

TEMPERATURE AND PRECIPITATION TRENDS DUE TO CLIMATE CHANGE IN THE HUIXTLA RIVER BASIN IN CHIAPAS, MEXICO

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ABSTRACT

The objective of this work was to analyze whether there is a trend in climate change in the Huixtla River basin on the Mexican Pacific coast in the State of Chiapas. To detect this, temperature and precipitation trends were analyzed using data for the 1960–2014 period and the 27 indices proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) at Des poblado, Escuintla, Finca Chicharras, Huehuetán, Huixtla, and Motozintla weather stations of the National Meteorological Service (SMN). Missing data were collected where necessary for precipitation using the U.S. National Weather Service method and for temperatures using the Climate Engine platform. The indices were obtained with RCLimDex by conducting the proposed data quality controls and classified on the basis of their statistical significance (0.05) and their increasing or decreasing trend. Among the changes found, higher temperatures were detected in the middle and lower western parts of the basin (TX90p), as well as a longer period of hot days (WSDI). The upper and lower eastern parts of the basin presented a shorter period of hot days. The upper and lower parts of the basin showed a cooling trend, with colder days (TX10p) over longer periods (CSDI). Across the basin, precipitation has increased by one and five days (RX1day and RX5day) as well as in total amount (PRCPTOT). In general, there were shorter dry periods (CDD) and longer wet periods (CWD). Rainfall above the R5mm, R10mm, R20mm, R70mm, and R150mm thresholds across the basin showed an increasing trend.

Keywords: indices, ETCCDI, RCLimDex.

INTRODUCTION

The World Meteorological Organization (WMO, 2022) defines climate change as a statistically significant variation in the average state of climate or its variability occurring continuously over a long period of time, spanning at least three decades. In this regard, the Intergovernmental Panel on Climate Change mentions change detection as the act of addressing the question of whether the climate has a statistically demonstrable change. The causes of observed changes in a natural system affected

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by climate must be established following a set of consistent methods (IPCC, 2014). These statistically measured methods link human-induced changes in climate to a deterioration in human health, plant and animal life, and marine processes.

In its sixth synthesis report, the IPCC (2023) mentions examples of key risks in different regions, with a medium confidence level, in the Central and South American region, including the risk to water security, severe impacts on human health, degradation of coral reefs, food security risk from extreme droughts, and damage to structures from natural disasters. This report also mentions that systemic barriers, such as missing information on finance and practices, including the absence of climate knowledge and data, hinder progress on adaptation.

In an attempt to answer questions about climate extremes affecting human and natural systems, indices are used that attempt to extract information from daily data, weather observations, and objectively (Zhang *et al.*, 2011). These indices are proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) as defined by Frich *et al.* (2002) and are based on the European Climate Assessment (ECA) indices (Klein Tank *et al.*, 2002) for analyzing climate trends during the second half of the 20th century. A total of 27 indices were defined.

In Mexico, the ETCCDI indices have been used in several studies, both for temperature and precipitation. Among them, Ortiz-Gómez *et al.* (2020) calculated 10 precipitation indices for the state of Zacatecas for the 1961–2014 period. Ruiz-Álvarez *et al.* (2020) obtained 11 precipitation-related indices for the entire state of Aguascalientes for the 1980–2013 period. Colorado-Ruiz and Cavazos (2021) focused on 15 precipitation frequency and intensity indices, of which eight are part of the ETCCDI list, to evaluate extreme and non-extreme daily precipitation trends for Mexico and the southern United States from 1981 to 2010.

Since 2005, on the coast of the State of Chiapas, Mexico, maximum 24-hour rainfall values and increased instantaneous flows have been observed in several watersheds in the area (Pérez-Nieto *et al.*, 2012), with the worst effects registered in the Huixtla watershed. Moreover, the Chiapas coast features an area known as the “coffee route,” which is particularly vulnerable to variations in temperature and precipitation considering that diseases such as coffee rust can intensify (Libert-Amico and Paz-Pellat, 2018).

Research carried out in the State of Chiapas concerning the use of indices for the detection of climate change trends includes the work of de la Mora-Orozco *et al.* (2016), where they analyzed data from 16 stations for the 1960–2009 period for eight indicators based on maximum and minimum temperatures and precipitation. Similarly, Figueroa-Gallegos (2016) conducted research at two meteorological stations located in the Sabinal River basin, Chiapas. It is necessary to expand research in different hydrological regions. The objective of this study was to obtain the ETCCDI climate change indices related to temperature and precipitation for the Huixtla River basin located on the coast of Chiapas and analyze their trends.

MATERIALS AND METHODS

The study area is located within hydrological region No. 23, “Costa de Chiapas,” defined by the Huixtla River basin and classified as RH23, Chiapas, by the National Water Commission (CONAGUA). In this region, only meteorological station 7077 Huixtla is located within the Huixtla River basin; the other stations used for the study are located surrounding the basin: 7038 Despoblado, 7053 Escuintla, 7057 Finca Chicharras, 7075 Huehuetán, and 7119 Motozintla of the National Meteorological Service (SMN) (Figure 1). The Huixtla River basin has an area of 828.97 km² and presents a sharp variation in altitude, ranging from 0 to 2500 m (Figure 1).

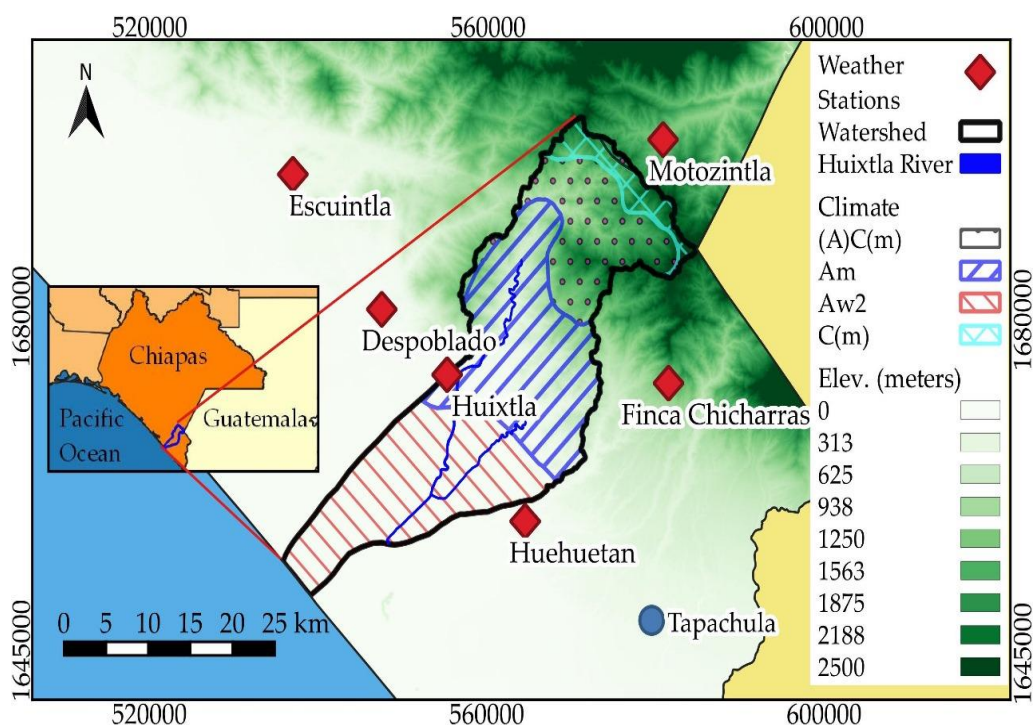


Figure 1. Location of the basin under study, the meteorological stations analyzed, their climatic classification, georeferencing, and altitude in the state of Chiapas, Mexico.

Climate and land use of the basin

The predominant climates in the basin under study (Figure 1) are warm sub-humid with summer rainfall (Aw2), warm humid with summer rainfall (Am), semi-warm humid with summer rainfall ((A)C(m)), and temperate humid with summer rainfall (C(m)) (García, 2001). It is important to note that several stations are also located in the Huehuetán River and the Despoblado River basins, which results in a larger area of analysis by having to use data from weather stations in neighboring basins.

According to the cartography Series VII of Land Use and Vegetation Scale 1:250 000 (INEGI, 2021), the main land uses and vegetation in the basin are permanent and semi-permanent rainfed agriculture, cultivated pasture, mangrove, and *tular* in the middle and lower parts of the basin, and mesophilic mountain forest, secondary arboreal, and shrubby vegetation of pine, pine-oak, and oak-pine forest in the upper part of the basin. The Chiapas coffee route is set through some of these analyzed weather stations. According to the Local Climatic Effects Chart Scale 1:250 000 (INEGI, 1984), in the period from May to October, the total rainfall in the basin ranges from 1700 to 3000 mm, with the highest rainfall in the middle part of the basin. From November to April, the annual rainfall varies from 125 mm at low elevations to 700 mm at mid-high elevations. The average maximum temperatures for most of the year range from 21 to 33 °C. Average minimum temperatures range from 12 to 21 °C in the period from May to October and from 9 to 18 °C in the period from November to April.

Weather stations

The stations were selected on the basis of their proximity to the basin under study and the length of the temperature and precipitation data records (more than 30 years), with no more than 20 % missing data (SMN, 2023). The periods of analysis were set in relation to the maximum record of each station and were defined as follows: 1965–2014 for Despoblado station, 1960–2014 for Escuintla station, 1961–2013 for Finca Chicharras station, 1965–2014 for Huehuetán station, 1961–2014 for Huixtla station, and 1960–2014 for Motozintla station. More recent years were not analyzed due to incomplete data.

Generation of missing data

Daily data series for minimum and maximum temperatures and precipitation were obtained from the National Weather Service website (SMN, 2023). These data series presented missing data for all variables on different days and years. Missing data for maximum and minimum temperatures from 1980 onwards were generated using the Climate Engine platform (<https://www.climateengine.org/>) for each weather station; for years prior to 1980, the U.S. National Weather Service (WS) method was used (Campos-Aranda, 1998). For missing precipitation data, the WS method was also used.

Data analysis and quality control

Data preparation and calculation of the 27 ETCCDI indicators was carried out as recommended in the user manual of the RClmDex software (Zhang *et al.*, 2018). Four additional user-defined parameters were also included in the analysis (frost days, summer days, ice days, and tropical night days), making a total of 31 indices (Table 1). Basic and extra data quality control was performed with the component included in the RClmDex (Zhang *et al.*, 2018). Quality control consists of identifying values inconsistent with the series or outliers, such as negative precipitation amounts, very high precipitation, rounding conditions, and data repeated on a certain number of

Table 1. List of Expert Team on Climate Change Detection and Indices (ETCCDI) indices (Zhang *et al.*, 2018).

Identification	Indicator	Definition	Unit
FD0	Frost days	Number of days in a year when daily minimum temperature (TN) < 0 °C.	Days
CDD	Consecutive dry days	Maximum number of consecutive days with daily precipitation (RR) < 1 mm.	Days
CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days in which TN < 10th percentile.	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm.	Days
DTR	Daytime temperature range	Average monthly difference between daily maximum temperature (TX) and TN.	°C
GSL	Growing season length	Annual counts between the first period of at least 6 days with daily mean temperature (TG) > 5 °C and first period (after July 1st) of 6 days with TG < 5 °C.	Days
ID0	Ice days	Number of days in a year when TX (daily maximum) < 0 °C.	Days
PRCPTOT	Total precipitation	Total annual precipitation on wet days (RR ≥ 1 mm).	mm
R10	Number of days with heavy precipitation	Number of days in a year when precipitation (PCP) ≥ 10 mm.	Days
R20	Number of days with very heavy precipitation	Number of days in a year when PCP ≥ 20 mm.	Days
R95p	Very wet days	Total annual precipitation where RR > 95th percentile.	Mm
R99p	Extremely wet days	Total annual precipitation where RR > 99th percentile.	mm
Rnn	Number of days with rain over nn mm	Number of days in a year when PCP ≥ nn mm; nn is a user-defined parameter.	Days
RX1day	Wettest day	Maximum RR during the period of interest.	mm
RX5day	Wettest 5-day period	Maximum 5-day accumulated RR during the period of interest.	mm
SDII	Simple daily intensity index	Total annual rainfall divided by the number of wet days (defined by PCP ≥ 1.0 mm) in a year.	mm day ⁻¹
SU25	Summer days	Number of days in a year when TX (daily maximum) > 25 °C.	Days
TN10p	Cold nights	Percentage of days when TN < 10th percentile.	Days
TN90p	Hot nights	Percentage of days when TN > 90th percentile.	Days
TNn	Min Tmin	Monthly minimum value of TN.	°C
TNx	Max Tmin	Monthly maximum value of TN.	°C
TR20	Tropical nights	Number of days in a year when TN > 20 °C.	Days
TX10p	Cold days	Percentage of days when TX < 10th percentile.	Days
TX90p	Hot days	Percentage of days when TX > 90th percentile.	Days
TXn	Min Tmax	Monthly minimum value of TX.	°C
TXx	Max Tmax	Monthly maximum value of TX.	°C
WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when TX > 90th percentile.	Days

days continuously (Jaimes-Rodríguez *et al.*, 2022). Homogeneity analyses were performed with the RHtests V4 module (Wang and Feng, 2013a), which performs a Maximum Penalty F-Test for maximum and minimum temperatures, and with the RHtests_flyPrcp module (Wang and Feng, 2013b) for precipitation, which performs the transPMFred algorithm also based on the Maximum Penalty F-Test. Homogenization of the data series was also performed with quantile adjustment (Wang *et al.*, 2010) when the series were not homogeneous.

Index trend

To determine the degree of change or trends in the calculated indices and their statistical significance, the system proposed by Ruiz-García *et al.* (2021) of using signs and colors was used. In addition, a sign was associated with the degree of decrease or increase (- and +, respectively), ranging from low to very high, according to the slope of the line of adjustment (Table 2). A color was assigned in the case of a statistically significant difference (0.05). Indices that did not present statistically significant relevance were left without color. This process was performed by a module included in RCLimDex (Zhang *et al.*, 2018).

Table 2. Rating system for the slope of the line and statistically significant significance of the index.

Tendency	Range	Sign and color*	Range	Sign and color*
Low	-0.01 to -0.05	-	0.01 to 0.05	+
Moderate	-0.05 to -0.1	--	0.05 to 0.1	++
High	-0.1 to -0.5	---	0.01 to 0.5	+++
Very high	< -0.5	----	> 0.5	++++

*If not statistically significant, the color is omitted.

RESULTS AND DISCUSSION

Regarding the temperature indices (Table 3), Escuintla and Despoblado stations had the most indices (seven) with a statistically significant tendency to increase, followed by Chicharras with six. Motozintla had the most significantly decreasing indices, with 11, followed by Huehuetán, which had seven. Finally, Huixtla had five significant index increases.

For temperature indices, the Escuintla and Chicharras stations showed significant increases in the summer days index (SU25), with rates of 1.43 and 13.07 days per decade, respectively. This is consistent with the findings of de la Mora-Orozco *et al.* (2016), who found that most stations had an increasing trend in this index, but with marked oscillations. This is also in agreement with Zarazúa-Villaseñor *et al.* (2014), although with a slight increase and little impact in the Southern Gulf coastal plains.

Table 3. Temperature indices for the weather stations analyzed in Chiapas, Mexico.

Index	Despoblado	Escuintla	Chicharras	Huehuetán	Huixtla	Motozintla
Latitude (°)	15.203	15.331	15.133	15.002	15.141	15.364
Length (°)	-92.558	-92.656	-92.242	-92.400	-92.486	-92.248
Altitude (m)	63	92	1328	65	40	1260
SU25	-	+++	++++	-	-	----
ID0	ND	ND	ND	ND	ND	ND
TR20	+++	++++	+	---	----	----
FD0	ND	ND	ND	ND	ND	ND
SUnn*	++++	++++	++++	----	----	----
TRnn*	-	++	++	----	--	----
GSL	+	-	+	+	-	-
TXx	+	+	+	--	--	----
TXn	+	+++	+	+	+	----
TNx	-	-	-	--	-	--
TNn	+	+	-	-	+	----
TX10p	--	----	----	++++	++++	++++
TX90p	+++	++++	+++	----	----	----
TN10p	---	-	+++	++++	+++	++++
TN90p	++++	+	-	----	+++	----
WSDI	++++	++++	+++	-	++	----
CSDI	++	+++	++++	++++	++++	++++
DTR	+	++	-	-	-	-

*The abbreviations nn refer to temperature thresholds for the stations Despoblado, Escuintla, Huehuetán, and Huixtla established at 35 °C. Chicharras and Motozintla stations have a threshold established at 28 °C. ND: no index result.

The frequency of hot days (TX90p) showed an increasing trend from high to very high significance, with values of 3.94, 2.33, and 15.01 days per decade for Despoblado, Chicharras, and Escuintla, respectively (Figure 2A). At the same stations, the SU35 index changed at a very high rate of 7.20, 31.31, and 5.34 days per decade, respectively (Figure 2B). The WSDI shifted from very high to high by 4.34, 48.09, and 4.09 days per decade (Figure 2C). For SU25, TX90p, SUnn, and WSDI indices at Huehuetán, Huixtla, and Motozintla, there were decreasing trends from high to very high, especially in Motozintla, with values for the SUnn index of 46.27, 36.82, and 33.38 days per decade (Figure 2B), and for the TX90p index of 3.08, 2.26, and 3.84 days per decade (Figure 2A). This was also seen in the SU25 and WSDI indices, but with slower rates of decline (Figure 2C).

Hot-day behavior varied across the stations analyzed. Zarazúa-Villaseñor *et al.* (2014) found a general trend of increase in the Southern Gulf Coastal Plains, a region near the sea. Given the variability in the length of hot days, it is possible to conclude that the middle and lower western parts of the basin had more days with higher temperatures

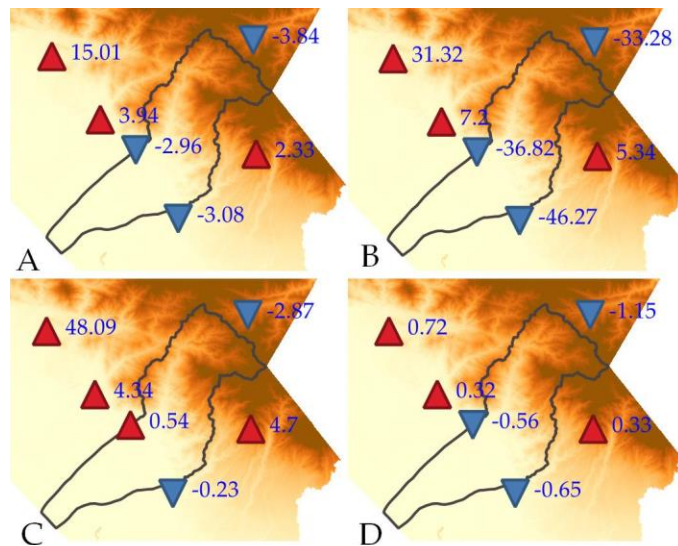


Figure 2. Temperature index trends and rates of change. A: TX90p; B: SUnn; C: WSDI; D: TXx. Δ : increase; ∇ : decrease.

(35 and 28 °C) and a longer period of hot days, whereas the upper and lower eastern parts of the basin had a shorter period of hot days and fewer days above the 28 °C threshold.

For the extreme maximum temperature (TXx) index, de la Mora-Orozco *et al.* (2016) reported a clear trend of increase in the State of Chiapas, with 10 out of 16 stations showing an increase; however, the stations they studied were not the same as the ones presented here. In this study, three stations had low increases (Despoblado, Escuintla, and Chicharras), while three had moderate to high decreases (Huehuetán, Huixtla, and Motozintla) (Figure 2D). This can be interpreted as a slight increase in extreme maximum temperatures from the center to the west of the basin, as well as a decrease in extreme maximum temperatures in the upper and lower basin.

For the frequency of cool days (TX10p), Huehuetán, Huixtla, and Motozintla showed a very high tendency of significant increase, with values of 6.62, 7.00, and 12.02 days per decade, in contrast to what was found in Despoblado, Escuintla, and Chicharras, which showed a moderate to high decrease at rates of 0.64, 3.37, and 1.5 days per decade. Similarly, the TN10p index, which measures the frequency of cool nights, increased significantly from high to very high in Huehuetán, Huixtla, Motozintla, and Chicharras (6.51, 2.92, 7.67, and 4.67 days per decade, respectively). However, the same TN10p index in Despoblado and Escuintla showed no significant decreasing trend. Zarazúa-Villaseñor *et al.* (2014) found a decreasing trend in most of the stations analyzed in the Southern Gulf Coastal Plains area, which contradicts the current frequency of cool nights.

The CSDI index or duration of the cold period increased in all stations, with values of 9.85, 17.1, 13.92, and 12.5 days per decade at Chicharras, Huehuetán, Huixtla, and Motozintla, respectively, but no significant increases in Despoblado or Escuintla. This is consistent with the behavior of the upper and lower parts of the basin, in this case with more cool days and for longer periods of time, with the latter being more generalized throughout the basin. In the middle of the basin, there was no apparent trend.

In terms of precipitation, Despoblado station had the most significant rates of change, with 12 indices overall, 10 increasing and two decreasing. This was followed by Escuintla and Motozintla, both with 10 indices, nine of which are increasing and one decreasing. Chicharras had the fewest significant trend indices (four), with three increasing and one decreasing (Table 4).

Table 4. Precipitation indices for the weather stations analyzed in Chiapas, Mexico.

Indices	Despoblado	Escuintla	Chicharras	Huehuetán	Huixtla	Motozintla
Latitude (degrees)	15.203	15.331	15.133	15.002	15.141	15.364
Length (degrees)	-92.558	-92.656	-92.242	-92.400	-92.486	-92.248
Elev. (msnm)	63	92	1328	65	40	1260
RX1day	++++	++++	+++	++++	+++	++++
RX5day	++++	++++	++++	++++	++++	++++
SDII	--	-	++	---	-	+
CDD	---	---	+++	---	---	---
CWD	+++	+++	+	++++	+++	+++
R95p	++++	++++	++++	++++	++++	++++
R99p	++++	++++	++++	++++	++++	++++
PRCPTOT	++++	++++	++++	++++	++++	++++
R0.1mm	---	-	---	++++	---	---
R5mm	++++	+++	-	++++	+++	++++
R10mm	++++	+++	+++	++++	+++	++++
R20mm	++++	+++	+++	+++	+++	+++
R70mm	+++	+	+++	+	+	+
R150mm	+	+	+	+	+	+

The RX1day and RX5day indices showed a general trend of increasing in all stations. For RX1day, there were very high significant increase rates in Despoblado, Escuintla, and Motozintla (12.25, 10.73, and 11.03 mm per decade, respectively) (Figure 3A), while the rest of the stations showed very high and high non-significant increase trends. Except for Chicharras, RX5day increased significantly at rates of 35.33, 19.85, 26.69, 15.85, and 19.95 mm per decade in Despoblado, Escuintla, Huehuetán, Huixtla, and Motozintla.

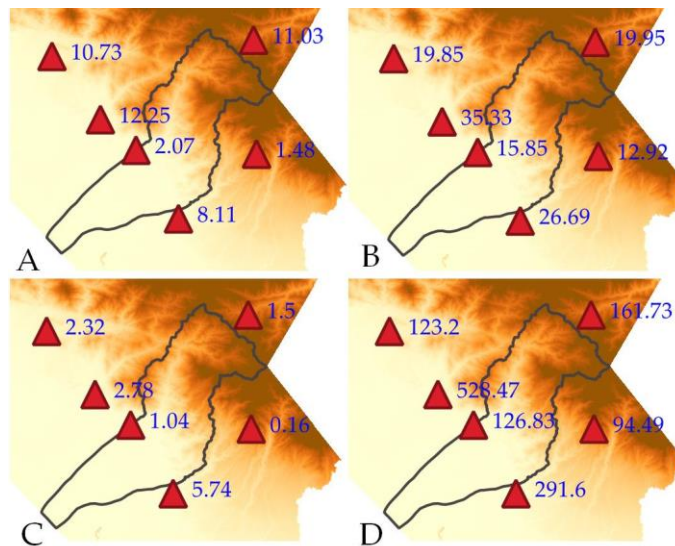


Figure 3. Precipitation trends and rates of change. A: RX1day; B: RX5day; C: CWD; D: PRCPTOT. Δ : increase.

The maximum precipitation in each month, over the course of one and five days, has increased throughout the basin, with the year 2005 highlighting the months of September and October, which experienced high precipitation in previous years. The SDII index showed only a moderately significant increase in Chicharras (0.93 mm day⁻¹ per decade) and a highly significant decrease in Huehuetán (1.65 mm day⁻¹ per decade).

For the maximum dry period duration, or CDD index, a significant, very high decrease trend was presented in most stations (4 out of 6), with rates of 19.35 days per decade in Despoblado, 5.51 days per decade in Escuintla, 16.99 days per decade in Huehuetán, and 20.92 days per decade in Motozintla, indicating dry periods of shorter duration in the basin. This is somewhat consistent with de la Mora-Orozco *et al.* (2016), who found a slight decreasing trend in CDD but no significant trend across the entire State of Chiapas.

There was a significant increase in the maximum duration of the wet period, or CWD (Figure 3C), with changes of 2.78 days per decade in Despoblado, 2.32 days per decade in Escuintla, 5.74 days per decade in Huehuetán, and 1.5 days per decade in Motozintla. The basin experienced both shorter dry periods and longer wet periods. This incremental behavior is consistent with Wootton *et al.* (2023), who found that the average length of the wet period in the Sierra Madre de Chiapas zone increased by 2.7 ± 13.6 days in the 1990–2016 period. Additionally, the wet season began earlier in lower-elevation zones.

The R95p and R99p indices showed a generalized tendency for a very high increase. R95p increased at very high rates across the stations, with values of 112.04 mm per

decade in Despoblado, 62.59 mm per decade in Escuintla, 106.7 mm per decade in Chicharras, and 55.24 mm per decade in Motozintla, but no significant increases in Huehuetán or Huixtla. R99p rates were lower than R95p but still quite high, with significant rates of 41.2 mm per decade in Despoblado, 44.75 mm per decade in Escuintla, and 19.47 mm per decade in Motozintla; however, rates at Chicharras, Huehuetán, and Huixtla were not significant.

In all of the stations analyzed, a very high increase trend was observed for the total precipitation index of wet days, or PRCPTOT (Figure 3D), which was not significant in the Chicharras station but increased at a very high rate of 94.49 mm per decade. In the remaining stations, there were statistically significant increases, with values of 528.47 mm per decade in Despoblado, 123.2 mm per decade in Escuintla, and 291.6 mm per decade in Huehuetán. This trend of increasing precipitation was consistent with what Wootton *et al.* (2023) found in their analysis of trends on the Chiapas coast, which showed increases in precipitation in June and September. As a result, total annual wet-day precipitation increased at a rapid rate across the basin, particularly along the coast.

For the annual total of days with a defined precipitation threshold (Rnmm) of 0.1, 5, 10, 20, 70, and 150 mm, the following was observed: for R0.1mm, there was no clear general trend of increase or decrease; for R5mm, there was a trend of increase in most stations from very high to high (significant in five stations), with Despoblado station having the highest rate of increase with 17.72 days per decade (Figure 4A). At R10mm (Figure 4B) and R20mm (Figure 4C), there was a similar pattern of significant increases ranging from very high to high, with Despoblado once again having the highest rate of 14.1 days per decade. The R70mm index showed a significant trend of increasing

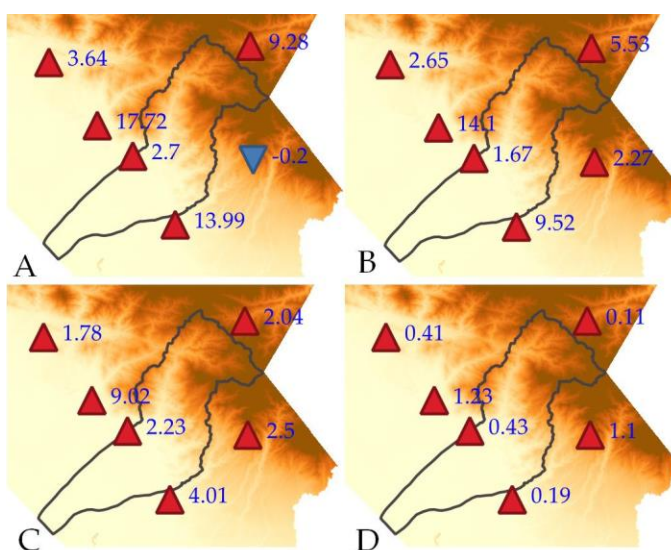


Figure 4. Trends and rates of change of Rnmm indices with defined precipitation thresholds. A: R5mm; B: R10mm; C: R20mm; D: R70mm. Δ : increase; ∇ : decrease.

from low to high at three stations, but at a slower rate than the lower rainfall Rnnmm indices; Despoblado had the highest rate at 1.23 days per decade, and Motozintla had the lowest at 0.11 days per decade (Figure 4D). Finally, in the R150mm index, there was a tendency to increase less than the R70mm, but only in Escuintla, with 0.2 days per decade.

From the behavior of the Rnnmm indices, it can be mentioned that there was a general trend of increase from very high to high in the occurrence of rainfall above the defined thresholds. The rate of change of these indices decreased when analyzing rainfall of greater magnitude, with the lowest rate in R150mm. This coincides with the occurrence of each event (0.1, 5, 10, 20, 70, and 150 mm) of rainfall during a year.

In general, these temperature and precipitation tendencies are more noticeable in the lower and upper parts, either due to their proximity to the sea or the dry zone on the Grijalva side; however, according to basin surveys, the middle parts have a good vegetation cover that has changed little over time. Although previous climate change studies have focused on the large Grijalva basin, it is the only available information on the State of Chiapas, as the Grijalva is where hydroelectric plants are located and thus the most studied area, leaving the Chiapas coastal hydrological region, which has high rainfall, water flow, and deforestation but no hydroelectric plants or storage dams (even of medium size), somewhat forgotten. On the other hand, when national studies are contracted to a single entity, accuracy suffers due to the number of weather stations considered and/or the inability to detail missing rainfall and temperature data.

CONCLUSIONS

Temperature changes in the Huixtla River basin are reflected in daily maximum threshold indices of 35 and 28 °C for the time period under consideration. Stations in the middle altitudes of the basin tend to raise their threshold to 28 °C, while those in lower or higher altitudes tend to lower their maximum threshold to 35 °C. Precipitation has also changed; most of the rainfall indices showed increasing trends, notably those related to daily (RX1day), 5-day (RX5day), and total annual wet days (PRCTOT). This results in increased rainfall across the basin and a longer wet period (CWD). These changes in precipitation are concentrated in daily rainfall greater than 5, 10, 20, and 70 mm per day.

REFERENCES

- Campos-Aranda FD. 1998. Procesos del ciclo hidrológico. Universidad Autónoma de San Luis Potosí: San Luis Potosí, México. 529 p.
- Colorado-Ruiz G, Cavazos T. 2021. Trends of daily extreme and non-extreme rainfall indices and intercomparison with different gridded data sets over Mexico and the southern United States. *International Journal of Climatology* 41 (11): 5406–5430. <https://doi.org/10.1002/joc.7225>

- de la Mora-Orozco C, Ruíz-Corral JA, Flores-López HE, Zarazúa-Villaseñor P, Ramírez-Ojeda G, Medina-García G, Rodríguez-Moreno VM, Chavéz-Durán ÁA. 2016. Índices de cambio climático en el estado de Chiapas, México, en el periodo 1960–2009. *Revista Mexicana de Ciencias Agrícolas* 13: 2523–2534.
- Figuroa-Gallegos JA. 2016. Índices de cambio climático en la cuenca del río Sabinal, Chiapas, México. *Aqua-LAC* 8 (2): 36–41. <https://doi.org/10.29104/phi-aqualac/2016-v8-2-04>
- Frich P, Alexander L, Della-Marta P, Gleason B, Haylock M, Klein Tank A, Peterson T. 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research* 19: 193–212. <https://doi.org/10.3354/cr019193>
- García E. 2001. Climas. Catálogo de metadatos geográficos. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Ciudad de México, México. <http://geoportal.conabio.gob.mx/metadatos/doc/html/clima1mgw.html> (Retrieved: May 2023).
- INEGI (Instituto Nacional de Estadística y Geografía). 1984. Conjunto de datos vectoriales del Continuo Nacional [Map]. Instituto Nacional de Estadística y Geografía. Ciudad de México, México. <https://www.inegi.org.mx/temas/climatologia/> (Retrieved: June 2023).
- INEGI (Instituto Nacional de Estadística y Geografía). 2021. Conjunto de datos vectoriales del uso de suelo y vegetación [Map]. Instituto Nacional de Estadística y Geografía. Ciudad de México, México. <http://geoportal.conabio.gob.mx/metadatos/doc/html/usv250s7gw.html> (Retrieved: June 2023).
- IPCC (Intergovernmental Panel on Climate Change). 2014. Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. 151 p.
- IPCC (Intergovernmental Panel on Climate Change). 2023. Climate Change 2023: Synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. <https://doi.org/10.59327/ipcc/ar6-9789291691647>
- Jaimes-Rodríguez J, Ibáñez-Castillo LA, Arévalo-Galarza GA, Vázquez-Peña MA, Monterroso-Rivas AI. 2022. Tendencias en la precipitación diaria de la cuenca alta Laja-Peñuelitas, Guanajuato. *Revista Mexicana de Ciencias Agrícolas* 12 (7): 1263–1274. <https://doi.org/10.29312/remexca.v12i7.2919>
- Klein Tank AMG, Wijngaard JB, Können GP, Böhm R, Demarée G, Gocheva A, Mileta M, Pashiardis S, Hejkrlik L, Kern-Hansen C *et al.* 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *International Journal of Climatology* 22 (12): 1441–1453. <https://doi.org/10.1002/joc.773>
- Libert-Amico A, Paz-Pellat F. 2018. Del papel a la acción en la mitigación y adaptación al cambio climático: la roya del café en Chiapas. *Madera y Bosques* 24. <https://doi.org/10.21829/myb.2018.2401914>
- Ortiz-Gómez R, Muro-Hernández LJ, Flowers-Cano RS. 2020. Assessment of extreme precipitation through climate change indices in Zacatecas, Mexico. *Theoretical and Applied Climatology* 141 (3): 1541–1557. <https://doi.org/10.1007/s00704-020-03293-2>
- Pérez-Nieto S, Arellano-Monterrosas JL, Ibáñez-Castillo LA, Hernández-Saucedo FR. 2012. Estimación de la erosión hídrica provocada por el huracán Stan en las cuencas costeras de Chiapas, México. *Terra Latinoamericana* 30 (2): 103–110.
- Ruiz-Álvarez O, Singh VP, Enciso-Medina J, Ontiveros-Capurata RE, dos Santos CAC. 2020. Observed trends in daily extreme precipitation indices in Aguascalientes, Mexico. *Meteorological Applications* 27 (1): e1838. <https://doi.org/10.1002/met.1838>

- Ruiz-García P, Conde-Álvarez C, Gómez-Díaz JD, Monterroso-Rivas AI. 2021. Projections of local knowledge-based adaptation strategies of Mexican coffee farmers. *Climate* 9 (4): 60. <https://doi.org/10.3390/cli9040060>
- SMN (Servicio Meteorológico Nacional). Climatología diaria 2023. Gobierno de México. Comisión Nacional del Agua. Servicio Meteorológico Nacional. Ciudad de México, México. <https://smn.conagua.gob.mx/es/> (Retrieved: September 2023).
- Wang XL, Feng Y. 2013a. RHtests V4 user manual. Climate Research Division. Atmospheric Science and Technology Directorate. Science and Technology Branch, Environment Canada. Toronto, Canada. <http://etccdi.pacificclimate.org/software.shtml> (Retrieved: May 2023).
- Wang XL, Feng Y. 2013b. RHtests_dlyPrpc user manual. Climate Research Division. Atmospheric Science and Technology Directorate. Science and Technology Branch, Environment Canada. Toronto, Canada. <http://etccdi.pacificclimate.org/software.shtml> (Retrieved: May 2023).
- Wang XL, Chen H, Wu Y, Feng Y, Pu Q. 2010. New techniques for the detection and adjustment of shifts in daily precipitation data series. *Journal of Applied Meteorology and Climatology* 49 (12): 2416–2436. <https://doi.org/10.1175/2010JAMC2376.1>
- WMO (World Meteorological Organization). 2022. FAQs—Climate. World Meteorological Organization. Geneva, Switzerland. <https://public.wmo.int/en/about-us/frequently-asked-questions/climate> (Retrieved: May 2023).
- Wootton A, Enríquez PL, Navarrete-Gutiérrez D. 2023. Regional patterns of vegetation, temperature, and rainfall trends in the coastal mountain range of Chiapas, Mexico. *Atmósfera* 36 (1): 91–122. <https://doi.org/10.20937/atm.53026>
- Zarazúa-Villaseñor P, Ruiz-Corral JA, Ramírez-Ojeda G, Medina-García G, Rodríguez-Moreno VM, de la Mora-Orozco C, Florez-López H, Durán-Puga N. 2014. Índices de extremos térmicos en las Llanuras Costeras del Golfo Sur en México. *Revista Mexicana de Ciencias Agrícolas* 5 (10): 1843–1857.
- Zhang X, Alexander L, Hegerl GC, Jones P, Tank AK, Peterson TC, Trewin B, Zwiers FW. 2011. Indices for monitoring changes in extremes based on daily temperature and precipitation data. *WIREs Climate Change* 2 (6): 851–870. <https://doi.org/10.1002/wcc.147>
- Zhang X, Feng Y, Chan R. 2018. Introduction to RCLimDex v1.9. Climate Research Division. Toronto, Canada. <https://github.com/ECCC-CDAS/RCLimDex/blob/master/inst/doc/manual.pdf> (Retrieved: May 2023).

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