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Spatio-Temporal Trends of Monthly and Annual Precipitation in Aguascalientes, Mexico

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Abstract: The objective of this research was to analyze the temporal patterns of monthly and annual precipitation at 36 weather stations of Aguascalientes, Mexico. The precipitation trend was determined by the Mann–Kendall method and the rate of change with the Theil–Sen estimator. In total, 468 time series were analyzed, 432 out of them were monthly, and 36 were annual. Out of the total monthly precipitation time series, 42 series showed a statistically significant trend ($p \leq 0.05$), from which 8/34 showed a statistically significant negative/positive trend. The statistically significant negative trends of monthly precipitation occurred in January, April, October, and December. These trends denoted more significant irrigation water use, higher water extractions from the aquifers in autumn–winter, more significant drought occurrence, low forest productivity, higher wildfire risk, and greater frost risk. The statistically significant positive trends occurred in May, June, July, August, and September; to a certain extent, these would contribute to the hydrology, agriculture, and ecosystem but also could provoke problems due to water excess. In some months, the annual precipitation variability and El Niño-Southern Oscillation (ENSO) were statistically correlated, so it could be established that in Aguascalientes, this phenomenon is one of the causes of the yearly precipitation variation. Out of the total annual precipitation time series, only nine series were statistically significant positive; eight out of them originated by the augments of monthly precipitation. Thirteen weather stations showed statistically significant trends in the total precipitation of the growing season (May, June, July, August, and September); these stations are located in regions of irrigated agriculture. The precipitation decrease in dry months can be mitigated using shorter cycle varieties with lower water consumption, irrigation methods with high efficiency, and repairing irrigation infrastructure. The precipitation increase in humid months can be used to store water and use it during the dry season, and its adverse effects can be palliated with the use of varieties resistant to root diseases and lodging. The results of this work will be beneficial in the management of agriculture, hydrology, and water resources of Aguascalientes and in neighboring arid regions affected by climate change.

Keywords: climate change; global warming; climate variability; weather stations; Mann–Kendall; Theil–Sen; time series; IPCC; growing season; spring–summer crops

1. Introduction

One of the main climatological challenges is to verify the presence of climate change and to quantify its magnitude. It is believed that anthropogenic greenhouse gasses are the leading cause of the warming that occurred in the second half of the 20th century [1], which has led to a climate change characterized by altering meteorological variable patterns [2]. The Intergovernmental Panel on Climate Change (IPCC) states that the global annual mean temperature increased around 0.65–1.06 °C during 1880–2012 [3]. Additionally, it is reported that during the 20th century, annual mean precipitation increased between 7% and 12% in high and middle (30°–85°) latitudes of the northern hemisphere, and just increased 2% in latitudes from 0° to 55° in the southern hemisphere [4]. Climate change affects the world population, so it is vital to determine its characteristics and then generate decisive actions of adaptation and mitigation.

Precipitation is the main path in which water enters the terrestrial surface and is the engine that propels the dynamics of ecosystems. Precipitation is water deposition, either in a solid or liquid form, and is precipitated from the atmosphere to the earth. For water droplets to get precipitated, the atmosphere must contain enough moisture, which can come from soil evaporation and oceans; with the help of wind, this moves by advection until the extent of saturating the air [5]. Due to the causes that originate it, precipitation can exhibit a significant temporal and spatial variability; this variability is responsible for hydrological problems, such as floods, droughts, landslides, and erosion, among others [5]. Precipitation is a critical component of the rain–runoff relationships and a factor that plays a fundamental role in agricultural production and desertification [6,7]. So, precipitation studies are invaluable, since they can help predict problems that threaten the natural resources and economic activities of a region.

The temporal precipitation trend is an indicator of climate change. At the global level, there is a need to know the temporal pattern of precipitation and adopt it as evidence of climate change [8]. One of the more significant potential consequences of climate change is the alteration in the regional hydrological cycle and changes in the river flow regimes (floods or low flows) [9]. The extreme surface temperature leads to higher evaporation rates and permits the atmosphere to transport larger water vapor quantities, which leads in turn to a more accelerated hydrological cycle [10]. According to [6], for scientists who study the atmosphere, one of the most significant problems is the description and analysis of precipitation variability. According to [8], the study of precipitation patterns is vital for understanding its future behavior; any change in precipitation is linked to socioeconomic phenomena, and changes in precipitation patterns represent most of the changes in the terrestrial atmospheric system. The authors of [11] state that the identification of precipitation trends plays an essential role in climate change adaptation and water resources management. In Trinidad, [12] analyzed trends in the monthly, seasonal, and annual precipitation; they reported that out of six weather stations utilized, just one showed a statistically significant trend in May, June, July, annual precipitation, dry season, and humid season. The authors of [13] studied the trends, variability, and seasonality of the maximum annual daily precipitation in the upper Vistula Basin, Poland. They found positive and significant trends, so that precipitation increases are expected. They also commented that the maximum daily precipitation occurred with a higher frequency between May and September and that in these months, 88% of the days with the highest daily precipitation occur. In the same way, Gemmer et al. [14] analyzed the monthly precipitation trends at 160 weather stations in China. They found that the number, spatial distribution, and sign of trends showed significant variability from one month to another, and also highlighted that the precipitation trend analysis and its mapping is beneficial work for understanding precipitation variation in that country. Similarly, Gedefaw et al. [15] investigated the annual and seasonal variability of the precipitation trend at five weather stations of Amhara Regional State, Ethiopia. They informed that annual precipitation increased in three locations and decreased in two, and that monthly precipitation increased in May, June, July, August, and September, and decreased in the rest of the months. Likewise, in a study of trend analysis and precipitation variation at nine weather stations of the Tafna Basin (Northwestern Algeria), Bougara et al. [16] found an increase in the monthly, seasonal, and annual precipitation. They commented that the said trend can lead to an increase in streamflow, and increase the potential risk of floods downstream. Additionally, Khaniya et al. [17] carried out an analysis of the temporal trend of precipitation from the perspective of water availability and under scenarios of climate variability in the Uma Oya Basin, Sri Lanka. They reported an absence of negative trends on seasonal precipitation but observed positive seasonal trends in three out of five weather stations. Positive trends helped to conclude that no water crisis is coming; on the contrary, the exceeding runoff produced by the precipitation increase could be transferred to other cities where water is scarce. In the same way, in a study of precipitation trends in Turkish, Partal and Kahya [18] found a significant decrease in annual precipitation in the western and southern as well as along with the Black Sea coast. On the other hand, Sayemuzzaman and Jha [19], in an analysis of the time series of the annual and seasonal precipitation at 249 weather stations in the North Carolina, United States, reported a positive trend of winter precipitation and negative trend on autumn precipitation. They also obtained a significant increase/decrease in spring and summer precipitation. Alike, Tabari and Talaee [20] studied the temporal variability of the annual and seasonal precipitation at 41 weather stations of Iran. They found a negative and significant trend of annual precipitation at seven weather stations. On a national scale, spring and winter precipitation were predominantly negative. Additionally, Zhao et al. [21] analyzed the precipitation characteristics at seven synoptic weather stations of Semi-Arid Loess Plateau, China. They discovered intense fluctuations in monthly precipitation, and commented that just two weather stations showed a negative and significant trend in April and November, while only one weather station had a positive trend in winter and a negative trend in spring and just two stations showed a negative trend in annual precipitation. In Calabria, Italia, Caloiero et al. [22] studied monthly precipitation trends at 129 sites; they obtained a variable pattern of trends and attributed it to orography and the position in the center of the Mediterranean watershed. In East Africa, Gebrechorkos et al. [23] analyzed seasonal and annual precipitation trends; at a seasonal scale, there was no statistically significant trend in neither East nor West Ethiopia and Kenya. However, there was a statistically significant and negative trend in large parts of Tanzania during the large rainfall season; in connection with the annual trend, there were a few statistically significant trends. On the other hand, Gentilucci et al. [24] studied the precipitation trend in Middle Adriatic Side, Marche region, Italia; they used it as a starting point in studying climate dynamics, and as a tool for land-use planning. The authors of [25] evaluated monthly precipitation trends in the Mediterranean fringe of the Iberian Peninsula; except for March, all months did not show a homogenous behavior of trends. In the same way, Jones et al. [26] analyzed precipitation trends in four regions and three different seasons in the Caribbean; they did not find statistically significant trends in time series up to a century long. The temporal pattern of precipitation can be determined with the help of statistical trends.

The hydro-agricultural sector of Aguascalientes, Mexico would benefit significantly with a study of precipitation trends. Given the geographical and topographical configuration of the Mexican Republic, the spatio-temporal pattern of rain through the territory presents significant discrepancies. In Mexico, despite the erratic or excessive character that precipitation shows in some regions, works focused on the trend analysis of this meteorological variable are scarce. For this country, some studies on precipitation have to do with convection and interannual variability, climate change projections with regional climatic models, intensity, and extreme indices; however, these have been carried out for specific regions of the country [27–30]. In Mexico, precipitation trend analysis has received limited attention, even though most of the agriculture is under rainfed conditions, and is the primary economic activity of the rural population. Moreover, Aguascalientes is a purely farming state with 125,246 hectares for agricultural production, from which, 90,000 are cultivated under rainfed agriculture and 35,246 are under irrigation [31]. For this state, in 1988, Lemus and Gay [32] had already reported an increase in the annual average temperature around 0.4 °C during the period 1978–1985 relative to the period 1921–1985. They also reported an increase of the aridity index and a decline of the net primary productivity (biomass, gr/m^2 year) and classified these lands as arid lands with an aridity index that oscillated between 3 and 6. In the west of the state, they observed a decrease in the forest area and an invasion of shrub vegetation. They also reported an increase on the surface covered by bush in the northeast, southeast, and west. According to Ruiz-Alvarez et al. [33], this state already faces increases of the monthly minimum temperature of between 0.09 and 1.19 °C decade^{-1}, and of the monthly maximum temperature of between 0.18 and 1.59 °C decade^{-1}. Additionally, reports exist that this state shows statistically significant increases on monthly evaporation up to 26.90 mm/month/year in March [34]. For this reason, studies that focus on the understanding of precipitation patterns would generate results of great value, mainly in this region where there are overexploited aquifers. For Aguascalientes, an analysis of precipitation trends would fill a gap of missing information, which is necessary for generating adaptation and mitigation actions to climate change.

The objective of this research therefore was to analyze the temporal pattern of monthly and annual precipitation in 36 weather stations of Aguascalientes state for the period 1980–2017. This study will generate vital information to adapt agricultural production and natural resources to current circumstances of climate change. In this way, we will help preserve the water resources of this region.

2. Materials and Methods

2.1. Area of Study

Aguascalientes state is located in the central high plains of the Mexican republic, in the region known as the north-central part of Mexico. It is between 21°38′ and 22°27′ north latitude, and 101°53′ and 102°52′ west latitude (Figure 1a). It encompasses an area of 5617.8 km^2 and adjoins Zacatecas in the north, northeast, and west; and Jalisco state in the south and east (Figure 1a) [35]. The total average annual precipitation is around 516.8 mm, and the total average annual evaporation oscillates around 1959 mm. In the state, three types of climates exist, such as semi-dry temperate, semi-dry warm, and temperate sub-humid with rains in summer, in which the mean temperature is around 17.1, 20.1, and 14.5 °C, respectively [35]. In Aguascalientes, between 2010 and 2017, the population increased from 1,184,996 to 1,321,453 [36,37]. The main economic activities of the state are agriculture, mining, service industry (electricity, urban water supply, and gas), construction, manufacture, and different businesses [37].

2.2. Meteorological Data

In the analysis of time series with a climate change approach, meteorological information plays a vital role. Records (period 1980–2017) of monthly precipitation coming from 36 weather stations belonging to Servicio Meteorologico Nacional (SMN) of Comision Nacional del Agua (CNA) were utilized (Table 1). These stations are well distributed over the state (Figure 1b) so that their records are pretty representative of the whole study area. The databases had already been subjected to a quality control and quality analysis by the staff of SMN. This analysis consisted of deleting outliers for a specific month and each weather station. Outliers were those monthly observations that were out of an interval (lower and upper limit), and they were deleted. This interval was defined by two allowable thresholds (maximum and minimum) (Adolfo Portocarrero Resendiz, Servicio Meteorologico Nacional, personal communication). In total, 468 time series were analyzed, 432 of these were monthly (12 months × 36 weather stations), and 36 were annual. It is possible to analyze the trends of meteorological variables when a broad temporal sample is available, and this is representative of the whole study area.

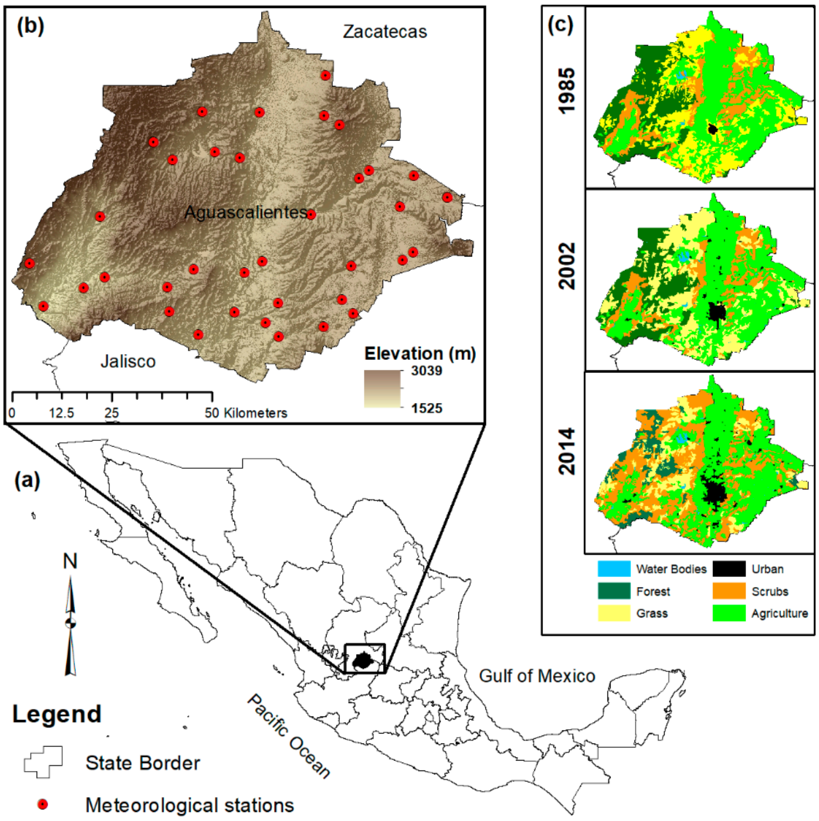

Figure 1. Location of Aguascalientes state in Mexico (**a**), spatial distribution of 36 weather stations (**b**) and land-use change for three years (**c**).

Table 1. Characteristics of the 36 weather stations used in the study.

ID	Weather Station	Latitude (N)	Longitude (W)	Elevation (m)	Duration of Data
1004	Cañada Honda	22°00′03″	102°11′56″	1925	1980–2017
1005	Presa El Niagara	21°46′50″	102°22′18″	1844	1980–2017
1008	Puerto de La Concepcion	22°12′10″	102°08′06″	2322.8	1980–2017
1010	La Tinaja	22°09′52″	102°33′15″	2525.7	1980–2017
1011	Malpaso	21°51′36″	102°39′50″	1730.2	1980–2017
1012	Presa Media Luna	21°47′40″	102°48′06″	1588.7	1980–2017
1013	Mesillas	22°18′48″	102°09′57″	2020.5	1980–2017
1015	Palo Alto	21°54′59″	101°58′10″	2037.5	1980–2017
1017	Presa Potrerillos	22°13′58″	102°26′37″	2171.9	1980–2017
1018	Presa Plutarco Elias Calles	22°08′29″	102°24′55″	2053.1	1980–2017
1019	Presa Jocoque	22°07′41″	102°21′34″	2006.2	1980–2017
1020	Presa La Codorniz	21°59′48″	102°40′27″	1850.2	1980–2017
1021	Rancho Viejo	22°07′24″	102°30′40″	2126.6	1980–2017
1022	San Bartolo	21°44′53″	102°10′13″	1997.6	1980–2017
1023	Calvillo	21°50′12″	102°42′42″	1684.6	1980–2017
1024	San Isidro	21°46′43″	102°06′14″	2004.4	1980–2017
1026	Tepezala	22°13′25″	102°10′08″	2110.2	1980–2017
1027	Venadero	21°52′38″	102°27′48″	2025.6	1980–2017
1028	Villa Juarez	22°06′03″	102°04′04″	1999.3	1980–2017
1030	Aguascalientes	21°53′44″	102°18′31″	1888.7	1980–2017
1031	El Novillo	22°01′08″	101°59′57″	2042.6	1980–2017
1032	Las Fraguas	22°02′21″	101°53′33″	2086	1980–2017
1033	Los Conos	21°53′52″	101°59′33″	2025.9	1980–2017
1034	Sandovales	21°53′06″	102°06′33″	2007	1980–2017
1045	El Tule	22°04′59″	102°05′28″	1981.7	1980–2017

Table 1. *Cont.*

ID	Weather Station	Latitude (N)	Longitude (W)	Elevation (m)	Duration of Data
1062	Arellano	21°48′07″	102°16′23″	1910.7	1980–2017
1073	La Tinaja	21°48′34″	102°07′47″	2027.1	1980–2017
1074	Cieneguilla	21°43′52″	102°27′10″	1838.8	1980–2017
1075	Montoro	21°45′26″	102°18′08″	1870.5	1980–2017
1076	Los Negritos	21°52′14″	102°20′57″	1887.1	1980–2017
1077	El Ocote	21°46′58″	102°31′03″	2044.6	1980–2017
1078	El Ocote	21°53′25″	102°49′57″	2328.9	1980–2017
1079	Peñuelas	21°43′33″	102°16′20″	1900.3	1980–2017
1080	Presa Canutillo	21°50′15″	102°31′20″	1949.7	1980–2017
1081	Rancho Seco	22°05′18″	101°58′02″	2067.2	1980–2017
1082	Rincon de Romos	22°13′52″	102°18′55″	1965.3	1980–2017

2.3. Statistical Analysis

To make inferences on the trends of the time series, robust methods of analysis are required. The monthly precipitation was organized in boxplots for determining the behavior of sample precipitation. For this, outliers of monthly precipitation were defined with 4STD as recommended by the World Meteorological Organization [38]. The time series trends of monthly and annual precipitation were determined with the non-parametric Mann–Kendall test [39,40]. The reject criteria of the null hypothesis (Ho: there is no trend in the time series) was based on a critical value of alpha equal to 0.05. This method has demonstrated excellent robustness in a great variety of studies of hydrometeorological time series trends. Its main advantages lay in the test results, which are not affected when missing observations exist through the time series, and it does not require observations to follow a specific distribution function; and it is not affected by outliers either with magnitudes with a value of zero [8,41–43]. The first requirement before analyzing trends is to verify whether observations of the time series are correlated or are independent. According to Bayazit and Önöz [44], the presence of correlation or serial autocorrelation in observations of a time series increase the risk of making type I error, which is rejecting the null hypothesis when there no temporal trend exists. The Mann–Kendall non-parametric technique is particularly sensitive to database autocorrelation and can lead to erroneous conclusions if autocorrelation is not explored. Before running the Mann–Kendall test, we carried out an exploratory analysis of databases to identify the statistical dependency/independence of the observations. The analysis consisted of that for each time series, autocorrelation function (ACF) graphs were constructed, and we could verify that the observations from each time series were statistically independent ($p \leq 0.05$) in 100% of the time series. Once the existing trend was determined, the annual magnitude of the rate of change was calculated with the help of the Theil–Sen non-parametric estimator [45,46]. Some of the main characteristics of the non-parametric Theil–Sen method are that it is not affected by errors on observations or by outliers, and it can be used when there are missing data through the time series. It is based on the median slopes, which is supported by a two-tailed confidence interval that helps to obtain the actual slope [46]. It is considered more precise than simple linear regression (least squares) for skewed and heteroskedastic data. It competes well with the least squares method in samples distributed normally in terms of its statistical power [47]. A full explanation of this methodology and examples of its use are available in [41]. In synthesis, it is possible to analyze trends in meteorological time series with the use of non-parametric techniques.

3. Results and Discussion

The objective of this study was to analyze the temporal trends of the monthly and annual precipitation observed at 36 weather stations that cover the study area representatively; the period we chose was 1980–2017. In this section, the main findings are presented and discussed, and particular emphasis is put on those trends that were statistically significant ($p \leq 0.05$).

3.1. Distribution of Data

In Aguascalientes, throughout the year, the precipitation shows significant oscillations. Boxplots show the variability of the monthly precipitation recorded at the 36 weather stations during the period of study (Figure 2). It is observed that the rainier months are June, July, August, and September, while the ones with lower precipitation are October, November, December, January, February, March, April, and May. At the same time, the months with more considerable rain variability are the ones that belong to the rainy season (June, July, August, and September). In contrast, the ones with less variability are the dry ones, from November to May. The months with more outliers were December through to May, while October was the month with fewer outliers; the rainy season from June to September did not show abnormal observations of precipitation. The more considerable variability in the observations of database was within the rainy season.

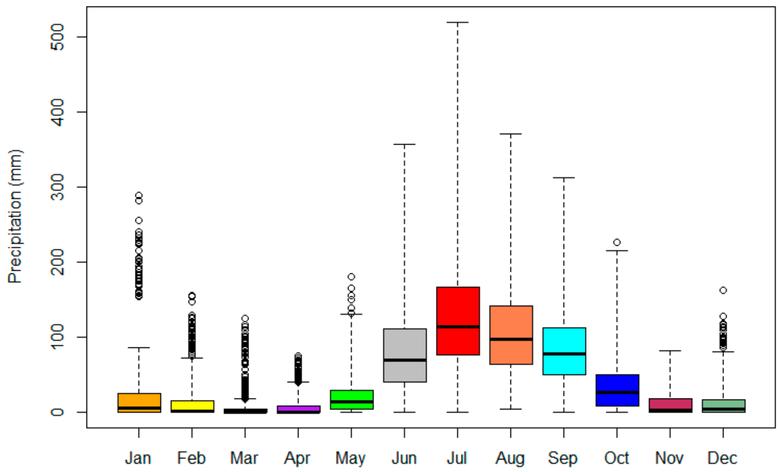

Figure 2. Boxplots for monthly precipitation in 36 weather stations of Aguascalientes.

3.2. Observed Trends

Out of all the time series studied, just a small proportion showed a statistically significant trend. Out of the total (468) time series utilized in the study, only 51 (10.90%) showed a statistically significant trend ($p \leq 0.05$) (Table 2). Most of the time series did not indicate any statistically significant change in precipitation in Aguascalientes.

3.2.1. Monthly Trends

Only a small proportion of monthly time series showed a statistically significant trend. Out of the total (432) time series of monthly precipitation analyzed, just 42 (9.72%) showed a statistically significant trend ($p \leq 0.05$). Except for February, March, and November, all months showed at least one station with a statistically significant trend ($p \leq 0.05$) (Table 2). On the other hand, out of the total of 42 time series of monthly precipitation with a statistically significant trend ($p \leq 0.05$), 34 were positive, and just 8 were negative (Table 2). The months with a smaller number of statistically significant trends were January, May, July, and December, each one with one statistically significant trend, whereas the month with the highest number of statistically significant trends was September, which showed 22 (Table 2). In summary, the months less sensitive to changes in precipitation were February, March, and November.

Statistically Significant Negative Trends

In Aguascalientes, four months showed a precipitation decrease. January had a statistically significant trend, which was negative and occurred at Canada Honda weather station, pretty close to the center of the state (Figure 3); its magnitude was −0.254 mm year^{-1} (Table 2). Other researchers have carried out works on monthly precipitation trends for other regions of the northern hemisphere. For norwest Iran, [8] reported magnitudes between −0.600 and −0.200 mm year^{-1}, which encompasses the trends we found in this research. On the other hand, the authors of [13,22], for five regions of Italy, reported ranks of trends from −1.480 to −0.690 mm year^{-1}, which was different to the trend we found in this work. Similarly, Kamau-Muthoni et al. [48] in eastern and southern Africa, found statistically significant negative trends that varied from −1.800 to −0.900 mm year^{-1}. At Canada Honda, the precipitation decrease in January can have adverse effects on irrigated agriculture, and water volumes required for irrigation can increase for crops, such as alfalfa, cabbage, wheat, oats, and triticale; thus, groundwater extractions would increase. Evidence of a precipitation decrease that also participates in the risk increase of fires exists [49]. On the other hand, April had a statistically significant negative trend at stations Aguascalientes and Presa El Niagara, close to the center and south state (Figure 3); their magnitudes were −0.022 and −0.018 mm year^{-1}, respectively (Table 2). For this month, other researchers have reported relatively variable results. The authors of [8] reported trends from −1.800 to −0.200 mm year^{-1}. Additionally, Kamau-Muthoni et al. [48] found statistically significant negative trends that oscillated between −3.6 and −0.01 mm year^{-1}. Similarly, the authors of [25] found that for this month, 20.5% of the time series were statistically significantly negative; however, their investigation did not report any magnitude. In the area of influence of Aguascalientes and Presa El Niagara weather stations, in April, a negative trend of precipitation could increase the aridity index when combined with the evaporation increase [34]. This can increase the natural vegetation dormancy and aggravate the problem of low forest productivity [50]. This can also increase the volume of irrigation required in the early sowing of corn. Similarly, October showed a statistically significant negative trend at Palo Alto (east), San Isidro (southeast), La Tinaja II (southeast), and El Ocote I (south–southwest) weather stations (Figure 3). Magnitudes of these trends oscillated between −1.269 and −0.638 mm year^{-1} at El Ocote I and San Isidro, respectively (Table 2). For this month, the magnitudes reported by other authors for other parts of the northern hemisphere are somewhat different. The authors of [51] found negative trends that varied from −1.680 to −1.590 mm year^{-1}. Similarly, Asakereh [8] reported statistically significant negative trends between −0.600 and −0.200 mm year^{-1}. The authors of [13,22] found statistically significant negative trends that varied from 2.860 to −1.520 mm year^{-1}. The October precipitation decrease causes a decrease of effective precipitation (Pe), which is useful in the irrigation scheduling of autumn–winter crops (garlic, oats, and wheat); as Pe decreases, irrigation requirements increase. The decrease of precipitation can contribute to the increase in groundwater extraction and the depletion of aquifers of the region. Figure 4a presents an example of a precipitation time series for October at Palo Alto weather station, where there was a statistically significant negative trend of −1.139 mm year^{-1}. In the same way, December had a statistically significant negative trend at El Ocote I (south–southeast) weather station (Figure 3), which had a magnitude of −0.030 mm year^{-1} (Table 2). For this month, [8] reported a negative trend of −0.200 year^{-1}, which predominated in the greatest part of the study area. Some other authors, for this month, have reported a decrease to 19.7% of precipitation during the period 1887–1996 [52]. At El Ocote I weather station, the precipitation decrease implies less natural moisture availability for crops and vegetation, and it would therefore be necessary to pump more groundwater for agriculture, generating a direct impact on the aquifers of the state. In regions where, by nature, it is difficult to have access to water, the negative trend of precipitation increases the cost of this resource [53], and also generates severe droughts [54]. In Aguascalientes, under a condition of a decrease of precipitation in dry months, it is suggested that irrigation water should be managed more efficiently. Irrigation systems with high conveyance and supply efficiency, such as drip irrigation, must be used. Additionally, programs and projects for repairing and maintaining irrigation infrastructure should be designed and implemented as this will help avoid great water volumes being lost by leaks through pipelines. Another alternative that would help use less water is the use of crop varieties with high water-use efficiency and a shorter growing cycle. Figure 4b shows an example of the time series of precipitation for December at El Ocote I weather station, where there was a statistically significant negative trend of −0.030 mm year^{-1}. In summary, in Aguascalientes, the negative trend of precipitation in these three months could bring with it severe agricultural and environmental consequences.

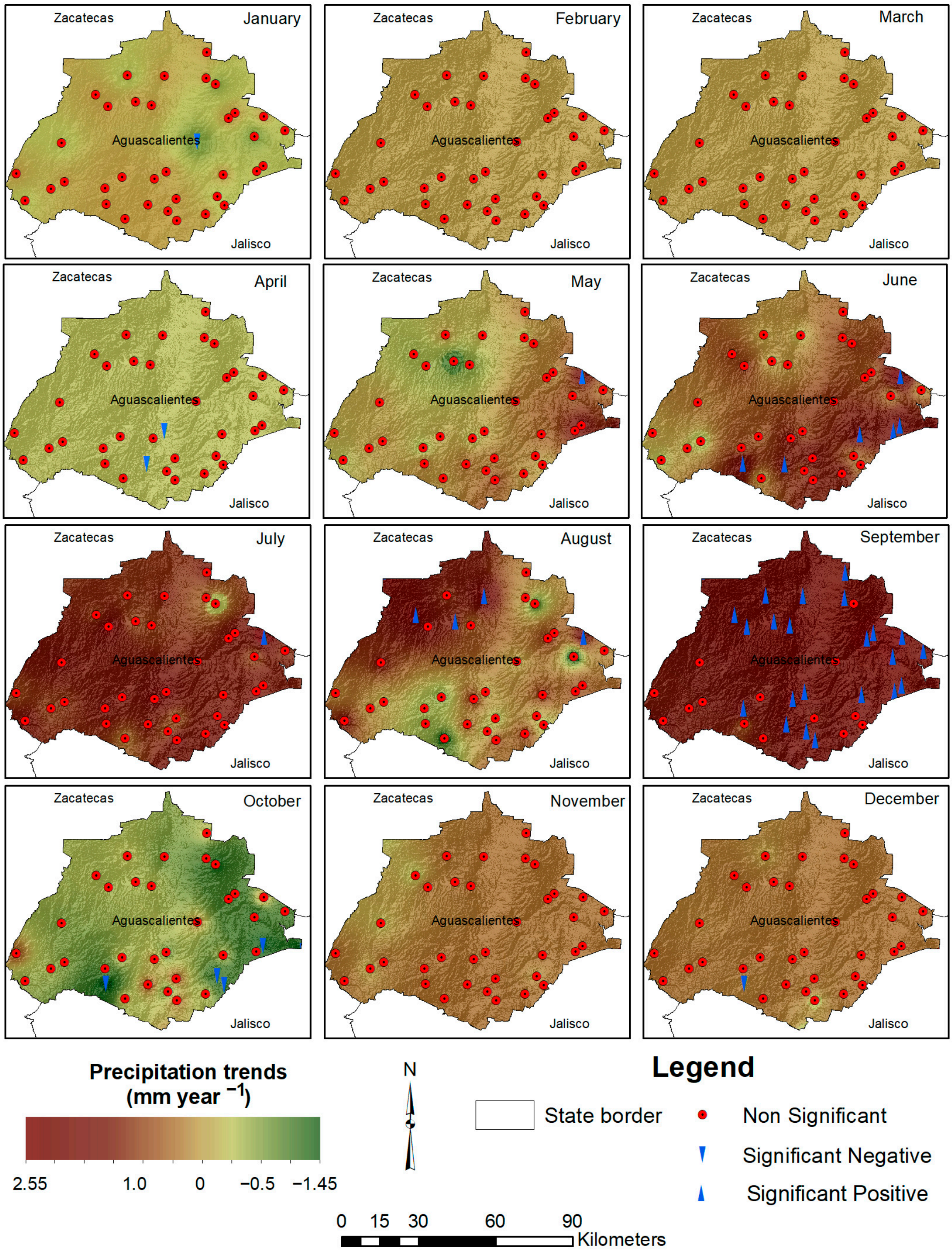

Figure 3. Spatial variation of monthly precipitation trend from January to December in Aguascalientes.

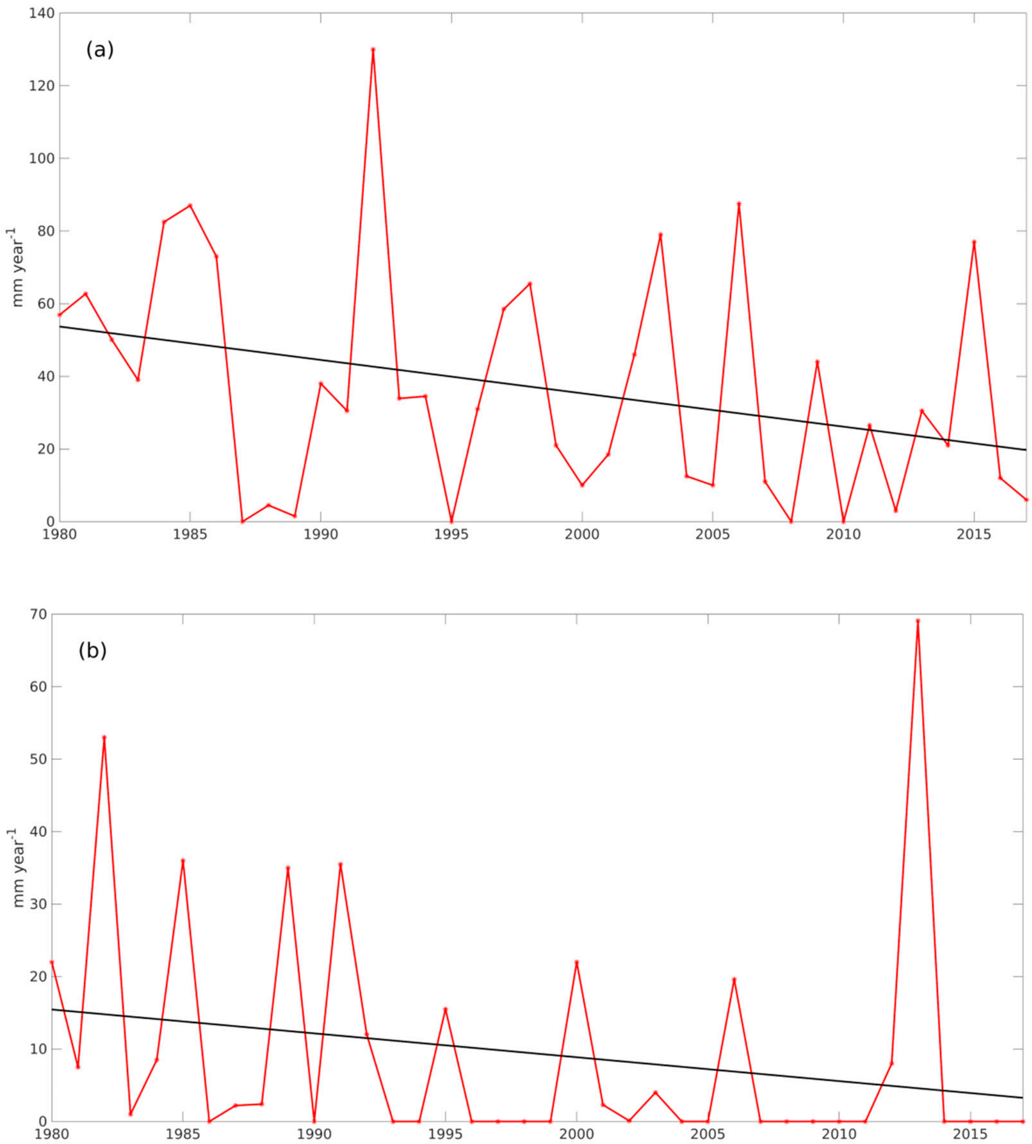

Figure 4. Examples of the time series at Palo Alto ($p \leq 0.05$) (**a**) and El Ocote I ($p \leq 0.05$) (**b**) weather stations.

In Aguascalientes, some cold months get drier, and the spring–summer growing cycle does not show any feature of a precipitation decrease. In total, during October–April, there were eight statistically significant negative trends, at sites with these trends, and since the point of view of atmospheric moisture, some cold months are getting even drier. The authors of [55] commented that when a cold environment gets drier, it increases the probability of agricultural frost occurrence; this is because in the air there are no water particles with a calorific capacity that absorb radiation emitted from the soil, so this radiation is lost rapidly to the upper layers of the atmosphere. On the other hand, there were no statistically significant negative trends of precipitation in February and March, since in these months, usually, there is no notable precipitation. Additionally, there were no statistically significant negative trends during May–September, the period covering the spring–summer growing cycle. In Table 2, the magnitude of the decadal and monthly precipitation trend of Aguascalientes is shown. Additionally, it can be observed that weather stations had statistically significant and negative trends as well as a summary of these. In summary, in Aguascalientes, some months are getting drier, and the spring–summer growing cycle is maintained without precipitation decreases.

Table 2. Trend of monthly and annual precipitation in Aguascalientes Mexico.

ID	Station Name	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1004	Cañada Honda	−0.254 *	0.000	0.000	−0.018	0.014	1.059	0.808	0.143	0.957	−0.064	0.000	0.000	2.188
1005	Presa El Niagara	0.000	0.000	0.000	−0.018 *	0.038	1.362 *	0.885	0.500	1.835 *	0.064	0.000	0.000	5.100 *
1008	Puerto de La Concepcion	−0.160	0.000	0.000	0.000	0.017	0.945	−1.450	−0.630	1.539	−1.033	0.000	0.000	−2.565
1010	La Tinaja	0.000	0.000	0.000	0.000	−0.222	0.941	0.375	1.750 *	1.583 *	−0.268	−0.107	0.000	3.938
1011	Malpaso	0.000	0.000	0.000	0.000	−0.050	−0.168	0.477	0.043	0.964	−0.364	0.000	0.000	0.479
1012	Presa Media Luna	−0.060	0.000	0.000	0.000	−0.180	0.038	1.041	1.037	1.026	−0.297	0.000	0.000	4.118 *
1013	Mesillas	0.000	0.000	0.000	0.000	0.000	0.586	0.833	0.315	1.633 *	−0.169	0.000	0.000	2.868
1015	Palo Alto	−0.074	0.000	0.000	−0.085	0.352	2.050 *	0.636	0.556	1.722 *	−1.139 *	0.000	0.000	4.425 *
1017	Presa Potrerillos	−0.088	0.000	0.000	0.000	−0.073	0.158	0.484	0.866	1.607 *	−0.190	0.000	−0.080	2.859
1018	Presa Plutarco Elias Calles	0.000	0.000	0.000	0.000	−0.395	0.086	0.133	0.972 *	1.662 *	−0.233	0.000	0.000	1.307
1019	Presa Jocoque	0.000	0.000	0.000	0.000	−0.267	0.289	0.345	0.537	1.983 *	−0.225	0.000	0.000	2.336
1020	Presa La Codorniz	−0.073	0.000	0.000	−0.012	−0.074	0.461	1.321	0.988	1.013	−0.351	−0.080	−0.030	2.755
1021	Rancho Viejo	0.000	0.000	0.000	0.000	−0.221	1.000	1.833	1.190	1.679 *	−0.250	0.000	0.000	5.100 *
1022	San Bartolo	0.000	0.000	0.000	0.000	−0.057	1.386	1.083	0.750	1.233	−0.167	0.000	0.000	4.421
1023	Calvillo	−0.029	0.000	0.000	0.000	−0.083	0.129	0.200	0.237	0.829	−0.245	−0.071	0.000	0.795
1024	San Isidro	−0.068	0.000	0.000	0.000	−0.140	0.350	1.286	−0.242	0.817	−0.638 *	0.000	0.000	0.186
1026	Tepezala	0.000	0.000	0.000	0.000	−0.167	0.850	−0.096	0.293	1.750 *	−0.438	0.000	0.000	0.953
1027	Venadero	0.000	0.000	0.000	0.000	−0.100	0.672	1.065	−0.318	0.871	−0.190	0.000	0.000	1.415
1028	Villa Juarez	0.000	0.000	0.000	−0.020	−0.039	0.607	1.129	0.508	1.956 *	−0.563	0.000	0.000	2.074
1030	Aguascalientes	0.000	0.000	0.000	−0.022 *	−0.110	0.780	1.622	0.094	1.647 *	−0.395	0.000	0.000	3.100
1031	El Novillo	−0.200	0.000	0.000	−0.058	0.096	0.332	0.041	−0.905	1.914 *	−0.756	0.000	0.000	0.280
1032	Las Fraguas	−0.063	0.000	0.000	0.000	0.000	0.228	0.500	0.273	1.250 *	−0.500	0.000	0.000	1.182
1033	Los Conos	−0.071	0.000	0.000	0.000	0.262	1.550 *	1.090	0.700	1.648 *	−0.765	0.000	0.000	5.358 *
1034	Sandovales	0.000	0.000	0.000	0.000	0.050	1.845 *	0.712	0.846	1.473*	−0.233	0.000	0.000	5.326 *
1045	El Tule	0.000	0.000	0.000	0.000	0.000	0.875	0.833	0.848	2.195*	−0.595	0.000	0.000	3.322
1062	Arellano	0.000	0.000	0.000	0.000	0.000	1.582	−0.156	−0.154	0.600	0.042	0.000	0.000	2.354
1073	La Tinaja	−0.059	0.000	0.000	−0.089	0.000	0.650	0.846	0.140	1.542	−0.786 *	−0.053	−0.003	1.550
1074	Cieneguilla	0.000	0.000	0.000	0.000	−0.056	0.067	−0.563	−0.700	0.765	−0.111	0.000	0.000	−1.710
1075	Montoro	0.000	0.000	0.000	0.000	0.000	0.842	−0.161	−0.144	1.438 *	−0.422	0.000	0.000	1.217
1076	Los Negritos	0.000	0.000	0.000	−0.031	−0.163	1.309	1.657	0.839	2.077 *	−0.095	0.000	0.000	5.063 *
1077	El Ocote	0.000	0.000	0.000	0.000	0.000	1.920 *	0.700	−0.256	0.121	−1.269 *	0.000	−0.030 *	−0.883
1078	El Ocote	0.000	0.000	0.000	0.000	−0.106	0.150	0.194	0.326	0.650	0.062	0.000	0.000	0.491
1079	Peñuelas	0.000	0.000	0.000	0.000	0.165	1.300	1.522	0.669	1.395 *	0.000	0.000	−0.130	5.900 *
1080	Presa Canutillo	0.000	0.000	0.000	0.000	−0.250	0.756	1.263	−0.200	1.588 *	−0.429	0.000	0.000	3.143
1081	Rancho Seco	0.000	0.000	0.000	0.000	0.349 *	2.555 *	2.418 *	1.334 *	2.072 *	0.000	0.000	0.000	10.055 *
1082	Rincon de Romos	0.000	0.000	0.000	0.000	−0.136	0.063	0.750	1.667 *	1.455 *	−0.400	0.000	0.000	1.840
Summary														
Stadistically significant positive		0	0	0	0	1	6	1	4	22	0	0	0	9
Stadistically significant negative		1	0	0	2	0	0	0	0	0	4	0	1	0

* Statistically significant at the 95% level ($p \leq 0.05$).

Statistically Significant Positive Trends

In Aguascalientes, statistically significant positive trends of precipitation occur only in rainy months. May showed a statistically significant positive trend only at Rancho Seco weather station in the east (Figure 3), whose magnitude was 0.349 mm year^{-1} (Table 2). For this month, the magnitude found in this study was pretty similar to the one reported by Kamau-Muthoni et al. [48], who published statistically significant positive trends that varied from 0.100 to 2.700 mm year^{-1}, which encompasses the trend we found here. Differently, the authors of [51] found statistically significant positive trends between 1.410 and 3.980 mm year^{-1}, which were significantly greater than the trend found in this research. Additionally, Yue and Hashino [52] reported precipitation increases in May until about 12.20% in the last part of the period 1887–1996. At Rancho Seco, the location where this trend was observed, beans and corn have always been cultivated under rainfed conditions, so it would be expected that a precipitation increase in this month brings better moisture scenarios for food production. Irrigated crops (lettuce, tomato, among others) would benefit from the water volume reduction of the irrigation used. Additionally, it is expected that precipitation increases the available soil moisture and helps the anticipated natural vegetation activation and enlarges the vegetation cycle. In a study about the effect of precipitation augment at an ecosystem level, Zeppel et al. [56] reported that it causes changes in the moment of certain physiological process occurrences, such as blooming, ripening of fruits, maturation of leaves, etc. Similarly, June showed a statistically significant positive trend at Presa El Niagara (south), Palo Alto (east), Los Conos (east), Sandovales (southeast), El Ocote I (southwest), and Rancho Seco (east) weather stations (Figure 3). The rank of the statistically significant positive trends for this month oscillated between 1.362 and 2.555 mm year^{-1} (Table 2). For this month, Asakereh [8] reported a statistically significant positive trend with a magnitude of 0.200 year^{-1}, which is relatively lower than the trends we found in this study. On the other hand, Abiy et al. [57] found a statistically significant positive trend of 0.980 mm year^{-1}, which was slightly shorter than the lower limit found in this work. For this month, other authors have also found a statistically significant positive trend in other regions of the northern hemisphere [18,58]. Most of the locations with a precipitation increase in this month have a great tradition in corn, beans, and alfalfa crops. Some others produce oats, sorghum, ballico (Perennial ryegrass), and vegetables, so that it is expected that these trends benefit the spring–summer growing cycle and lead to the use of less irrigation water and a reduction of groundwater extraction. However, the precipitation augment increases the occurrence of floods, the capacity of its erosive power, and nonpoint pollution [59]. The precipitation increase is associated with soil loss, changes in carbon content, temperature changes, changes in available moisture, and changes in soil organic matter content [60]. Figure 5a shows an example of the precipitation time series for June at Presa El Niagara, where there was a statistically significant positive trend of 1.362 year^{-1}. On the other hand, July showed a statistically significant positive trend only at Rancho Seco weather station, in the east of the state (Figure 3), whose magnitude was 2.418 mm year^{-1} (Table 2). For this month, the found trend in this study is within the rank of trends published for other parts of the northern hemisphere. The authors of [8] reported a statistically significant positive trend from 0.200 to 0.400 mm year^{-1}, which is significantly lower than ours. The authors of [57] reported statistically significant positive trends of around 2.1 mm year^{-1}, which is pretty similar to the magnitude we found in this study. On the other hand, Zelenakova et al. [61] commented that for this month, the greatest statistically significant positive trend was about 4.300 mm year^{-1}, which is relatively bigger than ours. Other authors, although without an emphasis on magnitudes, have also reported statistically significant positive trends in July precipitation [18,25]. At the Rancho Seco location, the precipitation increase in July could benefit rainfed crops, such as corn and beans, and irrigated crops, such as lettuce, onion, tomato, etc. The mountain vegetation could also benefit from this precipitation augment. The precipitation increase can also contribute to higher grass production from the grasslands. However, reports exist that once the growing cycle starts, a precipitation increase brings with it a water quality decrease of the rivers, due to the transport of sediments and compounds based on nitrogen due to the agricultural activities in this season of the year [62]. In the same way, August showed a statistically significant positive trend at San

Jose de La Tinaja (northwest), Presa Plutarco Elias Calles (north-central), Rancho Seco (east), and Rincon de Romos (north) weather stations (Figure 3). For August, the range of statistically significant positive trends found in this study oscillated between 0.972 and 1.750 mm year^{-1} (Table 2). For this month, and for other parts of the northern hemisphere, other researchers have reported magnitudes relatively higher than ours. The authors of [57] reported trends of 4.300 mm year^{-1} for southeast Florida. On the other hand, Krishnan et al. [51] reported a range of statistically significant positive trends from 2.320 to 3.920 mm year^{-1}. Similarly, Gonzalez-Hidalgo et al. [25] reported statistically significant positive trends; however, they did not inform their magnitudes. At these locations, spring–summer crops that could be favored by the precipitation increase are basically corn (forage and grain) and alfalfa, which are cultivated under both rainfed and irrigated conditions. However, in Aguascalientes, crops relatively sensitive to moisture excess also exist, and under scenarios of high precipitation they can be affected; for example, for beans, moisture excess enhances the conditions for the proliferation of root pathogens [63]. In general, under these circumstances, crops are exposed to damage caused by anoxia [64]. According to Neilson [65], another environmental effect from the precipitation increase is that it favors the invasion of woody shrubs in herbaceous vegetation. The month with the greatest number of statistically significant positive trends was September. This month had statistically significant positive trends at Presa El Niagara (south), San Jose de La Tinaja (northwest), Mesillas (north), Palo Alto (east), Presa Potrerillos (north), Presa Plutarco Elias Calles (north), Presa Jocoque (north-central), Rancho Viejo (northwest), Tepezala (north), Villa Juarez (northeast), Aguascalientes (central), El Novillo (east), Las Fraguas (east), Los Conos (east), Sandovales (east), El Tule (northeast), Montoro (south), Los Negritos (central), Penuelas (south), Presa Canutillo (southwest), Rancho Seco (east), and Rincon de Romos (north) (Figure 3). The variation range of these trends was between 1.250 and 2.195 mm year^{-1} (Table 2). Trends reported by other authors for this month and other regions of the northern hemisphere are relatively variable but encompass the magnitudes we found in this research. For example, Abiy et al. [57] informed statistically significant positive trends of 2.200 mm year^{-1}. The authors of [8] reported statistically significant positive trends with a magnitude of 0.200 mm year^{-1}. The authors of [13,22] found statistically significant positive trends of 0.320 mm year^{-1}. The precipitation increase in this month means a greater edaphic moisture availability that can be of agricultural importance for autumn–winter crops. Additionally, the precipitation increase can be of great significance for the vegetation and hydrological cycle maintenance, mainly for the runoff that supplies water to dams and recharges aquifers. However, the precipitation increase in September can cause more frequent delays in land preparation, sowing, and other activities for autumn–winter crops; additionally, nutrient percolation can occur, and in crops harvested in this month, it can produce yield reductions caused by rot and quality deterioration, which is particularly important for beans [64]. In agriculture, to reduce the effects of moisture excess in humid years, varieties resistant to diseases (diseases caused by fungus on the root) and lodging caused by water saturation can be adopted. Figure 5b shows an example of a time series of September precipitation at La Tinaja weather station, where there was a statistically significant positive trend of 1.583 mm year^{-1}. In synthesis, a precipitation increase, to a certain extent, seems to benefit spring–summer crops importantly, but according to the literature review, it can also result in agricultural and environmental threats.

September is the more susceptible month for higher humidity. Unlike the statistically significant negative trends, statistically significant positive trends occur in a specific part of the year, that is to say, from May to September. In this period, the months with the lowest number of statistically significant positive trends were May and July, each with a statistically significant positive trend, while the month with the highest number of statistically significant positive trends was September, which had 22. In Table 2, the weather stations with monthly statistically significant and positive trends are presented. It is observed that at some Aguascalientes locations, the more humid months are rainier.

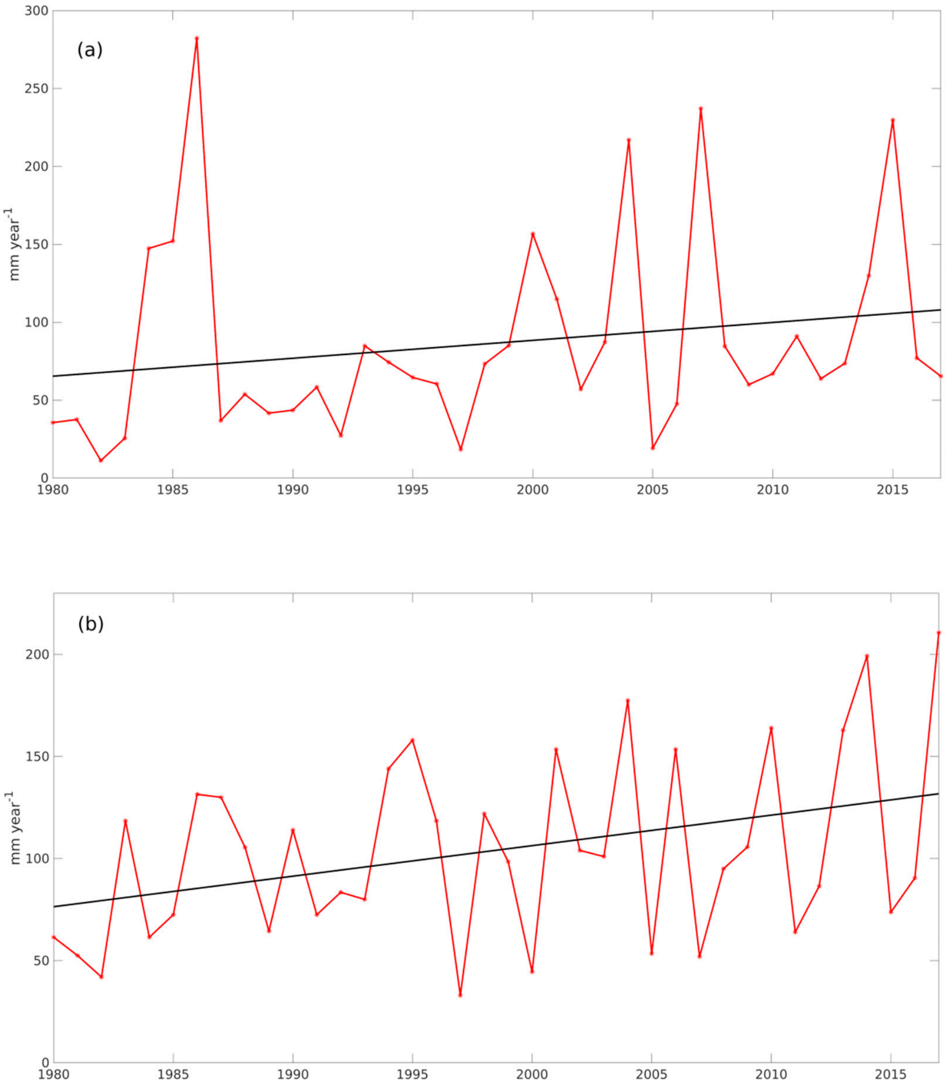

Figure 5. Examples of time series at Presa El Niagara ($p \leq 0.05$) (**a**) and La Tinaja ($p \leq 0.05$) (**b**) weather stations.

3.2.2. Annual Trend

In Aguascalientes, the annual rainfall shows only a statistically significant positive trend. Out of the total (36) annual time series analyzed, nine had a statistically significant positive trend (Table 2). Weather stations with this type of trend were Presa El Niagara (south), Presa Media Luna (southwest), Palo Alto (east), Rancho Viejo (northwest), Los Conos (east), Sandovales (east), Los Negritos (central), Penuelas (south), and Rancho Seco (east) (Figure 6). The statistically significant positive trends of annual precipitation oscillated between 4.118 and 10.055 mm year^{-1}, at Presa Media Luna and Rancho Seco, respectively (Table 2). In several works, a statistically significant positive trend of annual precipitation for other parts of the northern hemisphere has been reported. The authors of [57] found a statistically significant positive trend in the total annual precipitation of 2.1 mm year^{-1}. In Kentucky, Chattopadhyay and Edwards [7] reported statistically significant positive trends between 3.510 and 4.780 mm year^{-1}. Similarly, the authors of [48], for southwest Zambia and northern Lake Victoria basin, found trends from 3.000 to 15.000 mm year^{-1}. Differently, other authors, also for the northern hemisphere, found only statistically significant negative trends in total annual precipitation [8,12,13]. It is observed that in Aguascalientes, the magnitudes of statistically significant positive trends of annual precipitation are within the scales reported for other regions of the northern hemisphere. Some of these annual statistically significant positive trends originated from the statistically significant positive trend that was shown by some months. This occurred at Presa El Niagara (south), Palo Alto (east), Rancho Viejo (northwest), Los Conos (east), Sandovales (east), Los Negritos (central), Penuelas (south), and Rancho Seco (east) weather stations (Table 2). Figure 7 shows an example of a time series of the annual precipitation at Rancho Seco weather station, where there was a statistically significant positive trend of 10.055 mm year^{-1}. In essence, the statistically significant positive trends of annual precipitation found in our study are within the range of magnitudes reported for the northern hemisphere.

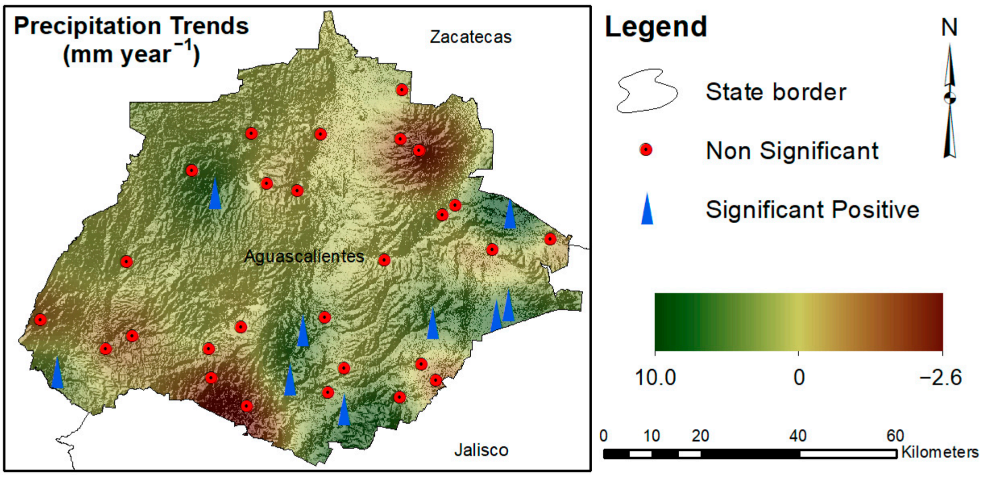

Figure 6. Spatial variation of the annual precipitation trend in Aguascalientes.

Increases in annual precipitation are distributed into two regions of the state. It is observed that, except for Rancho Viejo (northwest) and Presa Media Luna (southwest) weather stations, most of the stations with this kind of trend are located in the south and east of the state (Figure 6). Statistically significant positive trends located in specific zones can be due to the influence of factors causing the spatial variability in arid lands. In Table 2 (last right column), the magnitude of the decadal trend of annual precipitation is presented, and on the bottom of this table, a summary of those statistically significant stations can be observed. In Aguascalientes, annual precipitation basically increases just in the south and east.

Additionally, an analysis of the temporal trend of precipitation in the growing season (PGS) was carried out (May–September, growing season spring–summer) (maps and graphs not shown). This analysis allows identification of the likely future panorama of precipitation in this critical period on the agricultural production and the extent to which PGS changes explain the annual precipitation changes. We found statistically significant trends of PGS at 13 weather stations; all of them were positive. These trends varied between 3.481 and 9.200 mm year^{-1} in Aguascalientes and Rancho Seco, respectively. These trends confirm that some parts of Aguascalientes are getting more humid during the rainy season; in other words, for these regions, in the short term, problems related to precipitation deficiencies during the growing season are not foreseen. The interesting point is that the nine weather stations that showed statistically significant trends of annual precipitation also showed statistically significant trends of PGS, which indicates that in Aguascalientes, the annual precipitation increase is being explained to a great extent by the PGS increase. The weather stations with statistically significant and positive trends do not show a homogeneous spatial distribution; they are distributed at the south, southwest, east, northwest, center-south, southeast, north, and northeast. However, more interestingly, these trends just occurred in regions where irrigated agriculture is practiced, which is similar to the results reported by Sen Roy [66] and mentioned in Section 3.5 of this work. The findings of this part of the research could allow us to propose a new research hypothesis, which could help to reveal whether the massive introduction and adoption of irrigation systems in Aguascalientes and neighboring arid regions is contributing to the precipitation increase as was reported for India [66]. In Aguascalientes, PGS is increasing significantly at 13 locations and their vicinities.

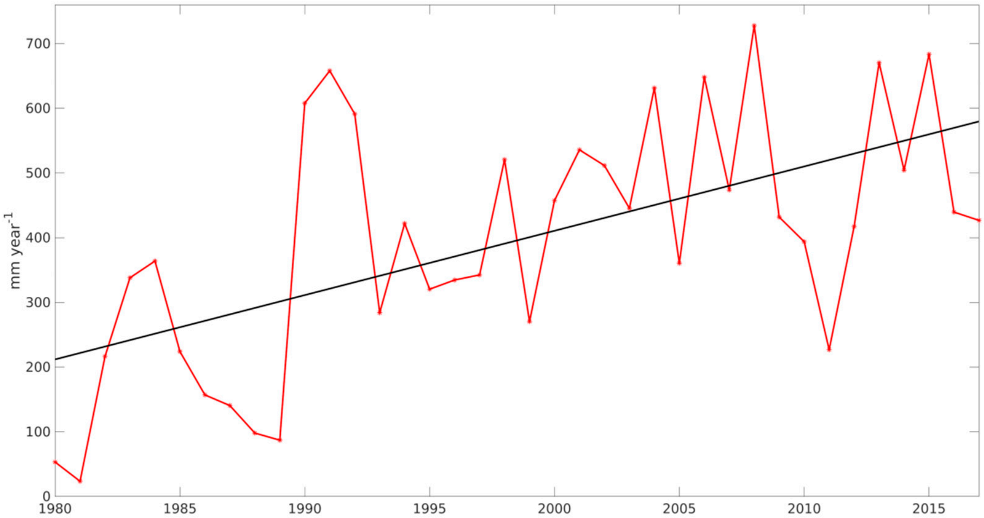

Figure 7. Example of time series at Rancho Seco ($p \leq 0.05$) weather station.

3.3. Possible Causes of Statistically Significant Negative Trends

It is known that polluting particles suspended in the atmosphere affect the precipitation formation process. Anthropogenic aerosol emissions have increased rapidly since the 1950s, and it is believed that this has participated in the precipitation reduction in different regions of the world [67–69]. Chemical particles released through anthropogenic activities affect the precipitation formation process. There exists evidence that aerosols and pollutant particles of the air affect cloudiness and precipitation formation processes. It has been documented that air contamination by high concentrations of big and submicronic particles inhibits the process of precipitation formation. They act as condensation nuclei of drops that form clouds with tiny drops, which are slow to condensate in more significant drops and precipitate, which is reflected in less precipitation reaching the land surface [70–73]. The presence of a high number of contaminant particles in the lower atmosphere promotes the generation of clouds that do not get precipitated but instead persist in the atmosphere until they re-evaporate. Thus, instead of precipitation, considerable cloudiness occurs, which is characteristic of air masses that are highly contaminated and saturated [70]. According to Rosenfeld [71], the smoke coming from the burn of agricultural residues provokes the effective radius of droplet formation becoming shorter; this causes the formation process of precipitation to be inhibited. This precipitation inhibition can be an essential contributor to the negative precipitation trend in several parts of the world. According to Polson et al. [74], anthropogenic aerosol is an external forcing that contributed to the precipitation decrease in the second part of the 20th century. In this regard, Aguascalientes has always stood out due to its vast extent of industrial activity. One important activity is mining, which is focused mainly on gold, silver, copper, zinc, and lead extractions [75]. The manufacturing industry has always been thriving, but in the last years, it has grown up even more with the arrival and expansion of the automotive industry [76]. Several brands of car manufacturers from different parts of the world have arrived in Aguascalientes. The business philosophy of the Aguascalientes government is that each enterprise arriving in this state must buy land to establish its buildings and production plants, which contributes importantly to land-use change [76]. Atmospheric aerosol seems to be one of the causes for the precipitation decrease in many parts of the world.

3.4. Possible Causes of Statistically Significant Positive Trends

It is believed that one of the more responsible factors for the precipitation increase is global warming. Essential moisture for generating precipitation can get into the atmospheric system either by advective transport from gulfs and oceans or through local evaporation [77,78]. Given that arid regions are located relatively far away from oceans and gulfs, these receive little moisture contribution from them [78]; in these lands, precipitation increase is attributed to more local moisture coming from higher evaporation rates. Thus, the precipitation volume increase is related to atmospheric moisture, and this late increase leads to more cloud formation, so that the increase in the atmospheric moisture content favors more extreme precipitation events, hydrological cycle intensification, and augments in the total precipitation [79]. During 1980–2010, an increase in extreme precipitation across all the globe was observed and was attributed to the moisture augment caused by changes in temperature [80]. Some researchers report that during 1951–2005, a precipitation increase of 4% and 4.7% in maximum precipitation in 1 and 5 days was observed, which was caused by atmospheric warming [81]. In several parts of the northern hemisphere (EEUU, Caribbean, and Hawaii), mean precipitable water increased significantly at an approximate rate of 5% decade^{-1} during 1973–1995, and provoked a significant increase from 2% to 3% in relative humidity in the southeast, Caribbean, and subtropical Pacific [82]. Several works indicate that the more responsible factor for the atmospheric humidity increase and precipitable water is global warming [78]. So, the temperature increase increases the capacity of the atmosphere for absorbing water, which is described by the Clausius–Clapeyron relationship [82,83]. In this way, the precipitation increase in Aguascalientes and other parts of Mexico can be explained by the temperature increase.

3.5. Other Possible Factors Responsible for Precipitation Changes in Aguascalientes

It is considered that the increase in cities' size is related to precipitation trends. Some researchers have documented that a close relationship exists between the growing/expansion of urban zones and the precipitation increase. The authors of [84] studied the urban expansion effect on precipitation trends. They found the existence of urbanization induced an effect on convective precipitation in Mexico City, which seemed to be increasing as the city grew up. In this sense, Aguascalientes has exhibited significant changes in its population size. According to INEGI, in 1980, the state accounted for 519,439 inhabitants, and for 2017, this same dependency reported 1,321,453 [37,85], and it is expected that the population of the state will increase at a rate of 2.55% per year. It is essential to highlight that the majority (63%) of this population resides in Aguascalientes. The effect of the increase on the urban suburbs' size is due to three factors: Mechanic turbulence coming from the rise in surface roughness, the addition of sensible heat from urban heat, and the presence or increase of anthropogenic condensation nuclei floating in the urban air [84]. On the other hand, in Arizona, Shepherd [86] found a significant effect of urbanization on precipitation trends in regions close to suburbs. He emphasized that precipitation had experienced a statistically significant increase from 12% to 14% between pre-urban and post-urban periods, respectively. It is expected that as population centers continue to increase, changes in the pattern of precipitation will manifest.

It is believed that land-use change modifies the mechanisms of connections and interactions that exist between the earth's surface and atmosphere. Different studies focused on identifying the influence of land-use changes on the climate have been carried out. The land-use and covered alterations modify the biophysical properties of the land, including its aerodynamic character, roughness height, vegetation architecture, vegetation fraction, and albedo [87–89]. These changes also alter the energy balance and atmospheric vapor content. It has been observed that the available energy increase of vegetated surfaces has essential effects on precipitation formation and storms caused by convection [89,90]. In the same way, the desert and semi-desert replacement by grass has increased precipitation significantly [91]. For Aguascalientes, this fact is relatively vital since, between 1985 and 2014, significant changes in land use have occurred. The total surface covered by bodies of water increased by 180.62%, i.e., there was an increment of 30.03 km^2; the forest area was reduced by 64.19%, which is equivalent to a loss of 686.74 km^2; the area covered by grassland grew by 9.72%, which equals an increase of 135.97 km^2; the urban area increased 983.25%, i.e., it had a growth of 190.24 km^2; the surface of scrub grew 19.37%, which equals to 162.60 km^2; and the agricultural area increased by 7.31%, i.e., 166.63 km^2 [92,93]. In Aguascalientes, precipitation changes mostly occurred at or pretty close to irrigated lands, and we suspect that the increase in irrigation use could be influencing the precipitation increases. In this state, the irrigated area has increased considerably through time. In India, after the introduction of massive irrigation systems, precipitation increased significantly [66]. The authors of [66] found that where irrigation was intensified, conditions that enhanced the precipitation increase were the increase of the latent energy flux, potential temperature (static moist energy), and changes on the field winds [66]. Under intensive irrigation use, an increase in the atmospheric moisture content and latent heat flux were distinguished [66]. According to Betts and Ball [94] and Betts et al. [95], soils with a higher moisture content produce a shallower boundary layer and therefore the concentration of large amounts of moisture and heat fluxes within a thin layer of air, which leads to greater convective instability. On the other hand, Schär et al. [96] stated that a high soil moisture content caused a decrease of the free convection level, and therefore the convective instability could be released. In Aguascalientes, all these local factors could be significant contributors to changes in the precipitation pattern.

In Aguascalientes, a climate factor that could be causing a precipitation decrease is the decrease in the diurnal temperate range (DTR). For this state, Ruiz-Alvarez et al. [33] found declines of DTR and attributed it to essential changes in the maximum and minimum temperature. The authors of [97] explained that a DTR decline causes the air to saturate faster and absorbs less and less moisture, which in turn causes significant decreases in evaporation. In arid lands, such as Aguascalientes, the potentially precipitable atmospheric water vapor comes mostly from local evaporation. This condition makes Aguascalientes vulnerable to precipitation decreases caused by an evaporation decrease. In this regard, for Aguascalientes, the authors of [34] observed a statistically significant evaporation decrease in every month of the year, so the said evaporation decrease could be one of the causes of the negative precipitation trend found in this work.

Additionally, a correlation analysis between precipitation and ENSO was carried out. It is well known that the ENSO (both warm and cold events) influences precipitation over Mexico [98,99]. Similarly, a relationship between precipitation and the ENSO over Mexico was found by [100]. Since the variability observed in the annual precipitation in Aguascalientes could be explained in terms of the ENSO–precipitation relationship, we ran a 38-year correlation analysis for the annual precipitation (1980–2017) and monthly Oceanic Niño Index (ONI) [101], for lag −1 (1979–2016), lag 0 (1980–2017), and lag +1 (1981–2018) (Figure 8). We found positive and significant correlations in almost the whole set of weather stations for six months around lag 0, which shows that the ENSO affects the precipitation in the region, which agrees with previous works [100,102]. These results could explain that the precipitation variability observed in Aguascalientes is mainly due to the ENSO.

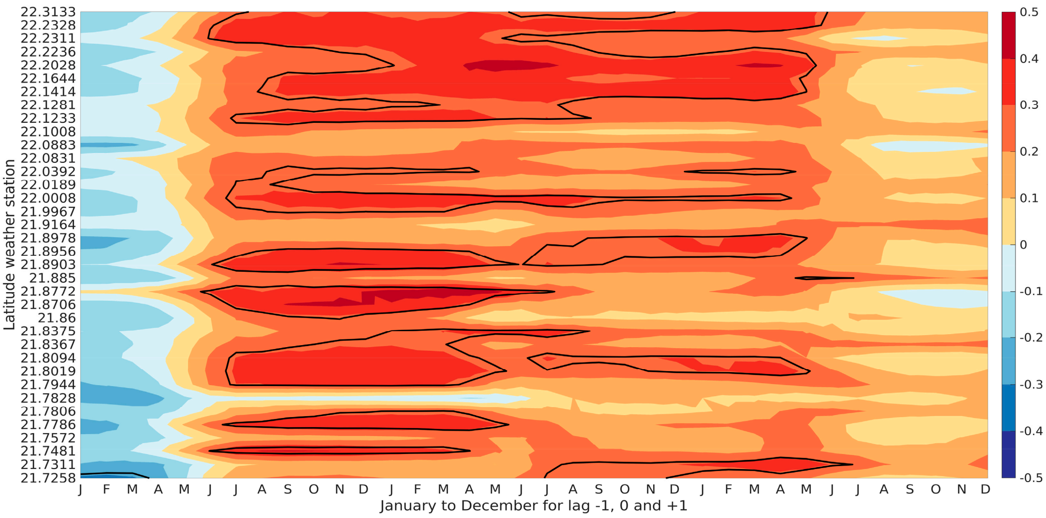

Figure 8. Correlation between annual precipitation and the Oceanic Niño Index (ONI) during 1980–2017 for lag −1, 0, and +1. Black contours indicate a significant correlation. The latitude in the Y-axis corresponds to each weather station.

4. Conclusions

The objective of this research was to analyze the temporal trend of monthly and annual precipitation at 36 weather stations of Servicio Meteorologico Nacional. The stations used were well distributed in the study area so that their observations were very representative, and the temporal duration of the sample period used was 37 years (1980–2017).

Out of the total time series of monthly precipitation analyzed, only a small proportion showed evidence of statistically significant changes in the temporal pattern of precipitation. There were only 8 statistically significant negative trends while 34 were statistically significantly positive.

In Aguascalientes, the statistically significant negative trends of precipitation occur separately in January, April, October, and December; and the consequences on hydrology, agriculture, and ecosystem fields are detrimental. The season of the year in which a statistically significant positive trend of monthly precipitation occurs is in the period of May–September. For this reason, the spring–summer growing cycle could be exempt from moisture scarcity problems; however, this condition of increased humidity can bring with it a series of environmental, agricultural, and positive hydrological consequences, but at the same time, others that are very detrimental.

As a consequence, on monthly precipitation changes, some weather stations showed changes in total annual precipitation; this occurred at nine stations, and the trend was positive. At these locations, increases in annual precipitation seem to be explained by the observed increases of rainfall during the growing season.

In general, the magnitudes both for statistically significant positive and negative trends are in agreement with other results reported for other parts of the northern hemisphere.

In Aguascalientes, the precipitation decrease, on the one hand, could be due to the global and local aerosol emissions. In this state, mining and manufacture are two essential sources that emit these classes of particles to the atmosphere more and more and with higher intensity. On the other hand, another local agent partially responsible for the precipitation decrease could be the decrease in the diurnal temperature range, which is caused by changes in local temperatures.

The precipitation increase, on the one hand, is caused by the atmosphere capacity increase, both at the global and local levels, for absorbing more enormous quantities of water vapor. Locally, the precipitation increase could also be influenced by the size of the main urban centers, and by the significant changes that have occurred on the land use, mainly on the intensification of the practice of irrigation agriculture.

The observed correlation between annual precipitation variability and ENSO seems to be that this is a responsible agent of the yearly variability of precipitation in Aguascalientes.

To attenuate the effect of the statistically significant negative trends of precipitation, agriculture should adopt irrigation systems of high efficiency and implement programs of rehabilitation and repairing of irrigation infrastructure in the state. Additionally, the use of crops with high water-use efficiency and with a shorter growing cycle should be intensified. On the other hand, one way of palliating the excess moisture effects in humid years is by using resistant varieties and hybrids to lodging and diseases caused by rot root.

At some Aguascalientes locations, where the May–September period is becoming rainier, programs that catch and store rainwater could be implemented for possible use in livestock during autumn, winter, and early spring, which are dry seasons.

As a complement of this research, it would be worth evaluating the pattern of available moisture with an edaphoclimatic water balance, where weather, edaphic, and crop characteristics could be integrated. This future research would help identify the magnitude of dry/humid periods of agricultural interest and its temporal pattern; this will provide a complete picture of the agricultural impacts of precipitation variability. Another potential future research topic is to verify whether, in Aguascalientes and neighboring arid regions, the precipitation increase is related to the adoption and intensification of agricultural irrigation.

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References

1. Wuebbles, D.J.; Fahey, D.W.; Hibbard, K.A.; DeAngelo, B.; Doherty, S.; Hayhoe, K.; Horton, R.; Kossin, J.P.; Taylor, P.C.; Waple, A.M.; et al. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*; Wuebbles, D.J., Fahey, D.W., Hibbard, K.A., Dokken, D.J., Stewart, B.C., Maycock, T.K., Eds.; U.S. Global Change Research Program: Washington, DC, USA, 2017; pp. 12–34. [CrossRef]
2. World Meteorological Organization (WMO). Available online: http://www.wmo.int/pages/prog/wcp/ccl/faq/faq_doc_en.html (accessed on 15 January 2020).
3. IPCC. *IPCC. Climate Change 2013: The Physical Science Basis; Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, C., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK, 2013; p. 1535.
4. IPCC. *IPCC. Climate Change 2001: The Scientific Basis; Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A., Eds.; Cambridge University Press: Cambridge, UK, 2001.
5. Rakhecha, P.R.; Singh, V.P. *Applied Hydrometeorology*; Springer: New York, NY, USA, 2009; 384p.
6. Rodriguez-Puebla, C.; Encinas, A.H.; Nieto, S.; Garmendia, J. Spatial and temporal patterns of annual precipitation variability over The Iberian Peninsula. *Int. J. Climatol.* **1998**, *18*, 299–316. [CrossRef]
7. Chattopadhyay, S.; Edwards, D.R. Long-Term Trend Analysis of Precipitation and Air Temperature for Kentucky, United States. *Climate* **2016**, *4*, 10. [CrossRef]
8. Asakereh, H. Trends in monthly precipitation over the northwest of Iran (NWI). *Theor. Appl. Climatol.* **2017**, *130*, 443–451. [CrossRef]
9. Zhang, Q.; Xu, C.Y.; Zhang, Z.; Chen, Y.D.; Liu, C.; Lin, H. Spatial and temporal variability of precipitation maxima during 1960-2005 in the Yangtze River basin and possible association with large-scale circulation. *J. Hydrol.* **2008**, *353*, 215–227. [CrossRef]
10. Menzel, L.; Burger, G. Climate change scenarios and runoff response in the Mulde catchment (Southern Elbe, Germany). *J. Hydrol.* **2002**, *267*, 53–64. [CrossRef]
11. Brown, K.; Kamruzzaman, M.; Beecham, S. Trends in sub-daily precipitation in Tasmania using regional dynamically downscaled climate projections. *J. Hydrol. Reg. Stud.* **2017**, *10*, 18–34. [CrossRef]
12. Beharry, S.L.; Clarke, R.M.; Kurmarsingh, K. Precipitation trends using in-situ and gridded datasets. *Theor. Appl. Climatol.* **2014**, *115*, 599–607. [CrossRef]
13. Młyński, D.; Cebulska, M.; Wałęga, A. Trends, Variability, and Seasonality of Maximum Annual Daily Precipitation in the Upper Vistula Basin, Poland. *Atmosphere* **2018**, *9*, 313. [CrossRef]
14. Gemmer, M.; Becker, S.; Jiang, T. Observed monthly precipitation trends in China 1951–2002. *Theor. Appl. Climatol.* **2004**, *77*, 39–45. [CrossRef]
15. Gedefaw, M.; Yan, D.; Wang, H.; Qin, T.; Girma, A.; Abiyu, A.; Batsuren, D. Innovative Trend Analysis of Annual and Seasonal Rainfall Variability in Amhara Regional State, Ethiopia. *Atmosphere* **2018**, *9*, 326. [CrossRef]
16. Bougara, H.; Hamed, K.B.; Borgemeister, C.; Tischbein, B.; Kumar, N. Analyzing Trend and Variability of Rainfall in The Tafna Basin (Northwestern Algeria). *Atmosphere* **2020**, *11*, 347. [CrossRef]

17. Khaniya, B.; Jayanayaka, I.; Jayasanka, P.; Rathnayake, U. Rainfall Trend Analysis in Uma Oya Basin, Sri Lanka, and Future Water Scarcity Problems in Perspective of Climate Variability. *Adv. Meteorol.* **2019**, *2019*, 3636158. [CrossRef]
18. Partal, T.; Kahya, E. Trend analysis in Turkish precipitation data. *Hydrol. Process.* **2006**, *20*, 2011–2026. [CrossRef]
19. Sayemuzzaman, M.; Jha, M.K. Seasonal and annual precipitation time series trend analysis in North Carolina, United States. *Atmos. Res.* **2014**, *137*, 183–194. [CrossRef]
20. Tabari, H.; Talaee, P.H. Temporal variability of precipitation over Iran: 1966–2005. *J. Hydrol.* **2011**, *396*, 313–320. [CrossRef]
21. Zhao, W.; Yu, X.; Ma, H.; Zhu, Q.; Zhang, Y.; Qin, W.; Ai, N.; Wang, Y. Analysis of Precipitation Characteristics during 1957–2012 in the Semi-Arid Loess Plateau, China. *PLoS ONE* **2015**, *10*, e0141662. [CrossRef]
22. Caloiero, T.; Coscarelli, R.; Ferrari, E. Analysis of Monthly Rainfall Trend in Calabria (Southern Italy) through the Application of Statistical and Graphical Techniques. *Proceedings* **2018**, *2*, 629. [CrossRef]
23. Gebrechorkos, S.H.; Hulsmann, S.; Bernhofer, C. Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. *Nature* **2019**, *9*, 11376. [CrossRef] [PubMed]
24. Gentilucci, M.; Barbieri, M.; Lee, H.S.; Zardi, D. Analysis of Rainfall Trends and Extreme Precipitation in the Middle Adriatic Side, Marche Region (Central Italy). *Water* **2019**, *11*, 1948. [CrossRef]
25. Gonzalez-Hidalgo, J.C.; Lopez-Bustins, J.A.; Stepanek, P.; Martin-Vide, J.; de Luis, M. Monthly precipitation trends on the Mediterranean fringe of the Iberian Peninsula during the second-half of the twentieth century (1951–2000). *Int. J. Climatol.* **2009**, *29*, 1415–1429. [CrossRef]
26. Jones, P.D.; Harpham, C.; Harris, I.; Goodess, C.M.; Burton, A.; Centella-Artola, A.; Taylor, M.A.; Bezanilla-Morlot, A.; Campbell, J.D.; Stephenson, T.N.; et al. Long-term trends in precipitation and temperature across the Caribbean. *Int. J. Climatol.* **2016**, *36*, 3314–3333. [CrossRef]
27. Cavazos, T.; Hastenrath, S. Convection and rainfall over Mexico and their modulation by the southern oscillation. *Int. J. Climatol.* **1990**, *10*, 377–386. [CrossRef]
28. Arriaga-Ramirez, S.; Cavazos, T. Regional trends of daily precipitation indices in Northwest Mexico and Southwest United States. *J. Geophys. Res.* **2010**, *115*, D14. [CrossRef]
29. Karmalkar, A.V.; Bradley, R.S.; Diaz, H.F. Climate change in Central America and Mexico: Regional climate model validation and climate change projections. *Clim. Dyn.* **2011**, *37*, 605–629. [CrossRef]
30. Ochoa, C.A.; Quintanar, A.I.; Raga, G.B. Changes in intense precipitation events in Mexico City. *J. Hydrometeorol.* **2015**, *16*, 1804–1820. [CrossRef]
31. Instituto Nacional de Investigaciones Forestales Agricolas y Pecuarias (INIFAP). *Agenda Técnica Agrícola de Aguascalientes*; Delegacion Coyoacan: Ciudad de Mexico, Mexico, 2017; 132p.
32. Lemus, L.; Gay, C. Temperature, precipitation variations and focal effects Aguascalientes 1921–1985. *Atmósfera* **2009**, 39–44.
33. Ruíz Álvarez, O.; Espejel Trujano, D.; Ontiveros Capurata, R.E.; Enciso, J.M.; Galindo Reyes, M.A.; Quesada Parga, M.L.; Grageda Grageda, J.; Ramos Reyes, R.; Ruíz Corral, J.A. Tendencia de temperaturas máximas y mínimas mensuales en Aguascalientes, México. *Rev. Mex. Cienc. Agrícolas* **2016**, *7*, 2535–2549.
34. Ruiz-Alvarez, O.; Singh, V.P.; Enciso-Medina, J.; Munster, C.; Kaiser, R.; Ontiveros-Capurata, R.E.; Diaz-Garcia, L.A.; Costa dos Santos, C.A. Spatio-temporal trends in monthly pan evaporation in Aguascalientes, Mexico. *Theor. Appl. Climatol.* **2019**, *136*, 775–789. [CrossRef]
35. Instituto Nacional de Estadística Geografía e Informática (INEGI). *Anuario Estadístico del Estado de Aguascalientes*; Gobierno del Estado de Aguascalientes: Aguascalientes, Mexico, 1995; 100p.
36. Instituto Nacional de Estadística y Geografía (INEGI). *Principales Resultados del Censo de Poblacion y Vivienda 2010*; Gobierno del Estado de Aguascalientes: Aguascalientes, Mexico, 2010; 80p.
37. Instituto Nacional de Estadística Geografía e Informática (INEGI). *Anuario Estadistico y Geografico por Entidad Federativa*; INEGI: Aguascalientes, Mexico, 2018; 642p.
38. Klein-Tank, A.M.G.; Zwiers, F.W.; Zhang, X. *Analysis of Extremes in a Changing Climate Insupport of Informed Decisions for Adaptation*; World Meteorological Organization: Geneva, Switzerland, 2009.
39. Mann, H.B. Non-parametric tests against trend. *Econometrica* **1945**, *13*, 245–259. [CrossRef]
40. Kendall, M.G. *Rank Correlation Methods*; Charles Griffin: London, UK, 1975.
41. Gilbert, R.O. *Statistical Methods for Environmental Pollution Monitoring*, 1st ed.; John Wiley & Sons: New York, NY, USA, 1987; pp. 204–224.

42. Hamed, K.H.; Rao, R.A. A modified Mann-Kendall trend test for autocorrelated data. *J. Hydrol.* **1998**, *204*, 182–196. [CrossRef]
43. Rio, S.; Penas, A.; Fraile, R. Analysis of recent climatic variations in Castile and Leon (Spain). *Atmos. Res.* **2005**, *73*, 69–85. [CrossRef]
44. Bayazit, M.; Önöz, B. To prewhiten or not to prewhiten in trend analysis? *Hydrol. Sci. J.* **2007**, *52*, 611–624. [CrossRef]
45. Theil, H. A rank-invariant method of linear and polynomial regression analysis, Part 3. *Proc. K. Ned. Akad. Wet. A* **1950**, *53*, 1397–1412.
46. Sen, P.K. Estimates of the regression coefficient based on Kendall's tau. *J. Am. Stat. Assoc.* **1968**, *63*, 1379–1389. [CrossRef]
47. Wilcox, R.R. *Fundamentals of Modern Statistical Methods*; Springer: New York, NY, USA, 2010; ISBN 978-1-4419-5524-1.
48. Kamau-Muthoni, F.; Omondi-Odongo, V.; Ochieng, J.; Mugalavai, E.M.; Kjumula-Mourice, S.; Hoesche-Zeledon, I.; Mwila, M.; Bekunda, M. Long-term spatial-temporal trends and variability of rainfall over eastern and Southern Africa. *Theor. Appl. Climatol.* **2019**, *137*, 1869–1882. [CrossRef]
49. Young, J.A. Cheatgrass. In *Noxious Range Weeds*; James, L.F., Evans, J.O., Ralphs, M.H., Child, R.D., Eds.; Westview Press: Boulder, CO, USA, 1991; pp. 408–418.
50. Hanson, P.J.; Weltzin, J.F. Drought disturbance from climate change: Response of United States forests. *Sci. Total Environ.* **2000**, *262*, 205–220. [CrossRef]
51. Krishnan, M.V.N.; Prasanna, M.V.; Vijith, H. Statistical analysis of trends in monthly precipitation at the Limbang River Basin, Sarawak (NW Borneo), Malaysia. *Meteorol. Atmos. Phys.* **2018**, *131*, 883–896. [CrossRef]
52. Yue, S.; Hashino, M. Long term trends of annual and monthly precipitation in Japan. *J. Am. Water Resour. Assoc.* **2003**, *39*, 587–596. [CrossRef]
53. Melillo, J.M.; Richmondm, T.; Yohe, G.W. *Climate Change Impacts in the United States: The Third National Climate Assessment*; U.S. Global Change Research Program: Washington, DC, USA, 2014; 841p. [CrossRef]
54. Alexander, L.V.; Zhang, X.; Peterson, T.C.; Caesar, J.; Gleason, B.; Klein Tank, A.M.G.; Haylock, M.; Collins, D.; Trewin, B.; Rahimzadeh, F.; et al. Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res.* **2006**, *111*, D5. [CrossRef]
55. Romo-Gonzalez, J.R.; Arteaga-Ramirez, R. *Meteorologia Agricola*; Departamento de Irrigacion de La Universidad Autonoma Chapingo: Chapingo, Mexico, 1983; 442p.
56. Zeppel, M.J.B.; Wilks, J.V.; Lewis, J.D. Impacts of extreme precipitation and seasonal changes in precipitation on plants. *Biogeosciences* **2014**, *11*, 3083–3093. [CrossRef]
57. Abiy, A.Z.; Melesse, A.M.; Abtew, W.; Whitman, D. Rainfall trend and variability in Southeast Florida: Implications for freshwater availability in the Everglades. *PLoS ONE* **2019**, *14*, e0212008. [CrossRef] [PubMed]
58. Hansel, S.; Petzold, S.; Matschullat, J. Precipitation trend analysis for Central Eastern Germany 1851–2006. In *Bioclimatology and Natural Hazards, Proceedings of the International Scientific Conference, Polana nad Detvou, Slovakia, 17–20 September 2007*; Skaverina, J., Blazenec, M., Eds.; Springer: Dordrecht, Switzerland, 2009; ISBN 978-80-228-17-60-8.
59. Delgado, J.A.; Groffman, P.M.; Nearing, M.A.; Goddard, T.; Reicosky, D.; Lal, R.; Kitchen, N.R.; Rice, C.W.; Towery, D.; Salon, P. Conservation practices to mitigate and adapt to climate change. *J. Soil Water Conserv.* **2011**, *66*, 118A–129A. [CrossRef]
60. Pan, Z.; Andrade, D.; Segal, M.; Wimberley, J.; McKinney, N.; Takle, E. Uncertainty in future soil carbon trends at a central U.S. site under an ensemble of GCM scenario climates. *Ecol. Model.* **2010**, *221*, 876–881. [CrossRef]
61. Zelenakova, M.; Purcz, P.; Poorova, Z.; Alkhalaf, I.; Hlavata, H.; Portela, M.M. Monthly Trends of Precipitation in Gauging Stations in Slovakia. *Procedia Eng.* **2016**, *162*, 106–111. [CrossRef]
62. Kaushal, S.S.; Likens, G.E.; Jaworski, N.A.; Pace, M.L.; Sides, A.M.; Seekell, D.; Belt, K.T.; Secor, D.H.; Wingate, R.L. Rising stream and river temperatures in the United States. *Front. Ecol. Environ.* **2010**, *8*, 461–466. [CrossRef]
63. Coakley, S.M.; Scherm, M.; Chakraborty, S. Climate change and plant disease management. *Annu. Rev. Phytopathol.* **1999**, *37*, 399–426. [CrossRef] [PubMed]

64. Hatfield, J.L.; Boote, K.; Fay, P.; Hahn, L.; Izaurralde, C.; Kimball, B.A.; Mader, T.; Morgan, J.; Ort, D.; Polley, W.; et al. Agriculture. In *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States*; A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research; U.S. Department of Agriculture: Washington, DC, USA, 2008; 362p.
65. Neilson, R.P. High-Resolution Climatic Analysis and Southwest Biogeography. *Science* **1986**, *232*, 27–34. [CrossRef]
66. Sen Roy, S.; Mahmood, R.; Quintanar, A.I.; Gonzalez, A. Impacts of irrigation on dry season precipitation in India. *Theor. Appl. Climatol.* **2011**, *104*, 193–207. [CrossRef]
67. Held, I.M.; Delworth, T.L.; Lu, J.; Findell, K.L.; Knutson, T.R. Simulation of Sahel drought in the 20th and 21st centuries. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 17891–17896. [CrossRef]
68. Lau, K.M.; Kim, K.M. Observational relationships between aerosol and Asian monsoon rainfall, and circulation. *Geophys. Res. Lett.* **2006**, *33*, L21810. [CrossRef]
69. Meehl, G.A.; Arblaster, J.M.; Collins, W.D. Effects of black carbon aerosols on the Indian monsoon. *J. Clim.* **2008**, *21*, 2869–2882. [CrossRef]
70. Gunn, R.; Phillips, B.B. An experimental investigation of the effect of air pollution on the initiation of rain. *J. Meteorol.* **1957**, *14*, 272–280. [CrossRef]
71. Rosenfeld, D. TRMM Observed First Direct Evidence of Smoke from Forest Fires Inhibiting Rainfall. *Geophys. Res. Lett.* **1999**, *26*, 3105–3108. [CrossRef]
72. Rosenfeld, D. Suppression of Rain and Snow by Urban and Industrial Air Pollution. *Science* **2000**, *287*, 1793–1796. [CrossRef] [PubMed]
73. Andreae, M.O.; Rosenfeld, D.; Artaxo, P.; Costa, A.A.; Frank, G.P.; Longo, K.M.; Silva-Dias, M.A.F. Smoking Rain Clouds over the Amazon. *Science* **2004**, *303*, 1337–1342. [CrossRef] [PubMed]
74. Polson, D.; Bollasina, M.; Hegerl, G.C.; Wilcox, L.J. Decreased monsoon precipitation in the Northern Hemisphere due to anthropogenic aerosols. *Geophys. Res. Lett.* **2014**, *41*, 6023–6029. [CrossRef]
75. González, J. Crece Producción Minera de Aguascalientes. Available online: https://newsweekespanol.com/2018/02/crece-produccion-minera-de-aguascalientes/ (accessed on 11 April 2020).
76. Manufacturing in Aguascalientes. Available online: https://napsintl.com/manufacturing-in-mexico/mexico-manufacturing-locations/manufacturing-in-aguascalientes/ (accessed on 11 April 2020).
77. Burde, G.I.; Zangvil, A. The estimation of regional precipitation recycling. Part II: A new recycling model. *J. Clim.* **2001**, *14*, 2509–2527. [CrossRef]
78. Li, R.; Wang, C.; Wu, D. Changes in precipitation recycling over arid regions in the Northern Hemisphere. *Theor. Appl. Climatol.* **2018**, *131*, 489–502. [CrossRef]
79. Trenberth, K.E. Conceptual framework for changes of extremes of the hydrological cycle with climate change. *Clim. Chang.* **1999**, *42*, 327–339. [CrossRef]
80. Lehmann, J.; Coumou, D.; Frieler, K. Increased record-breaking precipitation events under global warming. *Clim. Chang.* **2015**, *4*, 501–515. [CrossRef]
81. Zhang, X.; Wan, H.; Zwiers, F.W.; Hegerl, G.C.; Min, S.K. Attributing intensification of precipitation extremes to human influence. *Geophys. Res. Lett.* **2013**, *40*, 5252–5257. [CrossRef]
82. Trenberth, K.E.; Day, A.; Rasmussen, R.M.; Parsons, D.B. The changing character of precipitation. *Am. Meteorol. Soc.* **2003**, *84*, 1205–1218. [CrossRef]
83. Kininmonth, W. Clausius Clapeyron and the Regulation of Global Warming. *Fisica E* **2010**, *26*, 61–70.
84. Jauregui, E.; Romales, E. Urban effects on convective precipitation in Mexico City. *Atmos. Environ.* **1996**, *30*, 3383–3389. [CrossRef]
85. INEGI. *Anuario de Estadísticas Estatales 1980*; INEGI: Aguascalientes, Mexico, 1980.
86. Shepherd, J.M. Evidence of urban-induced precipitation variability in arid climate regimes. *J. Arid Environ.* **2006**, *67*, 607–628. [CrossRef]
87. Barlage, M.; Zeng, X. The Effects of Observed Fractional Vegetation Cover on the Land Surface Climatology of the Community Land Model. *J. Hydrometeorol.* **2004**, *5*, 823–830. [CrossRef]
88. Chang, J.-T.; Wetzel, P.J. Effects of Spatial Variations of Soil Moisture and Vegetation on the Evolution of a Prestorm Environment: A Numerical Case Study. *Mon. Weather Rev.* **1991**, *119*, 1368–1390. [CrossRef]
89. Pielke, R.A. Influence of the spatial distribution of vegetation and soils on the prediction of cumulus Convective rainfall. *Rev. Geophys.* **2001**, *39*, 151–177. [CrossRef]

90. Pielke, R.A.; Adegoke, J.; BeltraáN-Przekurat, A.; Hiemstra, C.A.; Lin, J.; Nair, U.S.; Niyogi, D.; Nobis, T.E. An overview of regional land-use and land-cover impacts on rainfall. *Tellus B Chem. Phys. Meteorol.* **2007**, *59*, 587–601. [CrossRef]
91. Sen, O.L.; Wang, B.; Wang, Y. Impacts of Re-greening the Desertified Lands in Northwestern China: Implications from a Regional Climate Model Experiment. *J. Meteorol. Soc. Jpn. Ser. II* **2004**, *82*, 1679–1693. [CrossRef]
92. INEGI Uso de Suelo y Vegetación. *Datos Vectoriales Escala 1:250,000 Serie I*; INEGI: Aguascalientes, Mexico, 1990.
93. INEGI Uso de Suelo y Vegetación. *Datos Vectoriales Escala 1:250,000 Serie VI*; INEGI: Aguascalientes, Mexico, 2014.
94. Betts, A.K.; Ball, J.H. The FIFE surface diurnal cycle climate. *J. Geophys. Res.* **1995**, *100*, 25679. [CrossRef]
95. Betts, A.K.; Ball, J.H.; Beljaars, A.C.M.; Miller, M.J.; Viterbo, P.A. The land surface-atmosphere interaction: A review based on observational and global modeling perspectives. *J. Geophys. Res. Atmos.* **1996**, *101*, 7209–7225. [CrossRef]
96. Schär, C.; Lüthi, D.; Beyerle, U.; Heise, E. The Soil–Precipitation Feedback: A Process Study with a Regional Climate Model. *J. Clim.* **1999**, *12*, 722–741. [CrossRef]
97. Roderick, M.L.; Farquhar, G.D. The Cause of Decreased Pan Evaporation over the Past 50 Years. *Science* **2002**, *298*, 1410–1411. [PubMed]
98. Kiladis, G.N.; Diaz, H.F. ENSO and precipitation variability over Mexico during the last 90 years. In Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop, Pacific Grove, CA, USA, 21–24 April 1992; pp. 63–70.
99. Bravo, J.L.; Azpra, E.; Zarraluqui, V.; Gay, C.; Estrada, F. Significance tests for the relationship between "El Niño" phenomenon and precipitation in Mexico. *Geofis. Int.* **2010**, *49*, 245–261.
100. Magaña, V.O.; Vázquez, J.L.; Pérez, J.L.; Pérez, J.B. Impact of El Niño on precipitation in Mexico. *Geofis. Int.* **2003**, *42*, 313–330.
101. National Weather Service, Climate Prediction Center. Available online: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php (accessed on 7 April 2020).
102. Bravo, J.L.; Azpra, E.; Zarraluqui, V.; Gay, C. Effects of El Niño in Mexico during rainy and dry seasons, an extended treatment. *Atmósfera* **2017**, *30*, 221–232. [CrossRef]