Analysis of trends in two climatic variables in the city of Ocotlán, Jalisco

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Abstract: Global warming affects all inhabited areas of the planet, but its impacts vary significantly across regions. The assessment of local-scale climate trends is fundamental for the development of effective mitigation and adaptation strategies. Currently, there is a lack of studies focused on analyzing climatic behavior and climat-change impacts in the city of Ocotlán, Jalisco. This study analyzes temperature and precipitation trends in Ocotlán, based on data recorded by the "El Fuerte" meteorological station from the National Water Commission. Temperature anomalies were calculated, and the Mann-Kendall test together with Kendall's correlation were applied to detect significant trends. Sen's slope was also estimated to quantify the magnitude of these trends. Additionally, monthly mean plots were generated to visualize the temporal evolution of the variables throughoutthe year. The results indicated an increase in mean temperature and daily thermal range, suggesting signs of climate change. Although precipitation did not exhibit a statistically significant trend, its negative correlation with maximum temperature may indicate a potential future decline in rainfall. These findings contribute to a better understanding of local climatic conditions and provide relevant information for decision-making in key sectors such as agriculture, public health and urban planning.

Keywords: climate change, temperature, precipitation, local climate analysis, trend detection

Introduction

Currently, the planet is facing a global process of climate change, manifested as a sustained increase in the mean atmospheric temperature. This global warming has increased the frequency of extreme weather events and has altered meteorological patterns (Clarke *et al*., 2022). These effects include severe heat waves, intensified precipitation, prolonged drought periods, and an increase in the frequency and intensity of tropical cyclones, among other phenomena, which have significantly affected the water cycle and agricultural production (Pörtner *et al*., 2022). Consequently, they have contributed to a decline in food security and compromised water security (Blunden & Boyer, 2024). The Intergovernmental Panel on Climate Change (IPCC, 2021) has unequivocally stated that greenhouse gases (GHGs), derived from human activities, are the main cause of global warming.

On the other hand, climate change affects all inhabited regions of the planet, although its impacts vary in intensity depending on geographical and environmental conditions. Therefore, a climate assessment at the local scale can provide key information for making more precise decisions regarding mitigation and adaptation to region-specific climate impacts (Doblas-Reyes *et al*., 2021). Among the most relevant climate variables are temperature and precipitation, fundamental physical parameters that determine the environmental conditions of a region (Khavse, Chaudhary, & IMD, 2022). Their analysis relies on statistical methods of climate trend and variability, to identify significant patterns supporting the detection of local climatic changes.

The city of Ocotlán, Jalisco, while having been included in studies on climate change at the regional or state level, has not been evaluated individually. Therefore, this lack of studies represents a significant knowledge gap, that limits the community's capacity to make informed decisions and design adaptation strategies in the face of climate change.

Therefore, the objective of this study is to analyze precipitation and temperature variables (maximum, mean, and minimum) for the period from 1961 to 2024, obtained from the "El Fuerte" meteorological station operated by Nacional Water Commission (CONAGUA) in Ocotlán, Jalisco, in order to detect trends in these variables and identify the warmest months of the year and the months of the rainy season.

Materials and Methods

Study area

The study area corresponds to the municipality of Ocotlán, located in the Ciénega region of the state of Jalisco, Mexico. The municipal seat is situated at 20°21′2.88″ N and 102°46′17.76″ W, at an elevation of 1,530 m above sea level.

Figure 1. Location map of Ocotlán, Jalisco (IIEGE, 2024)

The municipality of Ocotlán covers an area of 226 km², of which 68.1% is allocated to agricultural use, 8.7% corresponds to urban settlements, 16.8% to tropical forest, 3.1% to temperate forest, 2.2% to grassland, 1.0% to water bodies, and 0.05% shows an apparent absence of vegetation. The predominant climate is semi-warm and sub-humid (IIEG, 2024).

Meteorological data for the analysis of temperature and precipitation were obtained from the CONAGUA climatological station "El Fuerte" (ID 14047), located in Ocotlán, Jalisco (20°19'51" N, 102°45'48" W; 1,540 m a.s.l.). The station provides daily records of precipitation, evaporation, maximum temperature, and minimum temperature. Mean temperature was calculated as the arithmetic average of the daily maximum and minimum values. The dataset spans a 62-year period (1961–2024). However, 1986 was excluded from the analysis due to the complete absence of records for reasons not specified by the data provider.

Calculation of anomalies

One of the methods used to identify warming or cooling trends is the calculation of temperature anomalies. A temperature anomaly denotes the deviation of an observed temperature from a long-term reference mean (NOAA, 2025). It is computed as the difference between the annual mean temperature of a given year and the mean temperature of the reference period. The reference period typically spans at least 30 years. A positive anomaly indicates that the year was warmer compared to the reference period, while a negative anomaly reflects a relative cooling (NOAA, 2025). For the calculation of mean temperature anomalies in this study, anomalies were calculated as the difference between the annual average temperature recorded from 1961 to 2024 and the mean temperature of the reference period (1961 to 1991). Data analysis and graphical representation were performed using Microsoft Excel.

Mean plots and analysis of variance

For this study, mean plots were used as a visual tool to represent the averages of the analyzed variables and to observe their temporal trends. A plot was constructed for each variable with the aim of identifying its monthly behavior (Figure 3). Because the data did not meet the assumptions of normality and homoscedasticity, the analysis of variance (ANOVA) was performed using generalized linear models (GLM) with a Gaussian distribution. Mean comparisons were conducted using Tukey's test ($\alpha = 0.05$). All statistical analyses were performed in R software, version 4.4.2 (R Core Team, 2025).

Kendall's correlation

Kendall's correlation, also known as Kendall's tau (τ), is a non-parametric measure that assesses the association between two quantitative or ordinal variables. This coefficient makes it possible to identify the presence of a monotonic (increasing or decreasing) relationship between variables, without assuming a normal distribution of the data (El Hashash & Shiekh, 2022).

Mann-Kendall test

The Mann–Kendall test is a widely used non-parametric method for detecting trends in time series data. This test is based on comparing the relative magnitudes between pairs of observations. One of its main advantages is that it does not require the data to conform to any specific distribution (Khavse, Chaudhary, & IMD, 2022). The Mann–Kendall statistic (S) is defined as shown in Equation 1.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad \textbf{(1)}$$

where: n: number of years; xj y xk : annual values in years *j* and *k*, respectively, with *j* < *k*; sgn is the sign function.

A positive value of *S* indicates an increasing trend, whereas a negative value indicates a decreasing trend. After computing *S*, it is necessary to calculate the probability associated with this value and the sample size *n* to statistically assess the significance of the trend. For sample sizes greater than 10, a normal approximation of the Mann–Kendall test can be used (Khavse, Chaudhary, & IMD, 2022). To apply this approximation, the variance of *S* is first computed (Equation 2), and then the standardized test statistic (*Z*) is calculated based on the value of *S*, as shown in Equation 3.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad \textbf{(2)}$$

where: q: number of tied groups (groups with equal values); t_p: number of data points in group p.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} \; if\ S > 0 \\ 0\ si\ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} \; if\ S < 0 \end{cases} \quad \textbf{(2)}$$

Sen's slope

Sen's slope estimator is a non-parametric technique used to estimate the annual rate of change of a variable. It provides a reliable estimate of the trend slope under the assumption of linearity and does not require any specific distributional assumptions for the data being analyzed (Mehmood *et al*., 2024). Kendall's correlation, the Mann–Kendall test, and Sen's slope estimator were computed using R software, version 4.4.2 (R Core Team, 2025).

Results and Discussion

Temperature anomalies

The annual temperature anomalies recorded between 1961 and 2024 reveal alternating periods of warmer and cooler years, but overall they show a clear warming trend (dotted red line, Figure 2). Positive anomalies have increased in magnitude over time, with the highest value occurring in 2024. This finding aligns with global observations: the World Meteorological Organization (WMO, 2025) reported that 2024 was the warmest year on record. Year-to-year temperature variability can be influenced by natural factors such as solar activity and internal climate variability, including El Niño and La Niña events. These processes can modulate, and sometimes temporarily mask, the effects of human-driven global warming at regional and short-term scales (IPCC, 2021).

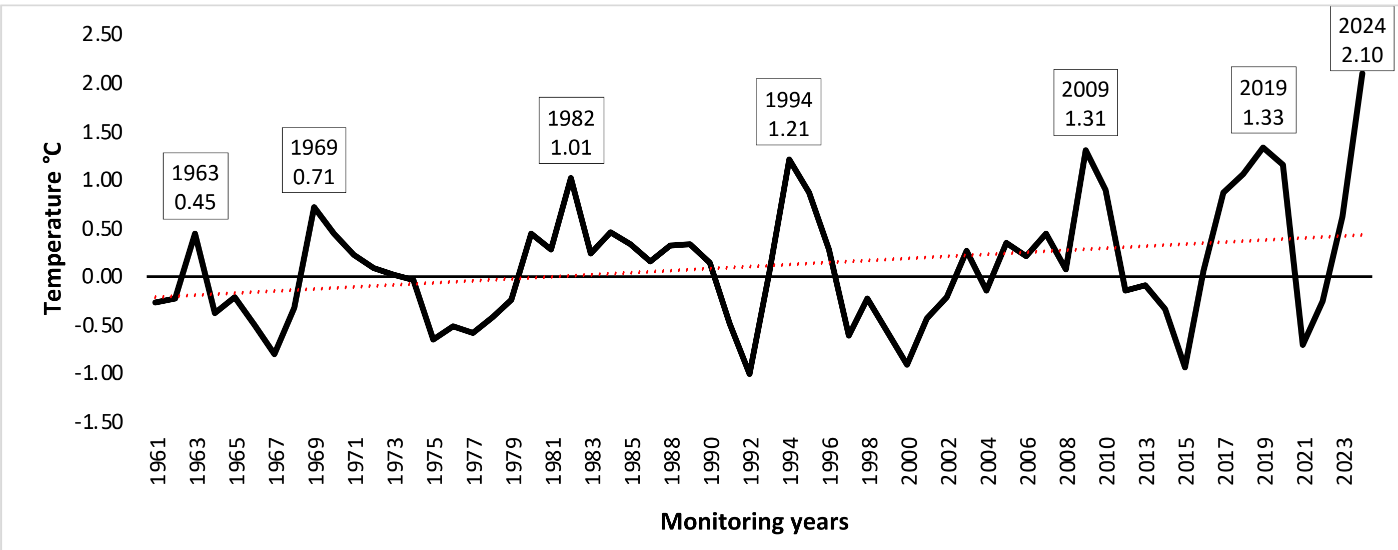

Figure 2. Temperature anomaly plot

It is important to highlight that the results of the temperature anomalies already reflect the manifestation of climate change. Nevertheless, it would be relevant for future studies to further investigate the identification of the natural phenomena and internal climate variability that influence the climate of the city of Ocotlán. This knowledge would be fundamental for improving the capacity for response and planning in short and medium-term decision-making.

Trends of the variables across the months of the year.

The evaluated temperature variables (minimum, mean, and maximum) show similar trends across the 12 months of the year, unlike precipitation, which exhibits a different pattern (Figure 3). Statistical analysis revealed a significant effect of month on maximum temperature (F = 2221; df = 11, 21816; P < 0.001), mean temperature (F = 5022.8; df = 11, 21816; P < 0.001), minimum temperature (F = 4277.3; df = 11, 21816; P < 0.001), and precipitation (F = 280.14; df = 11, 21816; P < 0.001). May was identified as the warmest month of the year, with average values of 31.4 °C for maximum temperature and 23.4 °C for mean temperature, followed by April and June. The lowest temperatures for these variables (mean and maximum) were observed in January and December. Regarding minimum temperature, the highest value occurred in June (16.4 °C), followed by May, July, and August, while the lowest values were recorded in December and January (7.4–8.2 °C) (Figure 3). These colder months are strongly associated with frost events and cold fronts in recent years, which have caused economic losses in agriculture. Therefore, the warmest months in Ocotlán are April, May, and June. Lino (2022) points out that in May, solar rays hit the Earth's surface in Jalisco perpendicularly, which contributes to a significant increase in temperature during that month. Although this phenomenon is repeated later in the year, its thermal effect is attenuated by the presence of rainfall.

Regarding precipitation, although it is present throughout the year, its volume is minimal outside of the rainy season, which begins in May, intensifies between June and August, reaches its peak in July, and ends in November (Figure 3).

This seasonality is consistent with the pattern observed at the state level, which is primarily influenced by the rainy period associated with factors such as the tropical cyclone season (Lino, 2022).

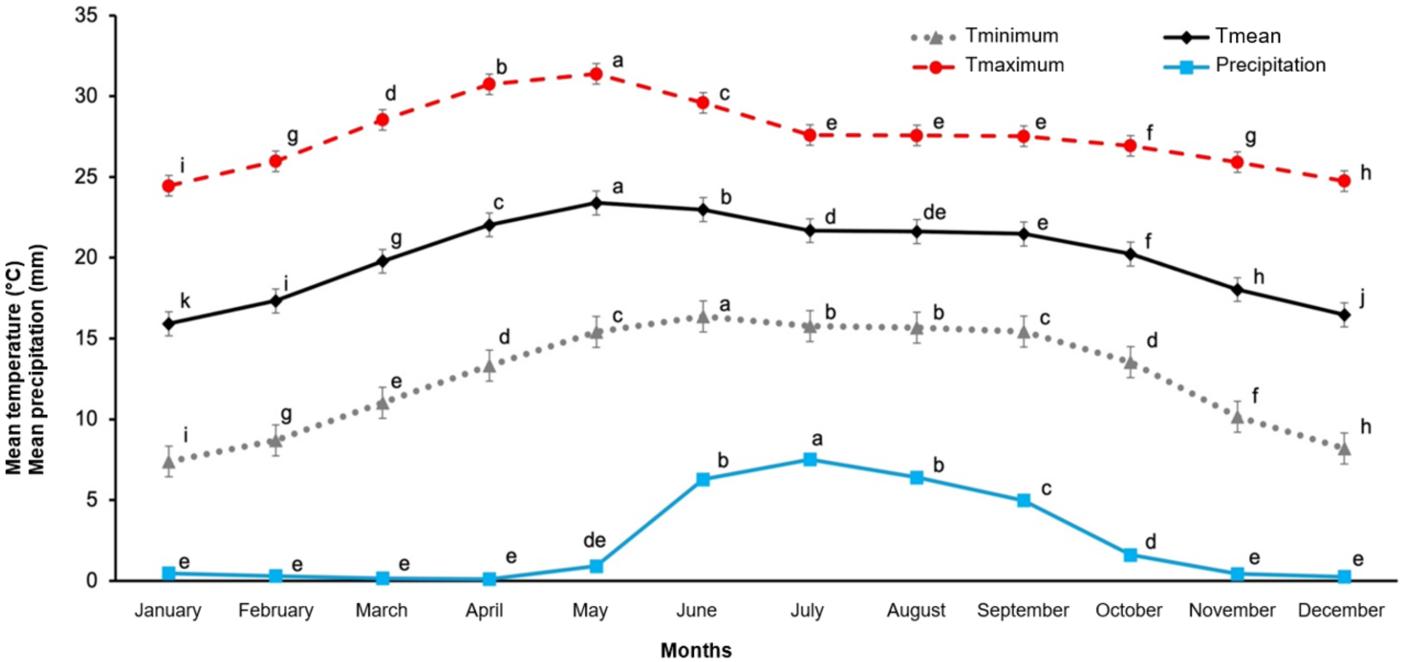

Figure 3. Mean ± SD of the studied variables (maximum, mean, and minimum temperature, and precipitation) corresponding to Ocotlán, Jalisco. Means sharing the same letter are not significantly different (Tukey's test, α = 0.5)

Kendall correlation, Mann–Kendall tests, and Sen's slope estimator

Regarding the Kendall correlation analyses (Figure 4), a significant negative correlation was observed between minimum temperature and time (Figure 4A; Table 1), indicating a progressive decrease in minimum temperature at a rate of −3.2e−05 °C per year. This suggests that Ocotlán is experiencing increasingly colder nights, which may have important implications, particularly for the agricultural sector. In contrast, mean temperature showed a significant positive correlation with time (Figure 4B; Table 1), with an increasing rate of 1.2e−05 °C per year, indicating a sustained rise in overall heat overtime. Similarly, maximum temperature exhibited a significant upward trend at a rate of 8.9e−05 °C per year (Figure 4C; Table 1), confirming an increase in daytime temperatures. The rise in mean temperature—driven primarily by the increase in maximum temperatures—represents a clear indicator of climate warming.

This pattern also reflects an increase in the daily thermal amplitude, a climate-change–related phenomenon that has been documented globally (Simolo & Corti, 2022) and is now evident in Ocotlán. Future studies should examine this variable in more detail, along with the extreme maximum temperature index (TXx) and the extreme minimum temperature index (TNn). At the state level, a significant increase in maximum temperature has been reported, while minimum temperature shows a non-significant decreasing trend (Lino, 2022). It is possible that local factors in Ocotlán, such as surface characteristics and land use, are contributing to this decrease in minimum temperature.

On the other hand, precipitation presents a negative correlation with time, although this is not statistically significant (Figure 4D, Table 1); which suggests high interannual variability or a more complex effect. This reinforces the need to continue monitoring this variable in subsequent years, due to its relevance to water availability and agricultural application.

Other significant correlations were identified between temperature variables (minimum, mean, and maximum) and precipitation (Figure 5), which is relevant for understanding climate interactions in the region. In particular, it was observed that the minimum temperature and the mean temperature show a positive correlation with precipitation (Figure 5A, B), suggesting that, in general, higher minimum and mean temperatures coincided with greater precipitation records. This pattern can help interpret the apparent negative—though not significant—trend of precipitation observed over the years (Table 1, Figure 4D). In contrast, the maximum temperature showed a significant negative correlation with precipitation (Figure 5C), indicating that as maximum temperatures increase, precipitation tends to decrease.

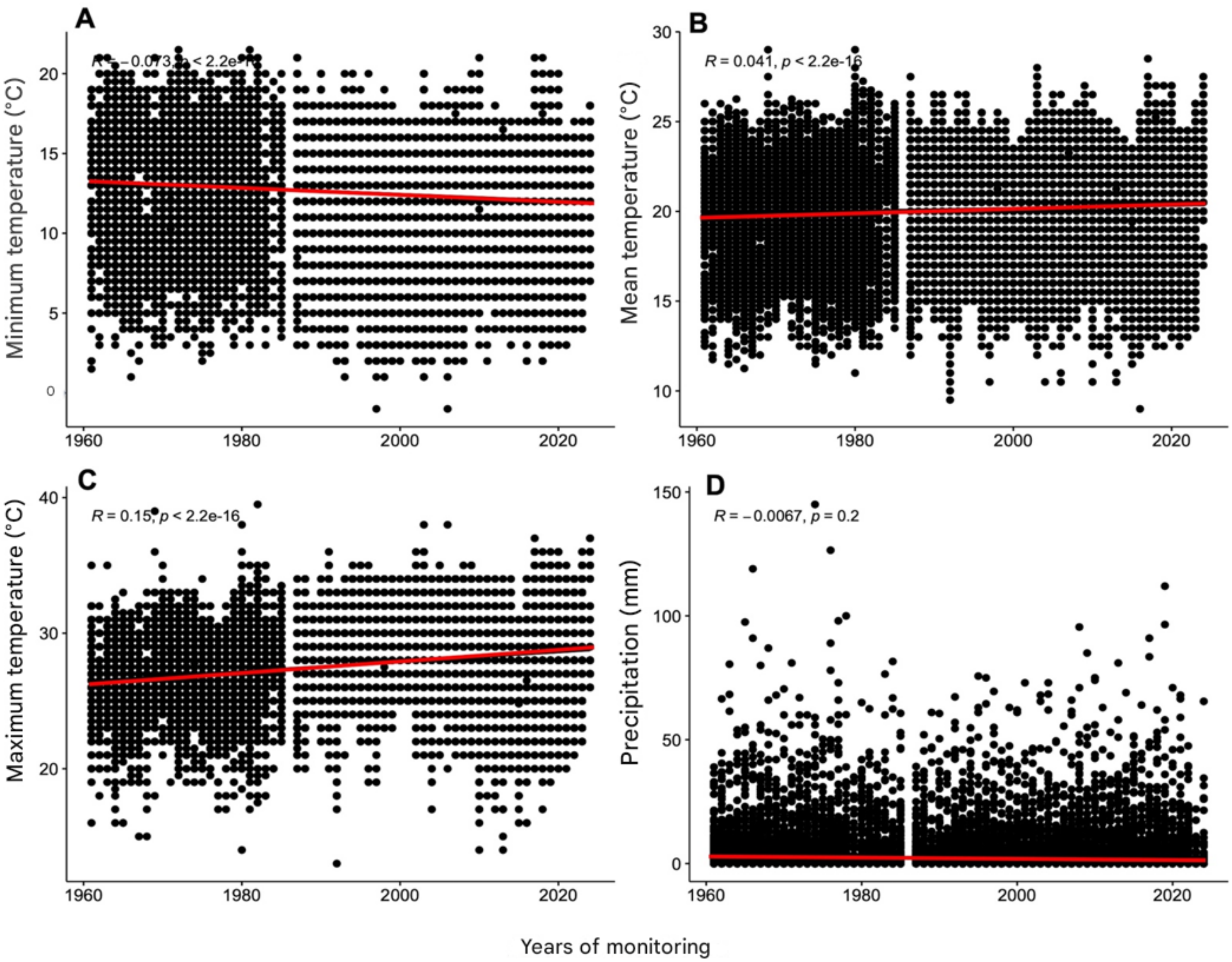

Figure 4. Kendall correlation of variables: A) Minimum temperature vs. time B) Mean temperature vs. time C) Maximum temperature vs. time D) Precipitation vs. time

Table 1. Statistical summary of the Mann–Kendall test for each variable under study with respect to the years

Variable	S	Z	P-value	R and trend	Sen's slope
Minimum temperature	-1.614581e+07	-15.06	p-value < 2.2e-16	R=-0.07 Negative trend	-3.2e-05 °C/year
Mean temperature	9.438886e+06	8.79	p-value < 2.2e-16	R=0.04 Positive trend	1.2e-05 °C/year
Maximum temperature	3.431826e+07	32.07	p-value < 2.2e-16	R=0.15 Positive trend	8.9e-05 °C/year
Precipitation	-7.464290e+05	-0.95	p-value = 0.3434	R=-0.007 Negative trend	0 mm/year

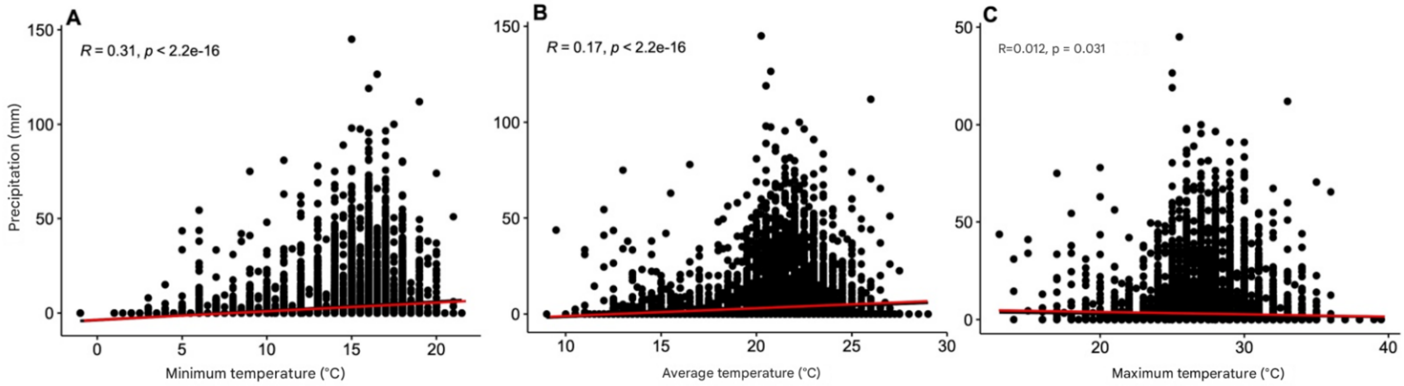

Figure 5. Correlation between the studied variables

The relationship between precipitation and temperature has been the subject of numerous international studies, which show variable results depending on the local conditions of each region. These analyses help improve understanding of climate behavior and support the development of more accurate predictive models. However, in Mexico, comprehensive studies examining the relationship between these variables are still limited, which constrains the ability to adequately interpret the observed climatic patterns (Becerril, Munguía, & del Rivero, 2024).

Conclusions

In the present study, the trends of temperature and precipitation in the city of Ocotlán, Jalisco, were evaluated based on data recorded by the CONAGUA "El Fuerte" meteorological station. The results provide evidence of an increase in mean temperature, as well as an increase in daily thermal amplitude, both considered consistent indicators of climate change. In contrast, precipitation did not exhibit a statistically significant trend; however, due to its negative correlation with maximum temperature, it cannot be ruled out that a significant decrease in precipitation levels may be recorded in the future. Likewise, it was observed that the warmest months of the year and the rainy season in Ocotlán coincide with patterns reported by previous state-level studies, which reinforces the validity of the observed results.

The findings of this research represent a relevant contribution to the urban context of Ocotlán by enhancing the understanding of its climate and the effects of climate change. These aspects should be considered in decision-making processes related to agriculture, urban planning, and public health. Nevertheless, much remains to be investigated regarding local climate dynamics and the potential impacts of climate change in the region.

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Author contributions: J.R-P. and S.C.-E: writing and analysis and interpretation of data; U. M.-Q: data collection, A.J. V.-B: provide materials, F.Z: conceptualization, design, and editing.

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