Article

Trends in daily precipitation in the upper Laja-Peñuelitas basin, Guanajuato

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Abstract

Detecting changes in the behavior of precipitation, temperature or any atmospheric variable is essential for decision makers. Identifying trends in the historical behavior of weather stations provides information for future climate behavior. The present paper analyzes the changes in the extremes of precipitation in the upper Laja-Peñuelitas basin in the state of Guanajuato, using the climate change indices developed by the team of experts on climate change detection and indices. A period of 36 years (1982-2017) was analyzed using daily precipitation data, selecting conventional weather stations with less than 25% of lost data, subjecting these databases to a process of data quality control and homogenization, obtaining 11 precipitation indices through the RClimDex program. The results show a statistical non-significant (62.09%) and significant (14.05%) upward trend, indicating that in the upper Laja-Peñuelitas basin, it is possible to establish the maintenance and slight increase in the behavior and amount of precipitation.

Keywords: climate change, homogenization RClimDex.

Introduction

The successful implementation of climate change adaptation strategies depends largely on the accurate and timely detection of climate changes at the regional and local levels in different parts of the world (Adger *et al*., 2005). In some regions of Mexico, the expected effects of climate change will be an increase in temperature greater than 3 °C and a decrease in precipitation of the order of 15%, these climate changes, in those regions, will decrease surface runoff and aquifer recharge which will make the problems of population and economic growth worse (Martínez and Patiño, 2012). In some other regions of the country, it is possible that different climate trends may occur due to the characteristics of the area and anthropogenic factors. To detect, by regions and in specific basins, these climatic changes, it is necessary to calculate climate change indices for specific regions of Mexico.

Indices derived from daily data are an attempt to extract information objectively from meteorological observations that answer questions about the extremes that affect many human and natural systems (Zhang *et al*., 2011). The team of experts on climate change detection and indices (IPCC) has coordinated a set of 11 precipitation indices and 16 temperature indices, adopted since the IPCC's fourth assessment report (AR4) (Yan *et al*., 2014). To calculate the indices, long and non-discontinuous time series of climatic variables are required (Persson *et al*., 2007). These can be calculated in the RClimDex program (Zhang and Yang, 2004b).

In this work, there is an interest in determining the trend of precipitation in the upper Laja-Peñuelitas basin through the generation of climate change indices of precipitation. This interest arises from the need to be prepared in the space and time of the basin, either to face floods or adapt to droughts. Floods and droughts can affect agricultural production and the security of the population. In this work, the study area has 36 years of daily temperature and rainfall data.

Materials and methods

Study area. For this study, the upper Laja-Peñuelitas basin was defined up to the hydrometric station 12 715 Puente Dolores (Figure 1). It is delimited within the coordinates 101° 31' 60.00" west latitude and 100° 51' 60.00" west longitude; 21° 6' 0.00" north latitude and 21° 33' 60.00" west longitude, covering an area of 1 683 km^2, according to INEGI (2010), it is located in the state of Guanajuato, Mexico in the hydrological region 12 Lerma-Santiago and specifically in the upper part of the sub-basin RH12Ha Laja - Peñuelitas. The altitude in the study area varies from 2 963 to 1 890 masl. The river of La Laja crosses the eastern part of the city of Dolores Hidalgo, Guanajuato.

Most of the basin (61%) has a temperate semi-arid climate, with the rest being temperate sub-humid (INEGI, 2008). The average annual rainfall is 558 mm, being concentrated mostly in the months from June to October. The predominant land uses and vegetation in the upper Laja-Peñuelitas basin are natural-induced grassland vegetation (34%) and rainfed agriculture (30%) (INEGI, 2016). Phaeozem soils, mostly clayey, represent 70% of the area of the study basin (INEGI, 1998).
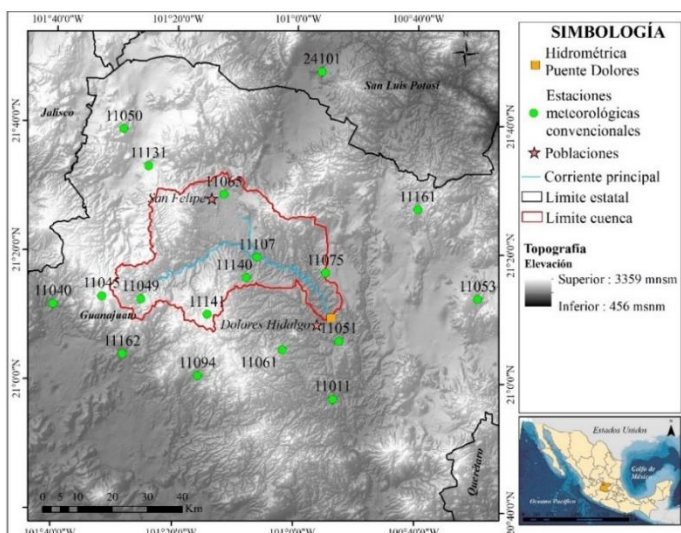
Figure 1. Location of the upper Laja-Peñuelitas basin.

Climate data and sources

Climate information from the National Weather Service through conventional weather stations within and near the basin was used (SMN, 2019). A first filtering was performed, selecting only the stations that did not exceed more than 25% (< 25%) of lost precipitation data (Arriaga and Cavazos, 2010), this was carried out for a period of 36 continuous years (1982-2017). A second filtering consisted of verifying the continuity of the data series, removing the weather stations that had a year or more without information as applied by Zarazúa *et al*. (2014), omitting this criterion for those stations that, due to their location, removing them represented an information gap for a specific area of the basin.

A third filtering was the removal of redundant weather stations, this generated by their proximity in the same geographical area. Data quality control is a necessary step before analysis of temperature and precipitation variation because erroneous outliers can seriously affect trends (Yan *et al*., 2014). Quality control was performed using the RClimDex program (Zhang and Yang, 2004b) for each database of the selected weather stations. Quality control consisted of identifying outliers such as amounts of daily precipitation less than zero, precipitation values that were too large, rounding problems, etc.

The homogenization of the data consisted of 1) verification of the changes based on their presence in each of the target stations vs their behavior in the nearby weather stations; 2) the analysis of the values of the PF_{MAX} statistical test; and 3) justification for changes due to external climate phenomena such as El Niño/Niña. Once the change points were detected, the process of homogenization of the data series was carried out with adjustment by QM quantiles (Quantile Matching Algorithm) in cases where the series were not homogeneous (Wang and Feng, 2013). Information on how the software detects inconsistencies and performs the homogenization process is provided by Wang and Feng (2013). The stations analyzed are shown in Table 1.

Table 1. Weather stations considered for the upper Laja-Peñuelitas basin.

Num.	Key	Name	Latitude (degrees)	Longitude (degrees)	Altitude (m)	Lost data[**] 1982-2017 (%)	Homogenized
1	11011	Cinco Señores	20.958	-100.893	2 062	2.06	Yes
2	11040	Los Castillos	21.195	-101.668	1 865	0.27	
3	11045	Media Luna	21.217	-101.534	2 221	4.22	
4	11049[*]	Nuevo Valle Moreno	21.211	-101.426	2 247	2.09	Yes
5	11050	Ocampo	21.65	-101.48	2 253	3	
6	11051	Peñuelitas	21.108	-100.878	1 906	0.53	
7	11053	Pozos	21.22	-100.496	2 206	9.99	Yes
8	11061	San Antonio	21.084	-101.034	2 090	12.51	
9	11065[*]	San Felipe (DGE)	21.484	-101.2	2 100	24.75	
10	11075	Soledad nueva	21.283	-100.917	2 011	21.61	Yes
11	11094	Guanajuato (DGE)	21.014	-101.266	2 008	3.26	
12	11107[*]	La Quemada	21.323	-101.107	2 003	13.71	
13	11131	Las Trojes	21.555	-101.409	2 198	13.46	
14	11140[*]	El Carbón	21.269	-101.136	2 115	3.82	Yes
15	11141[*]	Ciénega de Negros	21.173	-101.242	2 475	1.34	
16	11161	El Vergel	21.45	-100.664	2 192	3.95	Yes
17	11162	Comanjilla	21.068	-101.475	1 898	1.38	
18	24101	Villa de Reyes	21.804	-100.933	1 820	12.55	Yes

[*]= stations within the basin; [**]= for the precipitation variable.

Trends in precipitation

The RClimDex software (Zhang and Yang, 2004b) was used to estimate trends in precipitation (Table 2). The procedure followed was that indicated in Zhang and Yang (2004b), starting by making adjustments in the number of days when a rainfall value 'nn', Rnn is exceeded. The rainfall values to be exceeded, 'nn' and analyzed, according to the values that usually occur in the area, were the following: 1) 22.3 mm; 2) 37.3 mm; 3) 30 mm; 4) 40 mm; 5) 50 mm; 6) 60 mm; and 7) 70 mm. The latter since the range of 70 mm to 150 mm of maximum rainfall accumulated in 24 hours is classified as intense rainfall and is also used by the National Center for Prevention and Disasters (CENAPRED, for its acronym in Spanish) in Mexico in its classification of the different types of precipitation (Prieto *et al*., 2010).
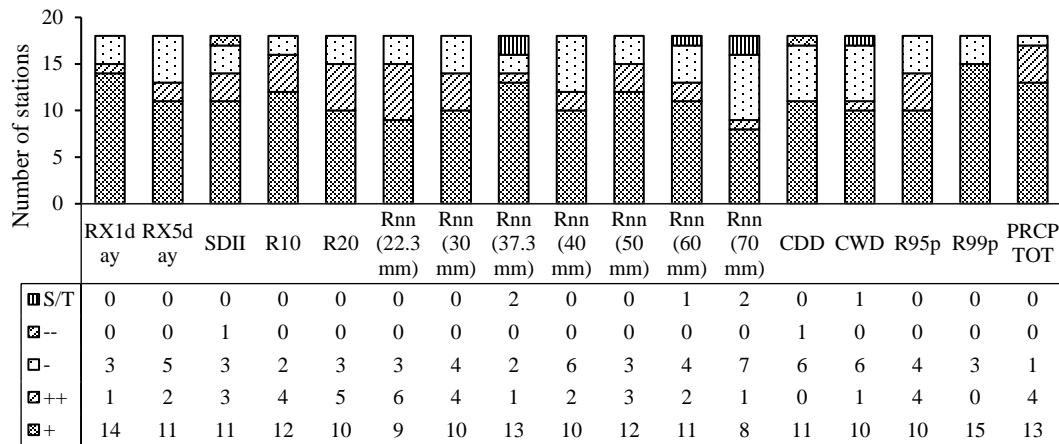
Table 2. Definitions of climate change indices of precipitation[*].

Index	Name description	Definition	Units
RX1day	Maximum amount of precipitation in 1 day	Annual maximum of precipitation in 1 day	mm
RX5day	Maximum amount of precipitation in 5 days	Annual maximum of precipitation in 5 consecutive days	mm
SDII	Simple daily intensity index	Total annual precipitation divided by the number of wet days (defined by precipitation$\geq$ 1 mm) in 1 year	mm d^{-1}
R10	Number of days with heavy precipitation	Number of days in 1 year when precipitation$\geq$ 10 mm	d
R20	Number of days with very heavy precipitation	Number of days in a year when precipitation$\geq$ 20 mm	d
Rnn	Number of days above nn mm	Number of days in a year when precipitation$\geq$ nn mm	d
CDD	Consecutive dry days	Maximum number of consecutive dry days with RR< 1 mm	d
CWD	Consecutive wet days	Maximum number of consecutive wet days with RR$\geq$ 1 mm	d
R95p	Very wet days	Total annual precipitation when RR > 95th percentile	mm
R99p	Extremely wet days	Total annual precipitation when RR> 99th percentile	mm
PRCPTOT	Total annual precipitation in wet days	Total annual precipitation in wet days (RR$\geq$ 1 mm)	mm

[*]= abbreviations are as follows; RR= daily precipitation, a wet day is defined when RR$\geq$ 1 mm and a dry day when RR< 1 mm; nn= user-defined parameter in millimeters (mm) (Zhang and Yang, 2004a; Zhang and Yang, 2004b; Vazquez, 2010; Ruiz *et al*., 2020).

Results and discussion

Figure 2 shows the number of weather stations (n= 18) and the positive or negative trends observed in the climate change indices defined in Table 2. The results show both those indices with statistical significant trend ($p\leq$ 0.05) and those that remain with a slope of the line = 0 (without trend) for the period 1982-2017. The results of Figure 2 were classified into five categories ($p\leq$ 0.05) according to: (+) non-significant increase, (++) significant increase, (-) non-significant decrease, (--) significant decrease and (S/T) without significant trend. The symbols of this statistical trend are shown at the bottom left of Figure 2.

	RX1day	RX5day	SDII	R10	R20	Rnn (22.3 mm)	Rnn (30 mm)	Rnn (37.3 mm)	Rnn (40 mm)	Rnn (50 mm)	Rnn (60 mm)	Rnn (70 mm)	CDD	CWD	R95p	R99p	PRCP TOT
S/T	0	0	0	0	0	0	0	2	0	0	1	2	0	1	0	0	0
--	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
-	3	5	3	2	3	3	4	2	6	3	4	7	6	6	4	3	1
++	1	2	3	4	5	6	4	1	2	3	2	1	0	1	4	0	4
+	14	11	11	12	10	9	10	13	10	12	11	8	11	10	10	15	13

Figure 2. Trends in the indices for the 18 weather stations in the upper Laja-Peñuelitas basin.

The presence of three types of trends was observed: non-significant upward (62.09%), non-significant downward (21.24%) and significant upward (14.05%). This mixed phenomenon also found in Aguilar *et al*. (2005) as there was a non-significant increase in precipitation, with very mixed spatial patterns of positive and negative trends when individual stations were studied. Figure 3 shows the spatial distribution of the weather stations that showed a significant trend (increase or decrease) in the annual maximum value of rainfall in 24 h (RX1day).
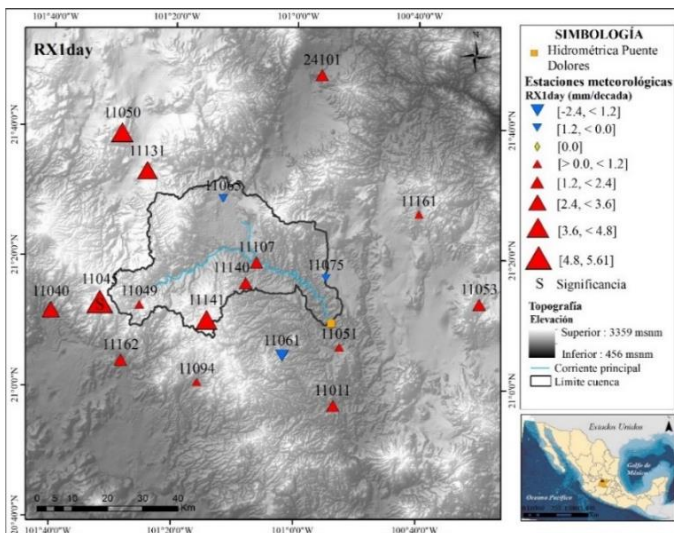

Figure 3. Trend of the maximum rainfall index in 24 h (RX1day).

The RX1day index only showed a statistically significant upward trend for the station 11045 Media Luna with 5.61 mm decade^{-1}, located on the side of the municipality of León, Guanajuato, in the upper part of the basin (approximately at 2 470 masl). In the rest of the weather stations in the upper part (Las Trojes, Salvatierra, and on the side of San Miguel de Allende, Guanajuato) there is a generalized non-significant upward trend.

When analyzing the trends of climate indices, if the reference is the general criteria for the country, it could be concluded that there are no significant upward trends in the maximum precipitation in 24 h, but if it is analyzed from the point of view of the standard deviations of the data of the basin under study, the following will be observed. Figure 4 shows an analysis for four indices of climate change, based on seeing their variation with respect to the standard deviation, the keys of the weather stations are observed around each circle, and the circles are how far they are in standard deviations from the arithmetic means.

For instance, Figure 4a shows the average annual values of the RX1day index and their location with respect to the standard deviations (σ) from the mean values of the stations in the basin. From the geographical point of view of the basin, stations 11 011, 11 040, 11 094, 11 141 showed an above-average increase of two standard deviations and station 11 131 with a decrease of two standard deviations for the RX1day index. Figure 4b, Figure 4c and Figure 4d show a similar analysis, based on standard deviations, for the indices of total annual precipitation, number of days with rainfall greater than or equal to 70 mm and number of days with rainfall greater than or equal to 20 mm.
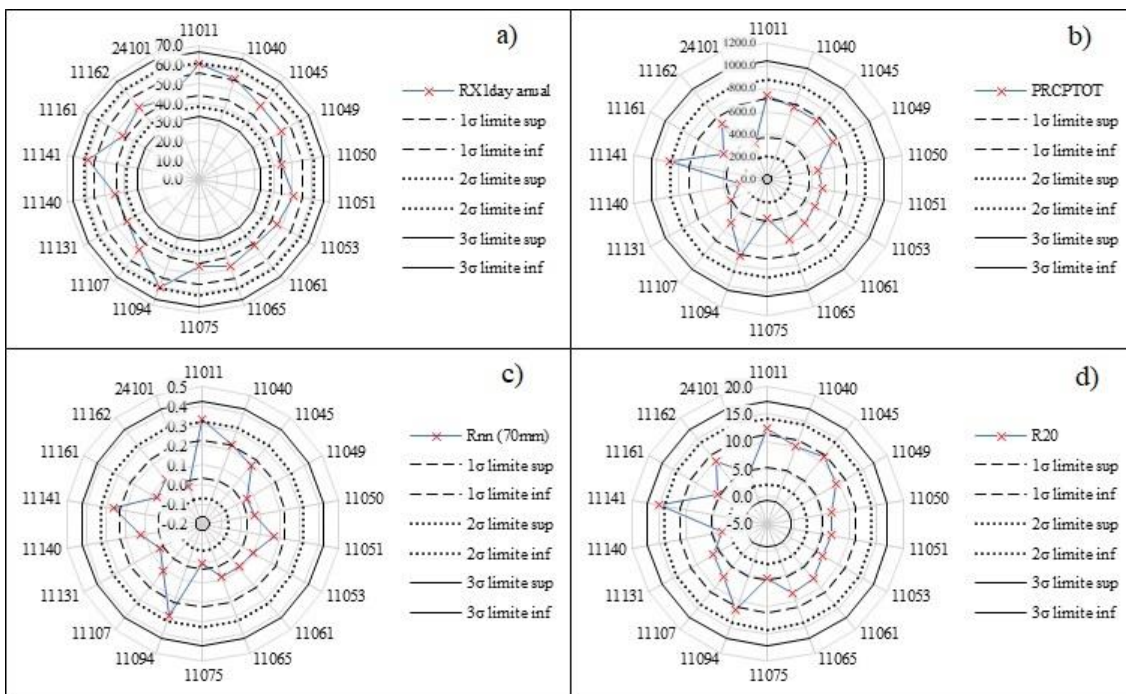
Figure 4. Average values of the indices RX1day (a); PRCPTOT (b); Rnn (70 mm) (c); and R20 (d).

Figure 5 shows the spatial distribution of the weather stations that had a significant trend in the upper Laja-Peñuelitas basin for the climate change indices RX5day (maximum amount of precipitation in five days), SDII (daily precipitation intensity), PRCPTOT (total annual precipitation in wet days) and Rnn (70 mm).
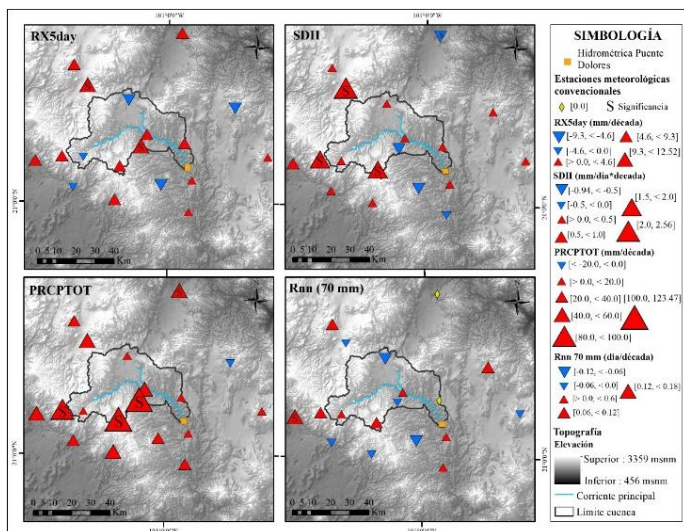
Figure 5. Trend of weather stations in the face of indices RX5day (top left); SDII (top right); PRCPTOT (bottom left); Rnn 70 mm (bottom right).

It is important to analyze the intensity of the rainfall because in general it is commented that, due to climate change, the rainfall events will be more intense, the maximum rainfall in 5 days is analyzed because it is a criterion when calculating runoff in a basin. In Figure 5, in general, there is a greater increase in the trend of intensity and annual rainfall indices; a slight increase in rainfall in 5 days and in general, there is no significant change in the number of days with rainfall equal to or greater than 70 mm, which is already a value of a heavy rainfall in this basin.

In contrast to what happens in this area of Guanajuato, Aguilar *et al*. (2005) found, for areas in northern Mexico, that the PRCPTOT did not show a significant trend despite the fact that the number of stations with positive trends was greater, finding a considerable number of negative slopes, grouped around the stations further north of Mexico and around those located on the southwest of the Central American Isthmus, these patterns averaging a non-significant positive trend of 8.7 mm decade[-1] from 1961 to 2003.

The Rnn index (70 mm) showed a statistically significant upward trend for station 11 040 (0.16 days decade[-1]), being present a mixed phenomenon of reduction and increase not significant for the basin. Figure 6 illustrates the spatial distribution of the weather stations that showed a significant trend in the upper Laja-Peñuelitas basin for the climate change indices R10, R20, Rnn (22.3 mm) and Rnn (37.3 mm). The R10 index showed a statistically significant upward trend for stations 11 045 (4.58 days decade[-1]), 11 140 (3.78 days decade[-1]), 11 141 (4.41 days decade[-1]) and 24 101 (2.08 days decade[-1]).

It is observed that the R20 index presented a regional influence in the upper-middle part of the basin, marked by the statistically significant upward trend for the stations 11 040 (1.29 days decade[-1]), 11 045 (3.44 days decade[-1]), 11 131 (1.93 days decade[-1]), 11 140 (1.81 days decade[-1]) and 11 141 (2.73 days decade[-1]), which makes it the second index with the highest number of significant stations; indicating that the number of days in a year with heavy rainfall based on the criteria of Prieto *et al*. (2010) is increasing, this will have an important effect in the future on the increase in the number of runoff with high flows.
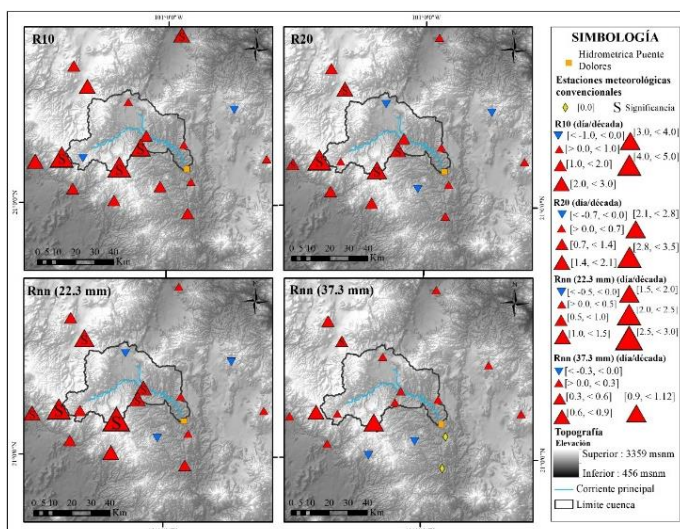
Figure 6. Trend of weather stations in the face of indices R10 (top left); R20 (top right); Rnn 22.3 mm (bottom left); Rnn 37.3 mm (bottom right).

Of the 11 indices of climate change in precipitation for the upper Laja-Peñuelitas basin, the Rnn index (22.3 mm) was the one that obtained the most stations with a statistically significant upward trend, with the stations 11 040 (1.12 days decade^{-1}), 11045 (2.11 days decade^{-1}), 11 107 (1.24 days decade^{-1}), 11 131 (1.8 days decade^{-1}), 11 140 (1.23 days decade^{-1}) and 11 141 (2.99 days decade^{-1}), marked by station 11 107 located in the center of the basin, identifying a regional pattern of increase in the middle-upper part of the basin.

Kachok and Ivanova (2019) calculated various indices for the El Vizcaino Biosphere Reserve in Baja California Sur during the period 1960-2012, with the CWD index showing an increasing trend as well as R20 and PRCPTOT, the latter phenomenon that repeats itself in the upper Laja-Peñuelitas basin. In the states closest to the study area, as presented by Núñez and García (2018) for 48 stations in the state of Jalisco near the upper Laja-Peñuelitas basin for the period 1980-2010, they calculated five precipitation indices, identifying positive trends for the indices: PRCPTOT (54% of the stations) with an average trend of 7.2 mm decade^{-1}, SDII index (77%) and an average trend of 0.4 mm day^{-1} decade^{-1}, RX1day (73%) with 3.9 mm decade^{-1}, CDD (85%) with 11.6 days decade^{-1}, these indices presenting, for the upper Basin Laja-Peñuelitas, the same behavior in the general trend.

On the other hand, with a negative trend, the CWD index (67%) presented an average value of -0.4 days decade^{-1}, this phenomenon is different for the basin, in which a greater number of positive than negative events occurred. Pita and Ortega (2020) for Zacatecas, near the upper Laja-Peñuelitas basin, for the period (1976-2015), the PRCPTOT index showed an increase with significant values in certain areas (one of them, the area closest to the study basin), this agrees with the results of this work, in which despite not being a completely significant phenomenon, the trend is to increase, the analysis of spatial trends indicated that the CDDs increased throughout the state, with the exception of two very local areas, one of them near the upper Laja-Peñuelitas basin, these areas presenting negative pending.

Nevertheless, the spatial and temporal statistical significance of this index was low; however, in the study basin and especially in the northern part of it, the phenomenon tends to increase, although it is not significant; finally, they identified an increase in the daily maximum precipitation (RX1day) in the last years, a behavior that also occurs in the upper Laja-Peñuelitas basin, although not significantly. Ruiz *et al*. (2020) obtained 11 climate change indices for the state of Aguascalientes, near in an easterly direction to the upper Laja-Peñuelitas basin in a range of 70 km, finding in small areas of the east and north of the state an increase in precipitation in 1 and 5 days (RX1day and RX5day), in the east and in the south, both the intensity of the rains and the number of days with heavy precipitation increased; in a very small area to the east, the total annual precipitation also shows evidence of an increase.

These behaviors in the eastern region of the state are consistent with the results obtained in this study. Martínez and Patiño (2012) mention that in the latitudes in which Mexico is located, the expected effects of climate change will be a decrease in precipitation; however, the present work shows an increase (significant or not significant) in rainfall, this is mainly visualized through the PRCPTOT, R10, R20 and Rnn indices for the study area.

Pita and Ortega (2020) point out that the results are generally consistent when analyzing adjacent places or areas with similar climatic conditions but may differ for remote hydrographic basins or regions with different climatic conditions, an example of this is what Velasco *et al*. (2015) showed, who, using two weather stations close to 38 km, in the limits of the state of Puebla and Tlaxcala in the period from 1970 to 2012, found an increase and a decrease for the PRCPTOT index, despite its short distance. In the same way, Kotlarski *et al*. (2017); Zittis (2017) indicate that the trends related to precipitations are not clear and there are significant differences from one country to another, which indicates that global changes in this climatic variable are not homogeneous throughout the world.

Conclusions

The present study was designed to identify changes and trends in climate extremes in the upper Laja-Peñuelitas basin using extreme indices related to precipitation for the period 1982-2017. Climate change indices are viable tools that allow the obtaining of trends from historical records and with these project future trends of increase or decrease in precipitation, which can be used as an input for studies that aim to determine changes in the climate and their effects in hydrological, biological, social matters, etc.

The climatic analysis of the upper Laja-Peñuelitas basin showed trends in climatic extremes of precipitation not previously studied in this particular area of Mexico, highlighting that the upper Laja-Peñuelitas basin presents the general tendency to increase rainfall phenomena. It is recommended that future studies on the upper Laja-Peñuelitas basin be oriented both to the future behavior of precipitation through the use of general circulation models (GCM), and to obtain the indices of climate change in temperature and thus generate a better panorama in the behavior of climatic extremes.

Climate change indices (total annual rainfall, maximum rainfall in 24 h, daily rainfall intensity, rainfall in five consecutive days and number of days with intense and very intense rainfall) showed a upward trend in the upper Laja-Peñuelitas basin, the latter is of great importance to consider in the design of hydraulic works and in matter of flood prevention.

Acknowledgements

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