33.6	64.3	81.6	70.9	85.2	73.1	49.7
Monthly values of the effective drought index (EDI), dimensionless									
1931	3.14	2.90	1.98	0.55	0.23	−0.02	−0.54	−0.90	−1.01
1932	−1.20	−0.57	−0.78	−1.30	−1.02	−0.84	−0.34	−0.65	−0.87
2015	0.23	1.18	3.65	4.04	2.96	2.12	1.99	2.88	2.59

The EDI graph shown in Figure 2 has a big similarity with the SPEI graph. It also shows that an important drought due to its duration and extreme severity, began in month 180 (December 1944) and ended in month 344 (August 1958). During this period, an extreme drought occurred with an EDI value of −2.46 in month 332 (August 1957). The last drought was important due to its severity, started in month 969 (October 2010) and ended in month 1002 (June 2013), and had its extreme minimum EDI of −2.11 in month 980 (August 2011).

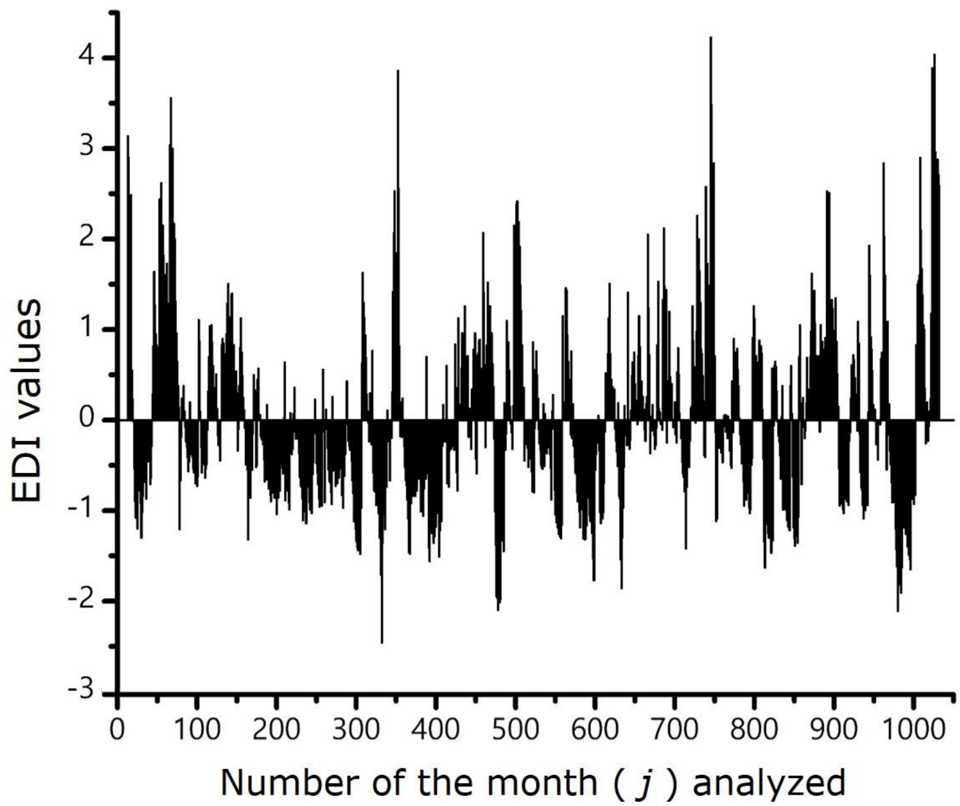

Figure 2. Evolution of the monthly EDI in the Zacatecas climatological station, Zacatecas, Mexico.

EDI at the Xilitla station, San Luis Potosí

Campos–Aranda (2018b) presents the graph of the SPDI with k = 12 months in the Xilitla climatological station with a warm–humid climate and with a record of 50 years (1965–2014). The percentages of extreme, severe, moderate, and mild droughts defined by the SPI are 0.2, 6.6, 13.9, and 31.6, whose sum is 52.3 %. On the other hand, with the EDI the following are obtained: 0.2, 4.1, 12.9, and 36.9, whose sum is 54.1 %. Table 4 shows part of the data and results of the application of the EDI in the Xilitla climatological station in the state of San Luis Potosí, Mexico.

Table 4. Data and partial results of the calculation of the EDI in the registry of the Xilitla climatological station, San Luis Potosí, Mexico.

Year	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov
Monthly precipitation (P_i), in millimeters									
1965	28.5	42.8	32.2	445.7	462.3	681.3	578.5	300.8	117.5
1966	95.6	106.3	226.6	726.4	192.1	193.0	183.7	534.4	76.0
1967	93.7	88.9	165.2	246.3	200.2	995.9	468.2	417.3	89.9
2013	20.7	22.8	311.5	218.5	603.5	602.3	1067.8	310.2	450.5
2014	90.9	86.7	233.6	659.8	323.0	296.1	530.3	487.1	55.5
Effective Precipitation (*PE*), in millimeters									
1966	2393.7	2150.8	2234.4	3827.5	3254.6	2972.6	2786.5	3768.4	3012.0
1967	1896.8	1694.6	1436.2	1762.1	1872.7	4439.8	4559.0	4637.7	3767.0
2014	3126.4	2685.9	2549.2	3860.9	3676.8	3551.5	4228.2	4614.6	3593.5
Monthly averages of effective precipitation, in millimeters									
$\overline{EP}_{nm}$	2035.3	1777.4	1761.3	2391.8	3004.5	3447.6	4252.2	4025.0	3357.2

Precipitation necessary to return to normal conditions (*PRN*), in mm									
1966	115.5	120.3	152.5	462.7	80.6	−153.0	−472.3	−82.7	−111.3
1967	−44.6	−26.7	−104.8	−202.9	−364.7	319.7	98.9	197.4	132.1
2014	351.6	292.7	253.9	473.4	216.6	33.5	−7.7	190.0	76.2
Monthly standard deviations of the *PRN*, in millimeters									
σ_{PRN}^{nm}	146.0	139.1	170.4	272.0	339.2	291.3	391.5	314.4	263.9
Monthly values of the effective drought index (EDI), dimensionless									
1966	0.79	0.87	0.89	1.70	0.24	−0.53	−1.21	−0.26	−0.42
1967	−0.31	−0.19	−0.61	−0.75	−1.08	1.10	0.25	0.63	0.50
2014	2.41	2.10	1.49	1.74	0.64	0.12	−0.02	0.60	0.29

The graph of the EDI shown in Figure 3 has a great similarity with the one cited for the SPDI. In it, two droughts stand out: (1) the penultimate one that contains the extreme minimum value of the EDI, begins in month 499 (June 2006) and ends in month 509 (May 2007), with the minimum of −2.12 in month 503 (October 2006) and (2) the last drought is the longest and most severe, beginning in month 550 (October 2010) and ending in month 582 (June 2013).

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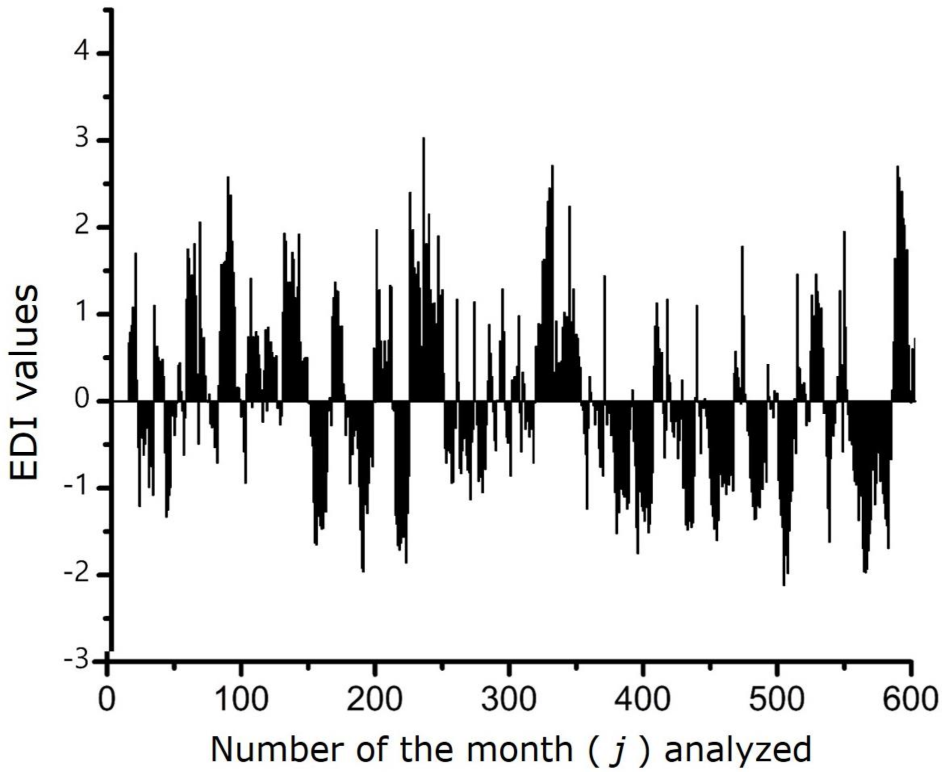

Figure 3. Evolution of the monthly EDI in the Xilitla climatological station, San Luis Potosí, México.

Discussion of results

The three contrasts conducted in different climates and for a 12-month duration of meteorological droughts, provide encouraging results, which suggest the systematic application of the EDI, due to its simplicity of calculation and the interpretive advantage of leading to a single evolution graph.

However, it is worth highlighting the need to carry out more contrasts, both in other climates and for different durations of drought; for example, the other eight commonly studied when applying the SPI, in 3, 6, 9, 18, 24, 36, 48 and 72 months (Cheval, 2015).

Conclusions

The three meteorological drought indices: SPI, SPEI, and SPDI, contrasted with the monthly EDI, the process moving sums of duration k from three completely different random variables and, however, the percentages of extreme, severe, moderate, and light droughts that they define only show results slightly different from those established with EDI, which requires a much simpler operational process of monthly precipitation.

In addition, the evolution graphs of each contrasted index: SPI, SPEI, and SPDI, in the cases analyzed, for a duration of k = 12 months, showed great similarity with the *unique* graphs of the monthly EDI, which define greater detail in relation with the changes presented by the monthly precipitation of climatological stations of different climates.

Therefore, the systematic application of the monthly EDI is recommended in the monitoring of meteorological droughts and index comparison studies because it does not require the definition of the duration *k* of the drought and is more sensitive to changes in the monthly precipitation, about the accumulated values of rain or another variable in the *k* months of duration.

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