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Articles

Reanalysis of the daily precipitation concentration index in the Río Grande of Morelia basin

Reanálisis del índice de concentración de la precipitación diaria en la cuenca del Río Grande de Morelia

Gerardo Núñez-González[1], ORCID: https://orcid.org/0000-0001-6274-5575

[1]Universidad de Guadalajara, Centro Universitario de la Costa Sur, Engineering Department, Jalisco, Mexico, gerardo.nunez@cucsur.udg.mx

Corresponding author: Gerardo Núñez-González, gerardo.nunez@cucsur.udg.mx

Abstract

The daily precipitation concentration index is a useful tool for the analysis of the statistical structure of rainfall. However, it is necessary to be careful with the data used for its calculation since this index can be sensitive to both the temporal location of the data and the length of the records. Thus, the objective of this work consisted of a re-analysis of the daily precipitation concentration index (CI) in the Río Grande de Morelia basin to determine how the temporal location of the data and the length of the records affect the CI values. In addition to analyzing the behavior of the CI under three different conditions. The results show that the temporary location of the records can affect the value of the CI, increasing it if the last available years are analyzed or decreasing it if records before 1980 are taken. Regarding the length of the records, it was found that the value of this index tends to stabilize in most of the cases studied for record lengths greater than 20 years. The behavior of the CI at the annual level is within that reported in the literature, and at the decade level and for the 30-year, a decrease in its variability was observed. Therefore, it is recommended that in studies of this type, a common recording period be chosen for the analyzes and a length according to the objectives pursued.

Keywords: Daily precipitation concentration, concentration index, CI, Río Grande de Morelia basin.

Resumen

El índice de concentración de la precipitación diaria es una herramienta útil para analizar la estructura estadística de la lluvia. Sin embargo, en su empleo es necesario tener cuidado con los datos usados para su cálculo, ya que este índice puede ser sensible tanto a la ubicación temporal de los datos como a la longitud de los registros. Así, el objetivo consistió en un reanálisis del índice de concentración de la precipitación diaria (CI) en la cuenca del Río Grande de Morelia para determinar cómo afecta la

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ubicación temporal de los datos y la longitud de los registros a los valores del CI, además de analizar bajo tres condiciones diferentes el comportamiento del CI en dicha cuenca. Los resultados muestran que la ubicación temporal de los registros puede afectar el valor del CI aumentándolo si se analizan los últimos años disponibles o disminuyéndolo si se toman registros anteriores a 1980. En cuanto a la longitud de los registros, se encontró que el valor de este índice tiende a estabilizarse en la mayor parte de los casos estudiados para longitudes de registros mayores a 20 años. El comportamiento anual del CI está dentro de lo reportado en la literatura; por década y para el periodo de 30 años se observó una disminución en su variabilidad. Así, se recomienda que en estudios de este tipo se elija para los análisis un periodo de registros común y de longitud acorde con los objetivos perseguidos.

Palabras clave: concentración de la precipitación diaria, índice de concentración, CI, cuenca del Río Grande de Morelia.

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Introduction

In recent years the concentration index of daily precipitation (CI) proposed by Martín-Vide (2004) has become a popular tool for analyzing the statistical structure of rainfall in different parts of the world as can be seen in the research works of Benhamrouche *et al*. (2015); Patel and Shete (2015); Yeşilırmak and Atatanir (2016); Monjo and Martín-Vide (2016); Mayer, Marzol and Parreño (2017); Zubieta, Saavedra, Silva and Giraldez (2017); Llano (2018); Serrano-Notivoli *et al*. (2018); Vyshkvarkova, Voskresenskaya and Martín-Vide (2018); Zamani, Mirabbasi, Nazeri, Meshram and Ahmadi (2018); Lu *et al*. (2019); Meseguer-Ruiz, Ponce-Philimon, Guijarro and Sarricolea (2019); Sarricolea, Meseguer-Ruiz, Serrano-Notivoli, Soto and Martín-Vide (2019); Velez, Martín-Vide, Roye and Santaella (2019), and Núñez-González (2020), among others. The popularity of this index is due to the fact that it is an easy index to calculate, and it can be interpreted in a simple way based on the behavior of the Lorenz curve, which relates the percentage of rainy days with the percentage of precipitation observed.

The interest in the study of the concentration of precipitation is due to the usefulness that this index has to explore risks associated with extreme precipitation events (Serrano-Notivoli *et al*., 2018) since when precipitation is concentrated in a few days the risk of phenomena such as floods, droughts, soil erosion, etc., increases (Coscarelli & Caloiero, 2012; Zubieta *et al*., 2017). In this sense, Roblero-Hidalgo *et al*. (2018) proposed the CI analysis as a measure to evaluate the torrentiality of rainfall in the Río Grande of Morelia basin, located in Michoacán, Mexico, because this basin has been affected in the past due to extraordinary flows in its tributaries (Roblero-Hidalgo *et al*., 2018).

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In their study, Roblero-Hidalgo *et al*. (2018) used daily precipitation data from 34 conventional meteorological stations, some of the stations with records between 1923 and 2015. However, not all stations have a common period of records. Thus, there are two stations with a period of records less than 10 years between the seventies and eighties, 7 stations covering a period of records between 20 and 30 years, 5 stations with records from 30 to 40 years starting in the year's seventies and eighties, 10 stations with records between 40 and 50 years with records began in 1929, 1943 and after 1960, and finally 10 stations with records longer than 50 years (Figure 1).

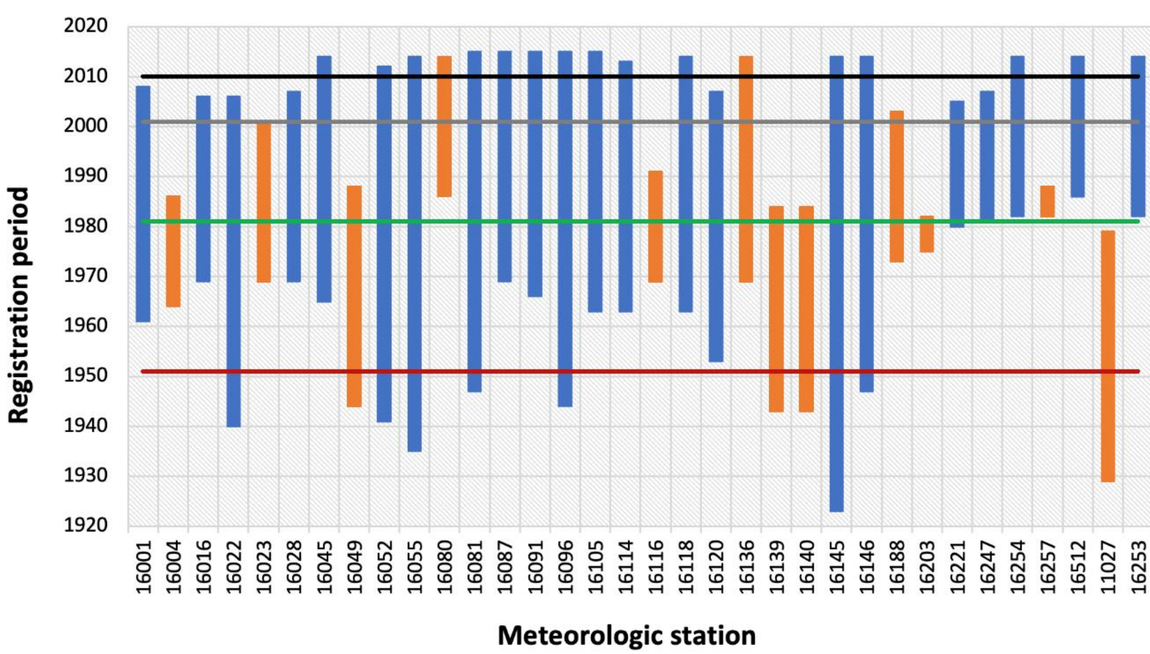

Figure 1. Registration periods of meteorological stations used in the work of Roblero-Hidalgo *et al*. (2018). Note: the stations shown in orange color are those discarded in this study.

The observed differences in the size of the precipitation time series and their temporal location can affect the comparison of the concentration index values between the stations. Particularly, about the location of the records, Benhamrouche and Martín-Vide (2012), in their work entitled "Methodological advances in the analysis of the daily concentration of precipitation in mainland Spain", where comparing the CI values obtained for the periods 1951-1980 and 1981-2010, they observed an increase in the CI value in more than 80 % of the stations, which suggests the importance of taking into account in the calculations a common period of registration.

However, regarding the effect of time series size on CI values, no information has been found in the literature consulted. In this manner, the objective of this work consisted in a reanalysis of the daily precipitation concentration index in the Río Grande de Morelia river basin to delve into the behavior of precipitation concentration as well as to find out how the temporal location of the data and the length of the records affect the CI values. In addition to analyzing for most of the stations the behavior of the daily precipitation concentration index in the Rio Grande basin when it is calculated year by year, for a common period of 10 years and a common period of 30 years. The above to analyze the interannual variability of the CI, besides to compare for common periods of records the behavior of the daily concentration index within the Río Grande of Morelia river basin which has a variety of climates ranging from the subhumid semi-cold $C(E)(w_2)(w)$ and tempered subhumid $C(w_2)(w)$ in the upper part of the basin, tempered subhumid $C(w_1)(w)$ in the middle and temperate $C(w_0)(w)$ in the lower part of the basin, which could affect the behavior of the concentration index.

Materials y methods

Data

For the development of this work was decided to use daily precipitation data of 34 conventional meteorological stations used by Roblero-Hidalgo *et al*. (2018). However, due to the objectives of the present work, it was decided to leave out of the study the stations that had a recording period of fewerthan 10 years, as well as the stations whose records ended before the year 1990. Figure 1 shows the recording periods of the stations used by Roblero-Hidalgo *et al*. (2018). In this figure, the stations that are in color orange are the ones that were discarded for the development of this work, also in Figure 2 the location map of the selected stations is shown.

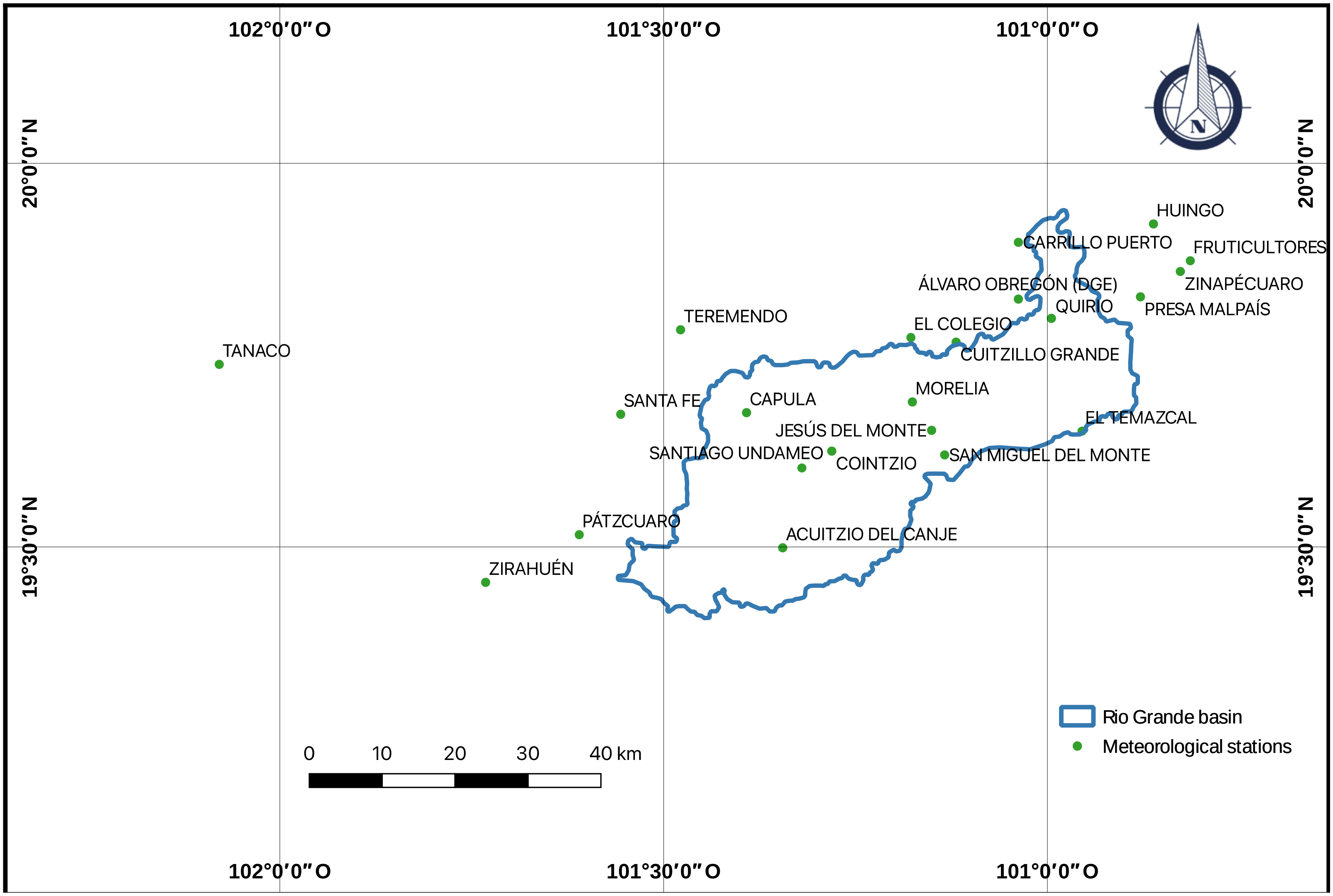

Figure 2. Location of meteorological stations used to calculate the precipitation concentration index.

To verify whether the concentration index in the study area is sensitive to the location of the records, it was decided to use the data from stations 16052, 16055, 16081, 16096, 16145, and 16146, which have a common period of registration between 1950 and 2010 (Figure 1).

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To calculate the CI, the data series of these stations were divided into two sub-periods, namely: 1951-1980 and 1981-2010. In the same manner, to verify the sensitivity of the concentration index to record length, using the data series of the aforementioned stations were constructed new time series of different lengths for each of the stations. The first series was composed of the data of 1951, the second series with the data for the years 1951 and 1952, and so on, a year was added to the new time series until the one containing all the data for the period 1951-2010 was reached, later the series construction process was repeated but now starting from the last year of records. Thus, the time series 61 was built with records from the year 2010, series 62 with data from years 2009 and 2010, and thus successively one year was added to the new series as in the aforementioned case.

On the other hand, to explore the behavior of the concentration index in the Río Grande of Morelia river basin, it was decided to calculate the CI under three different conditions. The first was to calculate the CI year-by-year for the available record period using the years with complete records. The second considers the calculation of the CI for the recording period of 1981-2010 and the third uses data from the decade of 2001-2010. Figure 1 shows the stations that were used in each of the analyses. The CI calculation for different periods was carried out to know their historical behavior, as well as to have a closer view of what has been observed in the basin in recent years.

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Methods

The calculation of the concentration index was carried out according to the methodology proposed by Martín-Vide (2004), in which a function of the form presented in equation 1 is adjusted between the accumulated frequency of days with rain and the amounts of precipitation associated with these frequencies:

$$y = axe^{bx} \quad (1)$$

where *a* and *b* are regression constants calculated by the least square's method.

The procedure to carry out the curve fitting in a summarized way consists of eliminating all the values equal to zero from the precipitation time series, then the precipitation data are grouped into classes of one millimeter, starting with the values less than one millimeter to the maximum value recorded. Once classified the data, the absolute frequencies of the rainy days and precipitation amounts are calculated for each class, then the percentage cumulative frequency of the rainy days and precipitation amounts are determined, which once plotted, they generate an exponential curve like the Lorenz curve, the value of the constants a and b of equation 1 is determined using the least square's method, for which Martín-Vide (2004) proposes the following equations:

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$$\ln(a) = \frac{\sum X_i^2 \sum lnY_i + \sum X_i \sum X_i lnX_i - \sum X_i^2 \sum lnX_i - \sum X_i \sum X_i lnY_i}{N \sum X_i^2 - (\sum X_i)^2} \quad (2)$$

$$b = \frac{N \sum X_i lnY_i + \sum X_i \sum lnX_i - N \sum X_i lnX_i - \sum X_i \sum lnY_i}{N \sum X_i^2 - (\sum X_i)^2} \quad (3)$$

where X_i is the cumulative percentage of rainy days, Y_i is the cumulative percentage of the amount of precipitation, and *N* is the number of precipitation events. A step-by-step explanation with an example of the calculation process can be consulted in the works of Martín-Vide (2004) and Roblero-Hidalgo *et al*. (2018), among others.

After setting the above-mentioned equation, it is calculated the area between the Lorenz curve and the equidistributional line using the following expression:

$$A = 5000 - \int_0^{100} axe^{bx} dx \quad (4)$$

Finally, the precipitation concentration index is calculated as the ratio of the area obtained with equation number 4, and the area of the triangle in the plane defined by the equidistributional line:

$$CI = \frac{A}{5000} \quad (5)$$

where *CI* is the concentration index, *A is* the area between the Lorenz curve and the equidistributional line, and *5000* is the area of the triangle delimited in the plane by the equidistributional line.

The results of the concentration index were subjected to a descriptive statistical analysis to know the trend and dispersion of the data. Additionally, the normality of the results obtained for the CI in the period 1981-2010 was analyzed according to the tests of Shapiro-Wilk, Crammer-von Mises, Lilliefors (Kolmogorov-Smirnov), and Anderson-Darling (Thode, 2002). The use of multiple tests was because the data sample used is small. Statistical and graphical calculations were performed through the open-source statistical platform R (R Core Team, 2013).

Finally, to know the spatial distribution of the concentration index within the study area an interpolation was performed based on the spline's method using the open-source GIS called QGIS (QGIS Development Team, 2020).

Results and discussion

Table 1 shows the results of the concentration index for the periods 1981-2010 and 2001-2010. The results of the CI for the period 1981- 2010 vary from 0.427 to 0.577, a range slightly lower than that found by Roblero-Hidalgo *et al*. (2018). The difference in the range of values can be attributed to the length of the time series used for the calculation of the CI in both works. Even though the range of values observed in the concentration index for the 30 years is lower than that reported by Roblero-Hidalgo *et al*. (2018), in this work, it was found that seven stations have a value of the CI for the 30 years slightly higher than indicated in the aforementioned research work, which is attributable to the random nature of rainfall.

Table 1. Concentration index for the periods 1981-2010 and 2001-2010.

Id	Name	CI 1981 – 2010			CI 2001 – 2010		
		a	b	CI	a	b	CI
16001	Acuitzio del Canje	0.0534	0.0291	0.545			
16016	Carrillo Puerto	0.0565	0.0284	0.545			
16022	Cointzio	0.0475	0.0303	0.555			
16028	Cuitzillo Grande	0.0638	0.0272	0.532			
16045	El Temazcal	0.0677	0.0269	0.515	0.0480	0.0301	0.557
16052	Huingo	0.0553	0.0287	0.544	0.0482	0.0300	0.559
16055	Jesús del Monte	0.1081	0.0223	0.459	0.0729	0.0260	0.514
16081	Morelia	0.0388	0.0322	0.577	0.0345	0.0333	0.589
16087	Pátzcuaro	0.0528	0.0292	0.547	0.0495	0.0299	0.551

16091	Álvaro Obregón (DGE)	0.0647	0.0271	0.530	0.0627	0.0274	0.533*
16096	Presa Malpaís	0.0489	0.0300	0.553	0.0493	0.0299	0.553*
16105	Quirio	0.0403	0.0319	0.571	0.0281	0.0354	0.603
16114	San Miguel del Monte	0.0676	0.0267	0.524	0.0712	0.0262	0.518+
16118	Santa Fe	0.1316	0.0205	0.427	0.1547	0.0195	0.375+
16120	Santiago Undameo	0.0637	0.0273	0.529			
16145	Zinapecuaro	0.0810	0.0250	0.500	0.0576	0.0283	0.540*
16146	Zirahuen	0.1016	0.0229	0.468	0.0799	0.0252	0.499+
16221	Fruticultores	0.0547	0.0291	0.534			
16247	Capula	0.0618	0.0277	0.529			
16254	Teremendo	0.0746	0.0259	0.506	0.0794	0.0251	0.506
16512	El Colegio	0.0417	0.0315	0.570	0.0403	0.0318	0.574*
16253	Tanaco	0.0952	0.0235	0.477			

Note: Due to data availability the values with (+) were calculated with records of 8 years and the values with (*) were calculated with records of nine years.

The values of the concentration index considered by Roblero-Hidalgo *et al*. (2018) as torrential and highly torrential (CI > 0.54) during the period 1981-2010 were observed mainly in the north and northwest regions (stations 16016, 16052, 16096, and 16105) as well as in the center of the basin at stations 16022, 16081 and 16254, and a lesser extent in the south and southwest of the basin at stations 16001 and 16087, respectively. The distribution of the highest concentrations could be important concerning risk prevention since a strong concentration in the northern area could generate problems in the middle (the area where the city of Morelia is located) and lower parts of the basin.

The calculation of the concentration index for the period 2001 - 2010 was only possible in fourteen of the 22 stations used in this work because in the rest there were no records for that period, even among the fourteen stations used there are four stations that only had records for nine years and two other stations with records for only eight years. The lack of records is not a new problem, in the case of Mexico it has already been pointed out by Gay-Garcia, Estrada-Porrua, and Martinez (2010), and internationally it has been mentioned by Cortesi, Gonzalez-Hidalgo, Brunetti, and Martin-Vide (2012), Llano (2018), and Serrano-Notivoli *et al*. (2018).

The range of values observed for the period 2001 - 2010 was between 0.375 and 0.603, a range greater than that found in this work for the period 1981 - 2010 and a little higher than the range observed by Roblero-Hidalgo *et al*. (2018) in the same study area. Although it should be noted that the increase in the range within which the concentration index values oscillate occurred towards the lower limit, this was due to a single value that is below 0.499, which occurred in station 16118. Discarding this value, the range of values for the CI would be very close to that found by Roblero-Hidalgo *et al*. (2018).

On the other hand, in eleven of the fourteen stations analyzed for the period 2001 - 2010, concentration index values were higher than those observed for the period 1981 - 2010; In the same manner, ten of the fourteen stations showed values higher than those found by Roblero-

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Hidalgo *et al*. (2018), which suggests that in recent years the concentration of precipitation in some parts of the basin has increased, although this concentration is still below that reported for the state of Jalisco by Núñez-González (2020).

Sensitivity of the CI to the location of the data and the length of the records

The comparison of the precipitation concentration can be affected if a common recording period is not taken into account in the stations with which are working. In Figure 3, the results of the concentration index calculated for the sub-periods 1951-1980 and 1981-2010 of the six stations with the longest records in the study area are presented. In this figure, it can be seen that the CI value was higher for the second period of records (1981-2010), matching with the results of Benhamrouche and Martín-Vide (2012). The differences between the two sub-periods range from 3 % in the case of weather station 16145 up to 14 % in the case of station 16055. While the differences may seem small, they should not be discarded because they can be a sign that in recent years the concentration of precipitation in the Río Grande of Morelia basin has increased.

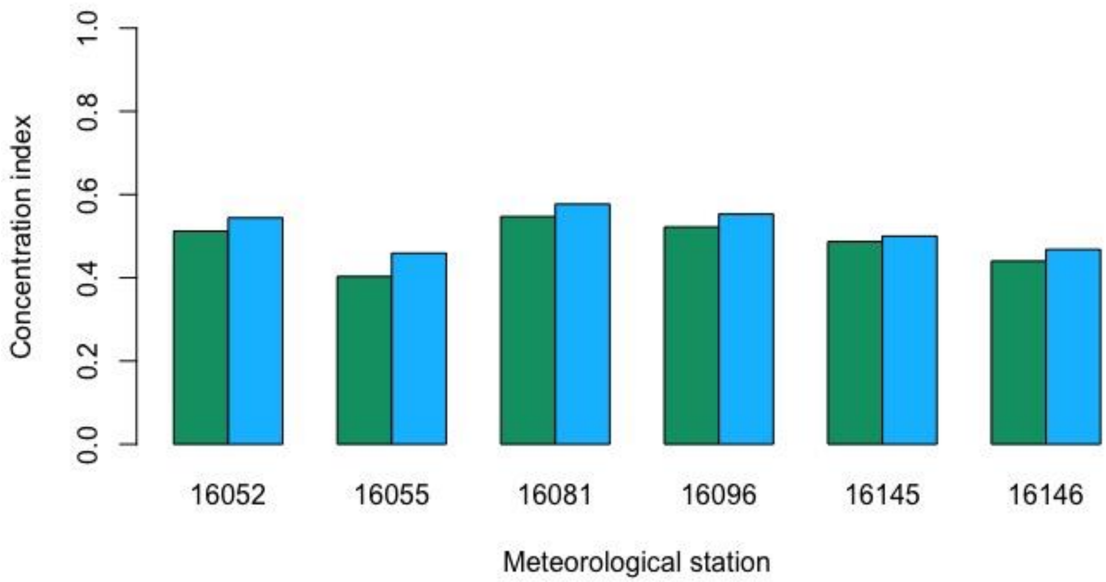

Figure 3. Sensitivity of the concentration index to the location of the records.

On the other hand, the differences observed in the CI between the two sub-periods reinforce the hypothesis that the location of the records may become an important factor when calculating the daily precipitation concentration index, especially if the objective is to compare the results between stations. Similarly, in Figure 4, it can be appreciated the effect of the length of time series in the calculated values of the CI from the data of the six stations with higher recording periods.

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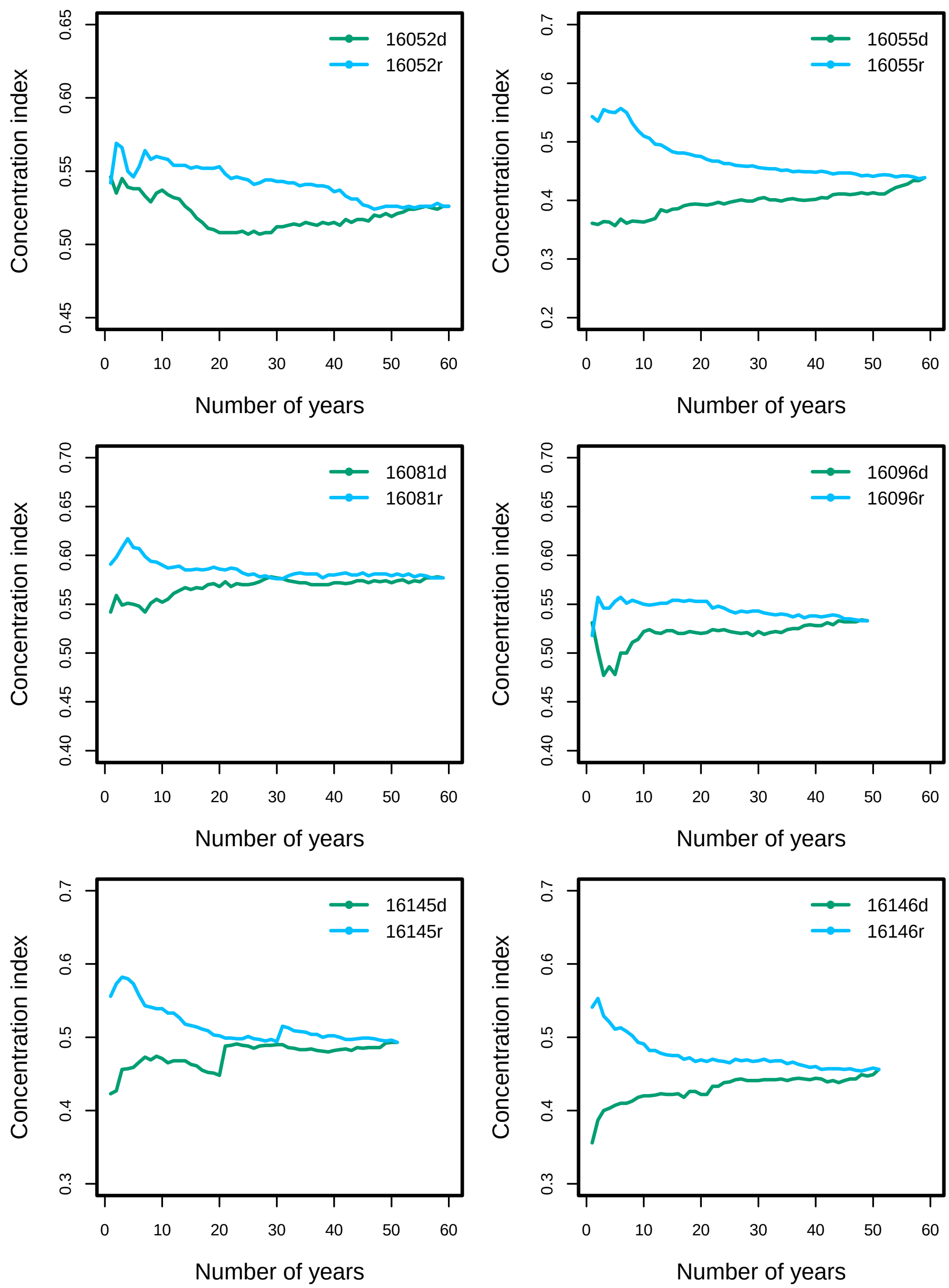

Figure 4. Sensitivity of the concentration index as a function of the length of the records. Note: The letter d after the name of the station

indicates that the series was built from start to finish and the letter r from the end to the beginning.

In five of the six stations presented in Figure 4, it can be observed that the level of variability in the concentration index is greater when the length of the records is less than 20 years, and for record lengths greater than 20 years, CI value decreases its variability. The exception to this behavior occurs in station 16052, where even for records with lengths greater than 20 years, important changes in the CI values continue to occur, that is, rapid stabilization of their values is not observed. This can be important when it is necessary to compare CI values between stations with less than 20 years of records. Although the aforementioned results correspond to a low number of stations, they are under the recommendations of the World Meteorological Organization regarding the length of the records used in the analyzes with climate data (OMM, 2007), for which it is desirable not less than 30 years of records.

The behavior of the concentration index at the annual level and for the periods 1981 - 2010 and 2001-2010

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With the data from the complete years of records, the concentration index was calculated at the annual level for each station to know the temporal variability of this index. The results are shown in Figure 5. In this figure, it can be observed that almost three-quarters of the stations (72.7 %) mainly present CI values above 0.5, which according to the works of Martín-Vide (2004), Zubieta *et al*. (2017), and Núñez-Gonzalez (2020), among others, would indicate that around 60 % of the rain is concentrated in the 25 % of the rainiest days. On the contrary, stations 16055, 16114, 16118, 16145, 16146, and 16254 have mainly concentration index values lower than 0.5, which would be the product of a more uniform distribution of rainfall throughout the year in the sites where these meteorological stations are located.

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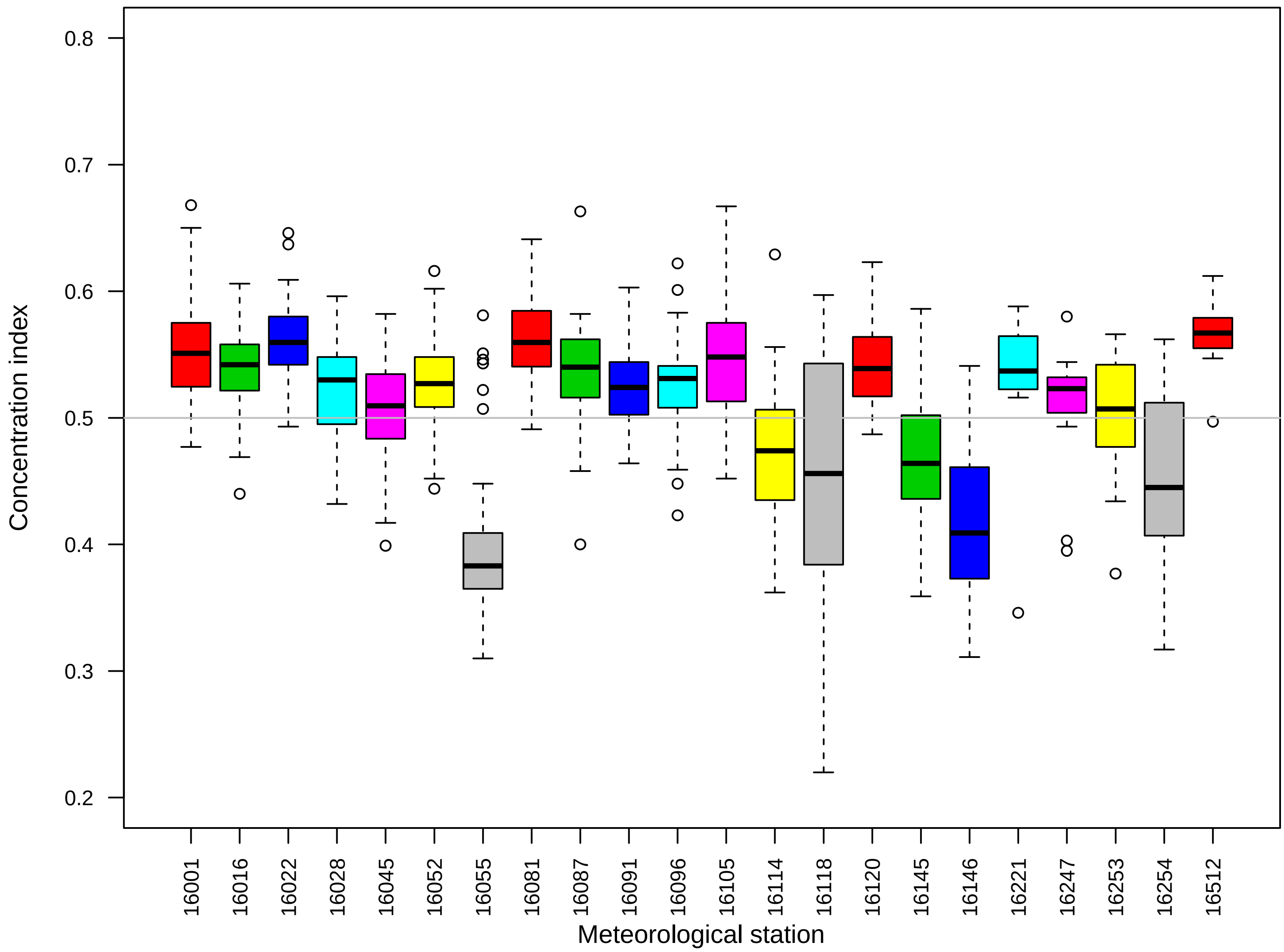

Figure 5. Distribution of the concentration index at the annual level.

The average annual values of the concentration index ranged between 0.395 and 0.567, which places the concentration of precipitation in the study area between moderate and moderate-high (Núñez-

González, 2020). In fact, in half of the stations, CI values higher than 0.6 were observed, although values of this type were observed only sporadically. Regarding the dispersion of the CI values according to the interquartile range, a high concentration of values around the median is observed except for stations 16118, 16145, 16146, and 16254.

On the other hand, Figure 6 shows the spatial distribution of the concentration index in the study area, which was obtained through the interpolation of the concentration index values of the 22 stations. For a clearer reading of the CI distribution, the isopleths with a separation of 0.01 were generated. In the distribution presented in this figure, it can be appreciated a very similar behavior to that found by Roblero-Hidalgo *et al*. (2018), in the sense that the areas with the highest concentration index values are observed in the middle and upper part of the basin, the lowest concentration values are found in the lower part of the basin.

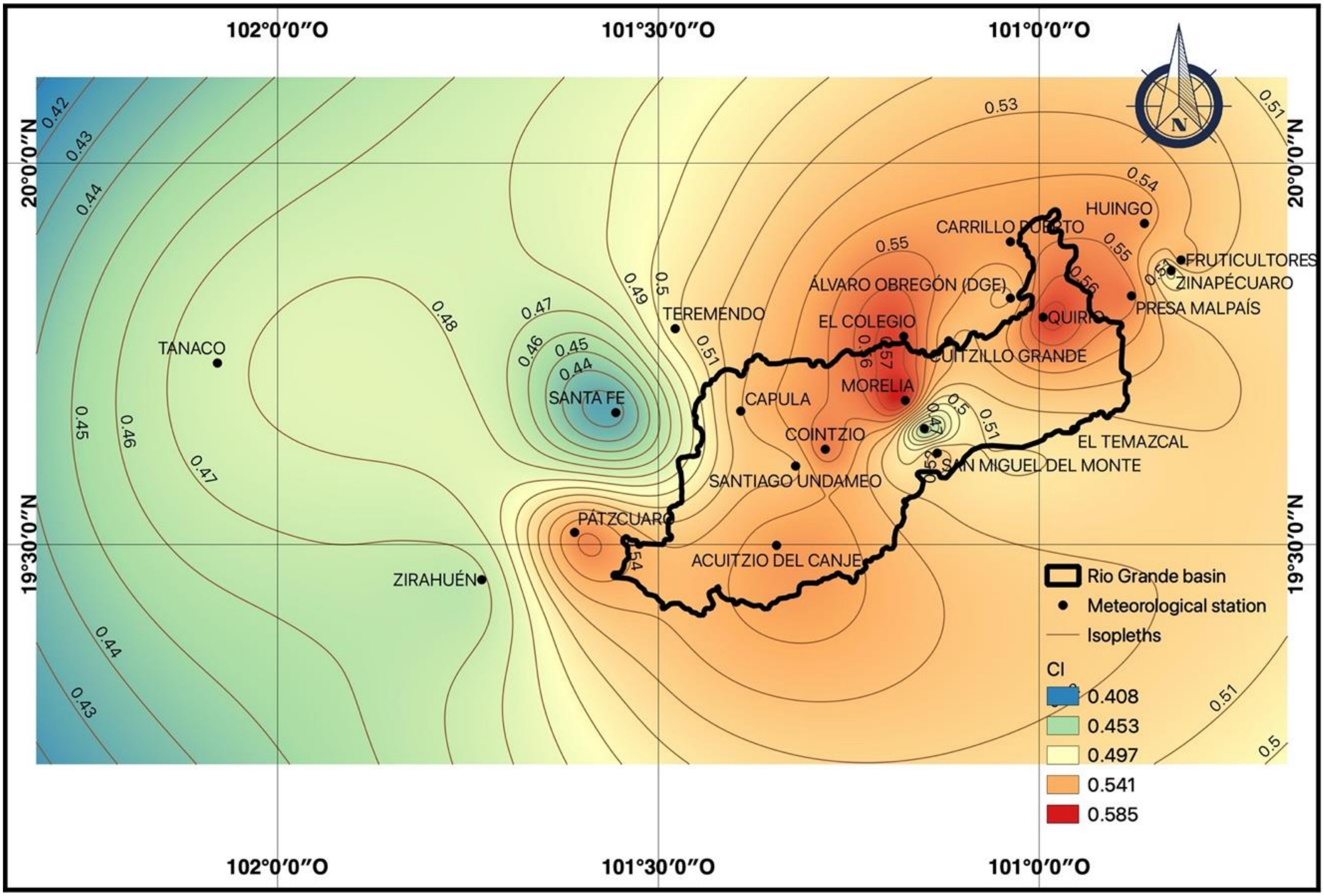

Figure 6. Spatial distribution of the concentration index.

The CI distribution mentioned above may be related to the types of climates observed in the study area since towards the upper part of the basin, there is the presence of semi-cold subhumid type climates $C(E)(w_2)(w)$ and temperate subhumid $C(w_2)(w)$, while in the middle part there is the presence of temperate subhumid climate $C(w_1)(w)$ and in the lower part of the basin the temperate climate $C(w_0)(w)$.

The coincidence in the spatial distribution of the concentration index observed in the two studies suggests a marked geographical distribution of precipitation in the study area. Also, the distribution of the highest CI values could be part of the causes that recently have caused flooding in the city of Morelia, which is located in the middle part of the basin and where the main channel of the basin is located, the Rio Grande.

Taking into account that the range of values observed for the CI between 1981 and 2010 was lower than that found by Roblero-Hidalgo *et al*. (2018), it was decided to verify whether even with the 22 stations used in this work, it could be considered that the values follow an approximately normal distribution. The above redefine the classification of torrentiality in the study area. To do this, the tests of normality aforementioned in the methodology of this work were applied and, it was found in all the tests that there is enough evidence to reject the null hypothesis at a significance level of 5 %, which states that data follow a normal distribution.

Once it was verified that the data from the 22 stations could be considered to follow an approximately normal distribution, the four levels of torrentiality were redefined following the methodology used by Roblero-Hidalgo *et al*. (2018), this methodology is based on the 0, 25, 50, 75, and 100 % quantiles to define class boundaries. The results obtained are shown in Table 2, where it is included a comparison with the results of the aforementioned investigators. Although the observed differences seem small, from 1 to 5 hundredths of the CI value, they could become important because the general variation range of this index is small, 0.427-0.577.

Table 2. Classification of the torrentiality degree of the basin

Roblero-Hidalgo *et al*. (2018) concentration index	Degree of torrentiality	Concentration index period 1981-2010
0.476-0.515	Torrential low	0.427-0.508
0.515-0.538	Medium torrential	0.508-0.531
0.538-0.560	Torrential	0.531-0.547
0.560-0.607	Highly torrential	0.547-0.577

Conclusions

The daily precipitation concentration index is a useful tool to analyze the statistical structure of rainfall at different sites, as well as to explore the possibility of risks associated with extreme precipitation events. However, when it will be used, it is necessary to be careful with the data used for its calculation since this index can be sensitive to both the temporal location of the data and the length of the records. Results obtained based on data with different recording periods can complicate comparisons, since in many cases, the results are influenced by particular climatic conditions; for example, in recent years the effects of climate change could have an influence.

On the other hand, the length of the records can also affect the values of the concentration index since this index tends to stabilize in periods longer than 20 or 30 years. In the same manner, the results show that when the concentration index is calculated at the annual level, the degree of variability is greater than when it is calculated for periods of 10 and 30 years, respectively.

The values obtained for the concentration index are within the ranges reported in the literature nationally and internationally. Moreover, these values can be classified to define the degree of torrentiality that can have precipitation within a basin.

On the other hand, the spatial distribution of the concentration of precipitation can be helpful to explain some of the causes that have generated flooding problems in recent years in the city of Morelia, Michoacan, Mexico.

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