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Analysis of Precipitation and Drought in the Main Southeastern Iberian River Headwaters (1952–2021)

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Abstract: This study evaluated the long-term changes in precipitation patterns and drought conditions in one of the key recharge areas of the hydrological system of southern and southeastern Spain, namely, the Sierra de Cazorla y Segura, which contains the headwater sectors of the catchment basins of two important rivers, namely, the Guadalquivir and the Segura. The research covered a period of 70 years (1952–2021) and undertook an exhaustive analysis of data from 348 pluviometric stations. The most relevant results are as follows: (1) most areas experienced a decrease in the precipitation volume and number of rainy days during the study period; (2) summer and winter showed the most significant decreases; (3) weak and moderate precipitation (<40 mm/d) showed significant decreases in both volume and frequency, while heavy precipitation (≥40 mm/d) showed the opposite behavior; (4) the durations of dry periods increased, while the durations of wet periods decreased in most areas; and (5) the SPEI showed an increase under drought conditions. This research underscores the need for water resource management and resilience strategies with interdisciplinary relevance in the face of changing hydrological patterns.

Keywords: annual and seasonal trends; dry spell; wet spell; precipitation; SPEI; drought; climate change

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1. Introduction

Human activity is inexorably changing the Earth's climate. The emission of greenhouse gases (GHGs) into the atmosphere has caused an increase in the average global temperature, which has altered the climate in such a way that will significantly affect not only future generations but also a large number of the planet's ecosystems and species. According to the latest Intergovernmental Panel on Climate Change report [1], it was estimated that human activities caused a total increase in the global temperature of 1.07 °C from 1850–1900 to 2010–2019. Furthermore, the report notes that it is likely that human activities have also altered precipitation on a global scale, estimating that precipitation over continental surfaces has increased since 1950, with a faster rate of increase since 1980. It also affirms that it is likely that the trajectory of mid-latitude storms has shifted toward the poles, with marked seasonality in these trends.

However, climate change does not affect all areas in the same way; although the global trend is an increase in precipitation, there are some regions around the world where different behavior has been observed. One example is the Mediterranean basin, where projections indicate a general decrease in rainfall, which could lead to major water supply problems in this region [2–4]. Similarly, other studies warned that not only will the amount of precipitation decrease but the precipitation regime will also change, leading to an increase in torrential rains and floods [5–7] and an increase in the risk of drought [2].

As in the rest of the Mediterranean basin, climate change has modified the pluviometric regime in the Mediterranean region of the Iberian Peninsula. Thus, recent studies in this

area warned of a negative trend in annual precipitation totals and an increase in interannual variability [8–10]. Other recent studies found that in certain river headwaters, the impact of the reduction in precipitation in recent years was greater [11,12]. In the eastern part of the Iberian Peninsula, river headwaters are of great importance. Rainfall variability, together with changes in land use and land cover, is the most important factor influencing the water regime of river flows in the headwaters of Mediterranean rivers [13]. Therefore, any change in rainfall patterns in these areas can affect the amount of water that flows downstream. It should be emphasized that this is a densely populated area with a high water demand. Moreover, agriculture plays a crucial role in the economy of the regions that these rivers flow through, such as Andalusia, the region of Murcia, and Castilla–La Mancha.

Robust trend analysis requires a long series of meteorological data. Moreover, if the area to be analyzed has a complex orography, it is necessary to acquire a dense network of meteorological observatories to evaluate the spatial differences in the territory. The Iberian Peninsula is characterized by a complex orography that alternates between vast coastal plains and mountainous massifs over 3000 m high, as well as deep river valleys. The headwaters of its rivers are usually located at high altitudes (over 1000 m) and in areas with a complicated topography; therefore, any climatological study that seeks to reflect the reality of such areas should use as many meteorological observatories as possible. In recent years, few works studied the evolution of precipitation in the headwaters of the rivers of the eastern Iberian Peninsula using a dense network of observatories. The only specific study was carried out by Miró et al. [12] in the headwaters where four major Spanish rivers converged; they warned of a significant decline in the precipitation volume and an alarming drought situation in the long term (36 months) over 70 years (1952–2021). Other studies carried out on larger areas and not focused on river headwaters warned of similar situations involving precipitation reductions [11,14]. Therefore, it is considered important to expand this area of knowledge and analyze the evolution of precipitation in the different headwaters of the rivers in the eastern Iberian Peninsula since information is limited at present.

In addition, very few studies analyzed the evolution of drought in the headwaters of the rivers in this region, where drought is one of the main risks in terms of economic and environmental impacts [15]. Only Miró et al. [12] and Lorenzo-Lacruz et al. [16] carried out specific studies, which revealed a situation of prolonged drought in the long term in the headwaters of several rivers in the eastern Spanish Mediterranean.

For the above reasons, this study aimed to analyze the annual and seasonal evolutions and changes in the precipitation behavior, as well as the drought trends, in the headwaters of several of the most important rivers of the Iberian Peninsula, such as the Guadalquivir, Guadiana, Segura, and, in part, the Júcar, using a dense network of temperature series over 70 years. This is a key location for the water recharge of these rivers, and a large part of the region's economic activity depends on its condition. Consequently, it is important to carry out a comprehensive analysis of the current trends in this region, as this will allow us to predict its future evolution with greater certainty.

2. Materials and Methods

2.1. Study Area

A rectangular area of the southeastern Iberian Peninsula located between latitudes 37.5° N and 39° N and longitudes 4° W and 2° W was selected for this study (Figure 1). It had an area of 30,425 km^2 (179.5 km W–E by 169.5 km N–S). This is an area of complex orography, in which the headwaters of several of the most important rivers in the south and southeast of Spain are located, such as the Guadalquivir, Guadiana, and Segura Rivers. In turn, four river basins converge in this area: two of them flow into the Atlantic Ocean, namely, the Guadalquivir River Basin (CHQ) and the Guadiana River Basin (CHG), while the other two flow into the Mediterranean Sea (Júcar River Basin (CHJ) and Segura River Basin (CHS)).

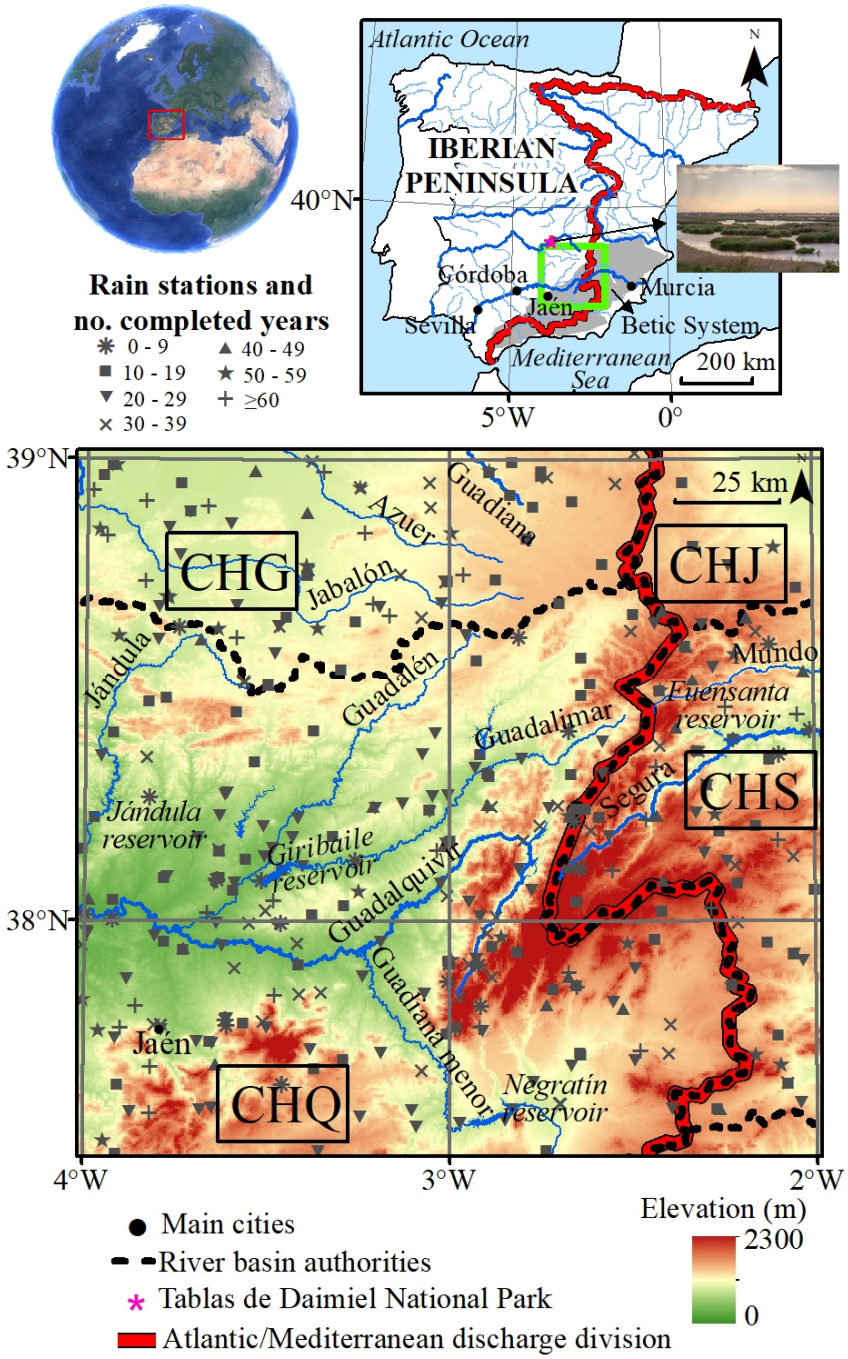

Figure 1. Area of study. Rain gauge stations are marked by symbols that correspond to the number of completed years originally available.

The CHQ, with an area of 17,623 km^2, was the largest of the basins studied. The Guadalquivir River, which is one of the longest and most abundant water flow rivers in Spain, has its headwaters in this area. This river is fundamental for the intense agricultural activity of southern Spain. In turn, some of its most important tributaries are located in this area, such as the Guadiana Menor, Guadalimar, Guadalén, and Jándula Rivers. The Negratín, Giribaile, and Jándula Reservoirs are also located in this area. The CHG, with an area of 5964 km^2, is located in the northwestern part of this region. This area contains the headwaters of the Guadiana River, which is the fourth-longest river in the Iberian Peninsula, as well as two of its tributaries, namely, the Azuer and Jabalón Rivers. This area is vital for the water supply of the Tablas de Daimiel National Park, which is located a few

kilometers to the north. The Tablas de Daimiel is a wetland, which is rare in Europe, and the last representative of the fluvial table ecosystem which was once characteristic of the central plain of the Iberian Peninsula. The CHS, with an area of 4801 km^2, hosts the origin of the Segura River, as well as that of its main tributary, the Mundo River. The Segura River sees large amounts of hydrological use due to the intense agricultural activity of SE Spain. The CHJ, with an area of 1731 km^2, was the smallest of the basins studied and was located in the extreme northeast of the region of interest.

The area of study was situated in the southeastern part of the Iberian Peninsula, with most of it forming part of the Betic System. This area has a complex orography, with several mountain ranges around it. To the east is the most important mountain chain, which includes the Atlantic/Mediterranean watershed, with a N–S direction, whose peaks exceed 2300 m in altitude. In the SW part, there is another significant mountain range, with an altitude that exceeds 2000 m. There is also a small mountain ridge in the extreme NW of the CHQ, exceeding 1200 m in altitude. The rest of the area has an altitude between 500 and 1000 m, except the area where the Guadalquivir River flows, whose altitude declines from its origin.

The study area contains, in the center and extreme SW, two areas of high annual rainfall (>800 mm), with some parts exceeding 1400 mm/year; they are some of the most pluviometric areas of the eastern Iberian Peninsula (Figure 2, left). In turn, these areas of high rainfall have a high annual number of rainy days (>75), in contrast to the surrounding areas, where they do not exceed 50 days/year, mainly in the E and SE parts (Figure 2, right).

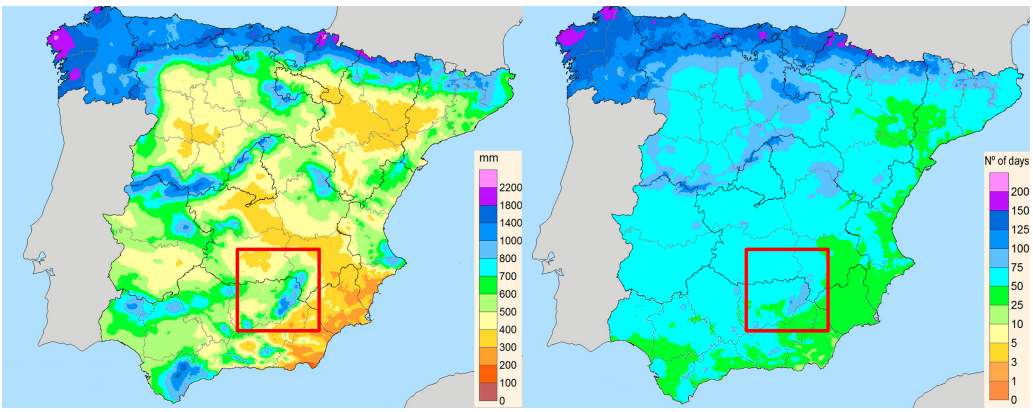

Figure 2. Average annual rainfall (on the **left**) and average annual number of days with rainfall of ≥1 mm (on the **right**) for the 1981–2010 reference period [17]. The red square represents the study area.

2.2. Daily Rainfall Database

The precipitation data used in this study belonged to the Agencia Estatal de Meteorología (AEMET). The selected study period was 1952–2021 (70 years). The reason for the start date of 1952 was the small number of stations present in the previous years, which made it difficult to carry out the gap-filling and homogenization processes necessary to complete this study. In the study area, AEMET had 366 pluviometric stations, but some of them collected very few data. Hence, a filter was used to discard those stations that did not have at least 7 complete years of rainfall data. After this filtering, 18 stations were discarded. Consequently, the final number of stations used was 348 (71 in CHG, 207 in CHQ, 63 in CHS, and 7 in CHJ). More than half of the selected stations had fewer than 25 complete years of data, and approximately 75% of them had complete data for fewer than half of all years. Only 25 stations (7% of the total) had more than 60 complete years of data (Figure 3).

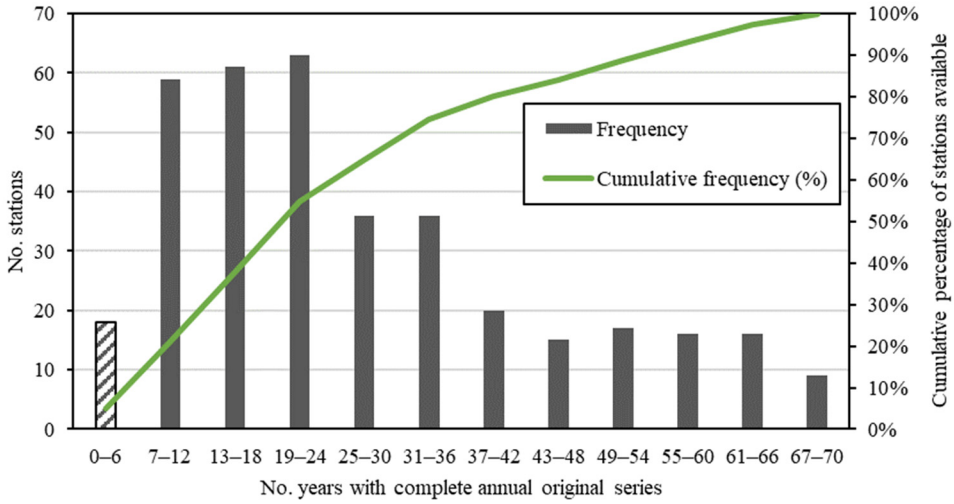

Figure 3. Available rain gauge observatories according to the quantity of complete annual original series for 1952–2021 (bars and left axis; the dashed bar indicates the number of stations with fewer than seven complete years, which were discarded for the study) and the cumulative frequency of the number of stations (line and right axis; calculated as the cumulative percentage of stations available).

Figure 4 illustrates how the number of stations selected for study evolved from 1952 to 2021. As can be seen, during the first few years, the number of rainfall stations increased from fewer than 100 in 1952 to more than 160 in the 1970s. After a slight decrease in the 1980s, the number of stations continued to increase until it reached a peak in the mid-1990s. Thereafter, the number of stations progressively decreased, including a rapid decrease to below 100 after 2014.

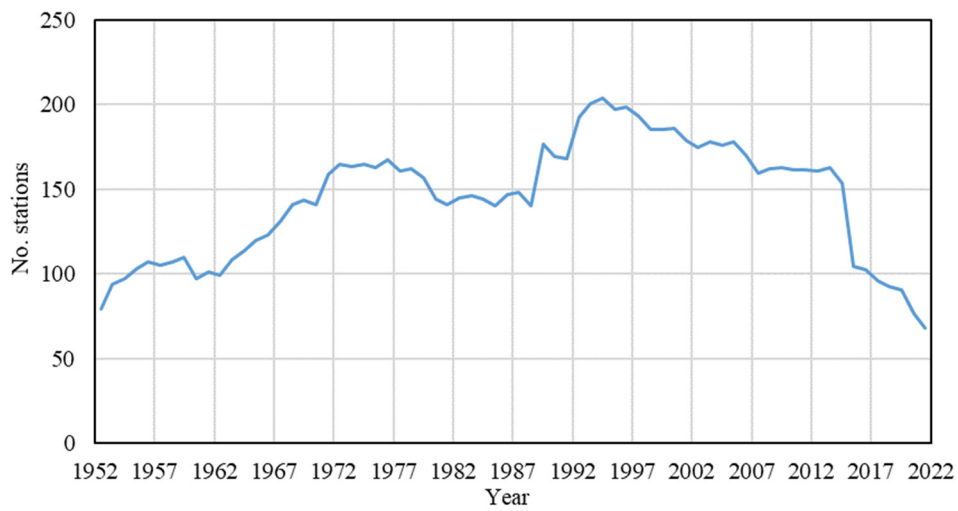

Figure 4. Observatories available throughout the period of study. Each datum represents the annual number of stations with at least 75% of the original daily data available.

All the pluviometric series used in this study were subjected to two statistical processes to improve their quality. First, the approach outlined by Miró et al. [18], employing the NLPCA-EOF-QM method (a combination of non-linear principal component analysis (NLPCA), empirical orthogonal functions (EOF), and quantile mapping techniques), was utilized to impute missing data. The validation process was carried out on an estimated daily data set. From the actual observed daily data set, an additional 5% was removed, which was equally distributed among all the series involved, as they were missing data in the backfilling process. These data were, therefore, estimated exactly as if they were missing point information. They were then validated with the actual data omitted from

the process. On average, low error values were obtained for the root-mean-square error (3 mm) and mean absolute error (1 mm), and both exhibited strong correlations (>0.9) for the daily rainfall estimation and a bias close to 0 for the monthly and annual sums. Second, the filled series were subjected to a homogenization process using the ACMANT method (ACMANTv3.0-ACMANTP3day [19,20]). After these processes of filling in missing data and homogenization, it was possible to obtain 348 daily accumulated precipitation series of 70 complete years for 1952–2021, which were part of the "Complete Daily Rainfall Database for a High-Resolution Analysis in the Eastern Iberian Peninsula: 1952–2021" (CDRD-HR-EIP-1952-2021), which consists of 4780 pluviometric stations covering the eastern Iberian Peninsula and the Balearic Islands.

2.3. Observed Change and Trend Analysis Methodology

Climatic normals were computed for two distinct 35-year periods (1952–1986 and 1987–2021). The analysis involved calculating the differences in precipitation between these two periods, both in terms of volume and the number of rainy days, which were defined as those days with daily precipitation $\geq$ 1 mm, following the same procedure as Miró et al. [12]. The results were spatially interpolated and plotted.

Non-parametric procedures were applied for the analysis of the precipitation series. The statistical parameters used for this purpose were as follows:

- To determine the presence of statistically significant trends, the Mann–Kendall trend test [21,22] was applied. The analysis was conducted using the statistical significance levels α = 0.1, α = 0.05, and α = 0.01. The outcomes were visualized on maps, with symbols representing different confidence levels: cross-shaped dots (>90%), half-filled dots (>95%), filled dots (confidence > 99%), and unfilled gray dots (indicating a non-significant trend).
- The annual Sen slope (change in absolute terms during the study period) and the annual relative change derived from the Sen slope were obtained for each pluviometric observatory.

To plot the results on maps, the local polynomial interpolation technique was used (200 m spatial resolution). This approach was successfully validated on precipitation data, according to the method described by Wang et al. [23].

2.4. Variables Assessed for Variations

The statistical techniques detailed in the preceding subsection were used to analyze the following rainfall-related factors:

1. Rainfall volumes and number of rainy days:
    - The changes in the number of rainy days and the annual and seasonal average rainfall between 1952–1986 and 1987–2021, using maps based on interpolated results.
    - The trends in rainfall volumes, analyzed for both the annual total and seasonal (winter: DJF; spring: MAM; summer: JJA; autumn: SON) totals for 1952 to 2021.
2. Daily precipitation classified by intensity:
    - First, precipitation was classified according to its intensity. For this purpose, 3 intensity intervals were chosen: <10 mm/d (weak precipitation), 10–40 mm/d (moderate precipitation), and $\geq$40 mm/d (heavy precipitation). For each intensity interval, as well as for the total (all intensity intervals together), the percentage of total rainfall and the total number of rainy days were computed. Subsequently, a comparison was made between the results for the periods 1952–1986 and 1987–2021.
    - Second, for the 3 types of rainfall intensity, the following analyses were performed:
        i. The relative change in the mean annual precipitation was measured for each pluviometric station between 1952–1986 and 1987–2021. These results are shown interpolated graphically on the map.

ii. Analyses involving the Mann–Kendall trend test and Sen slope for 1952–2021 were performed by grouping all the series into two groups (one group included the series with a decrease in precipitation between 1952–1986 and 1987–2021, while the second group consisted of those series with an increase in rainfall between the two periods under analysis). The results are shown as dot plots.

3. Dry (or wet) spell lengths: For this purpose, dry (or wet) spells are defined as two or more consecutive days without or with precipitation, respectively. The criterion of ≥1 mm was employed to distinguish between wet and dry days [24]. The Mann–Kendall trend test and the Sen slope for the absolute and relative changes during 1952–2021 were estimated for 3 different parameters:
   - The maximum duration of consecutive dry periods per year.
   - The mean duration of consecutive dry periods per year.
   - The mean duration of consecutive wet periods per year.

2.5. The Drought Index: The SPEI

For this study, the standardized precipitation evapotranspiration index (SPEI) was computed. The SPEI, which was developed by Vicente-Serrano et al. [25], was calculated for various time scales, including 3, 12, and 36 months, representing short-, medium-, and long-term periods, respectively. The SPEI's sensitivity to extreme events and probability functions necessitated a specific calculation method. In this case, this study employed the method proposed by Stagge [26], which utilizes the generalized extreme value distribution and factors in the potential evapotranspiration (PET) and daily rainfall. The McGuinness–Bordne method was employed to compute the PET. This method is preferable when limited variables are available, such as temperature, and is known to provide accurate results. It was previously successfully used for daily PET calculations in regions such as the UK [27]. The McGuinness–Bordne method was applied to all available thermo-pluviometric series for this study.

To obtain temperature data for the SPEI calculation, a process similar to that used for precipitation was employed. It involved using the same 141 AEMET stations in the study area (referred to as thermo-pluviometric stations), which had daily temperature records. Quality control, gap filling, and homogenization followed the procedures from Miró et al. [18] developed for precipitation, without requiring dry/wet ratio adjustments. Various gap-filling methods from Miró et al. [18] were applied to the temperature data. The most effective method was variational Bayesian PCA (VBPCA), which was proposed by Ilin and Raiko [28]. As with precipitation, the validation process was carried out on an estimated daily data set, removing an additional 5% of data equally distributed among all the series involved. These data were, therefore, estimated exactly as if they were missing point information and then validated with the actual data omitted from the process. After adjusting to preserve the probability density function (using a quantile mapping adjustment), the estimated daily missing temperature data consistently had a mean daily error (MAE) ≤ 1 °C and a root-mean-square error (RMSE) ≤ 1.4 °C. The obtained biases for the monthly and annual averages were almost negligible (<0.1 °C).

The results are presented as follows:

1. The SPEI trend using the Mann–Kendall test for each thermo-pluviometric station for 1952–2021 and the absolute change in the SPEI mean value between the sub-periods 1952–1986 and 1987–2021, where the results were interpolated on a spatial basis. The results are presented in a graphical representation on a map.
2. The time series of the calculated SPEI values, which involved averaging all thermo-pluviometric stations in each basin and presenting the results separately for different river basins.

3. Results

3.1. Observed Changes and Trend Analysis in Rainfall Volume and Number of Rainy Days

Figure 5 shows the recorded rainfall and the number of days with precipitation in 1952–1986 (left) and 1987–2021 (middle), as well as the relative change between the two periods (right). As can be seen, the precipitation changed considerably during the 70 years of the study period, not only for the amount of precipitation recorded, but also in terms of the number of rainy days. Except in the eastern part, which belonged to the CHS, 1952–1986 was wetter and had a greater number of rainy days than 1987–2021. The most affected areas were those with higher altitudes and higher average annual rainfall (Figures 1 and 2). As an example, the eastern part of the CHQ showed a decrease of more than 25% in rainfall volume, while in the western part, no clear trends were observed (slight declines and rises). However, a generalized decrease in the number of rainy days was observed, with above 15% in most of the basin and some areas above 25%. In the north of the study area, the CHG and CHJ presented similar results, with a generalized decline in rainfall volume and rainy days, with the latter being more pronounced. The CHS showed different behavior from the rest. In this basin, the decrease in the volume of precipitation affected its western part, which was the area with the highest altitude. On the other hand, its eastern part, which is the area with the lowest altitude and closest to the sea, registered an increase of 5–15% in rainfall volume. However, it was observed that the change in the number of rainy days mainly affected the western part, with a decrease of between 5 and 15% in the number of rainy days. In the rest of the basin, the variations were small (±5% rainy days), with a positive gradient toward the east.

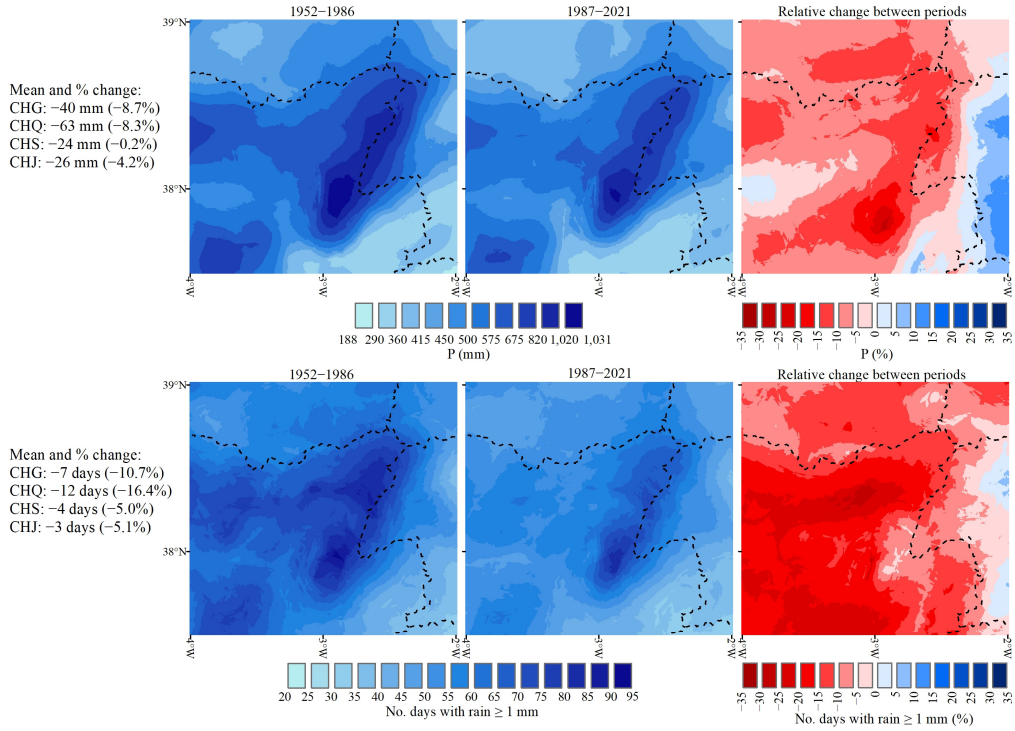

Figure 5. Average annual rainfall (**top**) and average annual number of days with precipitation (≥1 mm) (**bottom**) for 1952–1986 (left images) and 1987–2021 (center images), as well as relative change between periods (right images).

Furthermore, a statistical study was performed using trend and slope analysis (1952–2021) for the annual rainfall volume and number of rainy days (daily rainfall ≥ 1 mm), which is shown in Figure 6. The figures at the top show the precipitation behavior in terms of the volume recorded by the pluviometric stations. The majority of pluviometric stations showed a negative trend in the rainfall volume recorded during the 70 years of

study. In quantitative terms, 52% of the stations showed statistically significant negative trends, with only 1% showing a statistically significant positive trend. A detailed analysis of the basins revealed that different results were observed. On the one hand, the CHG basin had the highest percentage of observatories with a statistically significant negative trend (73%), followed by the CHQ (56%). In the latter, in the area bordering the CHS to the south, as well as in the area located to the west, which is at a lower altitude, the largest number of stations with trends without statistical significance appeared. Looking at the Sen slope, decreases of between 1 and 3 mm/year dominated most of the territory, with some areas exceeding 5 mm/year, which represented a relative loss of approximately 0.8% per year. On the other hand, the CHJ and CHS were the basins with the lowest percentages of stations with negative trends (14% and 19%, respectively). In both basins, these stations were located in the western part, bordering the CHQ, and in areas of high altitude. It should be noted that the CHS included the only five stations that showed a statistically significant positive trend, representing 8% of the total number of stations in the basin.

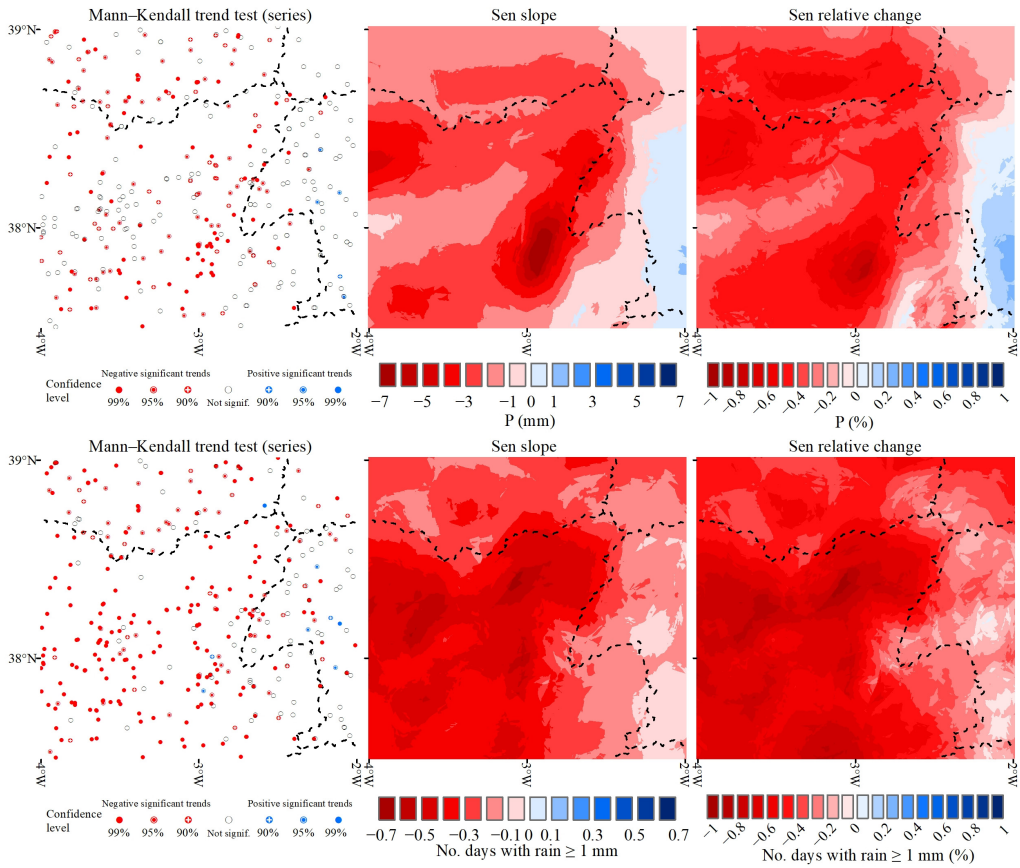

Figure 6. Trends (1952–2021), annual and relative (%) slopes for annual precipitation volume (**upper** images), and number of rainy days (≥1 mm) (**lower** images).

In the lower part of Figure 6, the same statistical analysis is presented, but, in this case, considering the number of rainy days, greater losses can be observed. A total of 74% of the rainfall stations analyzed showed a statistically significant negative trend. In particular, the CHJ, CHG, and CHQ presented more than 70% of stations with a negative trend in the number of rainy days, reaching 84% in the latter. At the same time, the number of rainy days decreased at a rate of more than 0.3 days per year in most of the CHQ territory and at a slightly lower rate in the rest, which meant percentage losses of more than 0.4% per year. Furthermore, it should be noted that, in the CHS, the number of stations with a statistically significant negative trend reached 40%, whereas five stations registered positive trends.

3.2. Observed Seasonal Changes in Rainfall Volume and Number of Rainy Days, and Trend Analysis of Seasonal Rainfall Volume

Figure 7 shows the relative changes in the seasonal values of the rainfall volume and number of days with rainfall (≥1 mm) between 1952–1986 and 1987–2021. Regarding the volume of precipitation (figures and data on the left), it can be seen that summer and winter experienced the greatest changes, with decreases of 20% and 19%, respectively. On the other hand, autumn showed a generalized increase in the volume of rainfall, which manifested as 10% more precipitation recorded in the most recent period, while spring was the least affected season, with losses of less than 10% dominating in all basins. In detail, it was observed that the greatest changes occurred in the CHQ and CHG during the summer and winter, with areas showing decreases between 30 and 40%. It can also be noted that in the extreme eastern part of the study area, the decreases were smaller, and even areas with considerable increases in the volume of precipitation in winter could be found in the CHS.

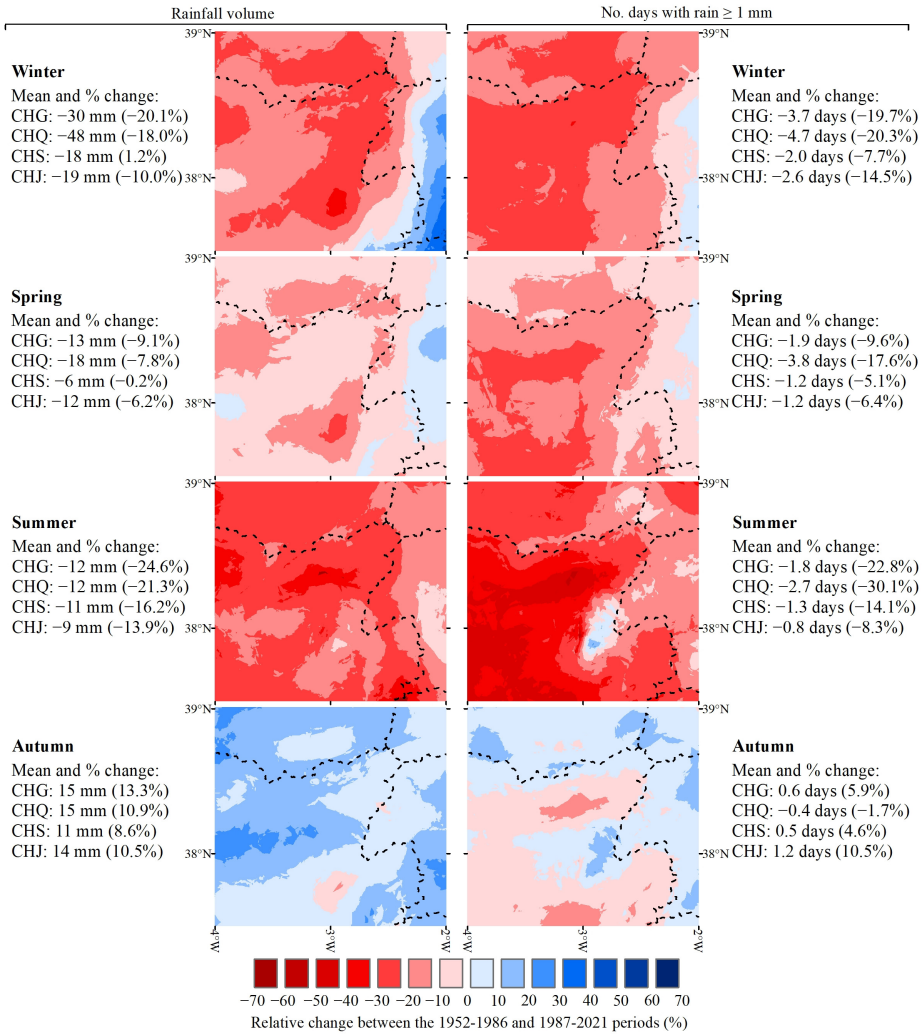

Figure 7. Relative changes in the seasonal values of rainfall volume (figures and data on the **left**) and in the number of rainy days (≥1 mm) (figures and data on the **right**) between 1952–1986 and 1987–2021.

Regarding the observed changes in the number of rainy days between the two periods analyzed (Figure 7, pictures and data on the right), the behavior was similar to that observed for the rainfall volume, with summer and winter as the most affected seasons. Likewise, spring also showed a strong overall decrease of 15%, while in autumn, there was very little difference between the periods. In detail, the analysis showed that the CHQ was the basin

where the largest decreases were recorded in all seasons. Examples included the decreases in the number of rainy days observed in summer in a large part of its territory, with values exceeding 40%. In winter, there was also a general decrease in the CHQ of more than 20%.

Changes in the seasonal rainfall volume were also studied using other analyses. Figure 8 displays the trends and slopes observed (1952–2021) for seasonal precipitation, showing important differences between seasons and basins. Winter and summer were the seasons with the strongest decreasing trends in rainfall volume, and the CHG and CHQ were the basins with the greatest number of rainfall stations with statistically significant negative trends. In winter and summer, more than three-quarters of the rainfall stations analyzed showed negative trends, albeit with important differences depending on the river basin. In the CHG, more than 90% of the rainfall stations showed negative trends in winter and summer, while in the CHQ, the highest number was reached in winter, with 88% of stations showing the same pattern. In contrast, in autumn and spring, there were very few stations with a statistically significant trend. In autumn, although the Sen slope was negative in most of the territory, only 13% of the rainfall stations registered negative trends with statistical significance. In spring, on the other hand, in the CHS, CHJ, and CHG, positive Sen slopes dominated and there were even 3% of the rainfall stations with a positive trend, with most of them located in the central part of the CHS. In contrast, the CHQ was dominated by negative slopes in both autumn and spring.

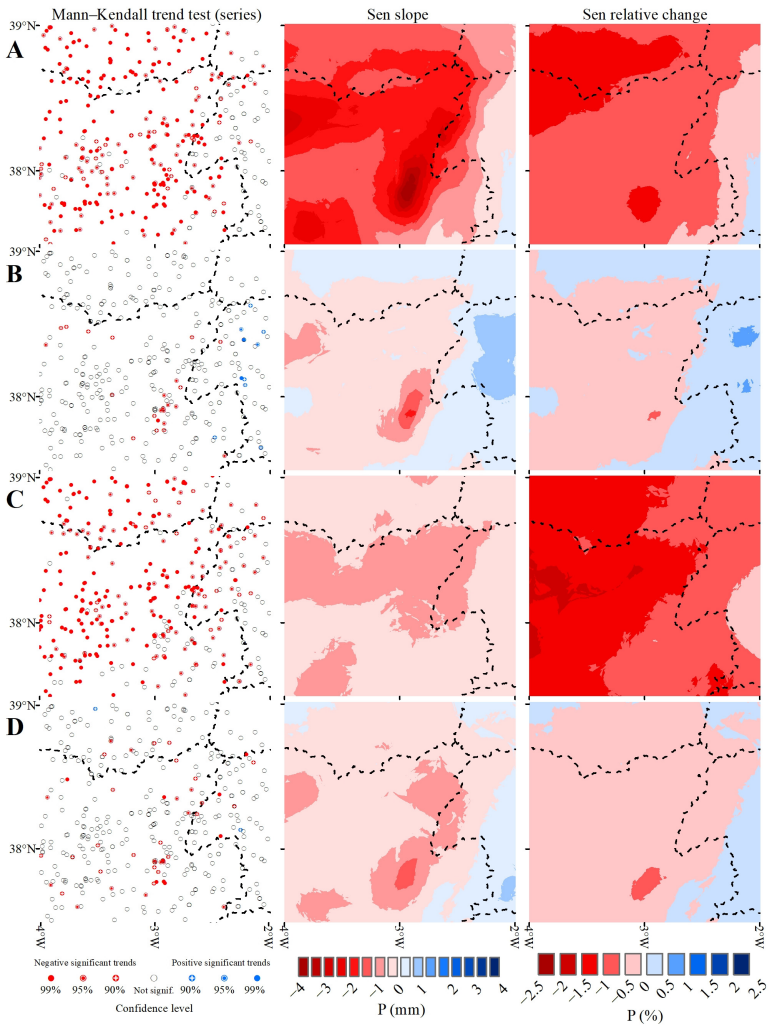

Figure 8. Trends (1952–2021), and annual (mm) and relative (%) slopes for seasonal precipitation ((**A**): winter; (**B**): spring; (**C**): summer; and (**D**): autumn).

3.3. Changes According to the Type of Precipitation, Classified by Intensity

Figure 9 shows the relative changes in precipitation recorded between the two 35-year sub-periods studied for the three intensity levels. Weak precipitation (<10 mm/d, left figure) experienced the greatest change, with a generalized decrease throughout the study area, with a greater magnitude in the extreme east. At the same time, moderate precipitation (10–40 mm/d, center figure) also decreased in most of the area studied, although to a lesser relative extent than weak rainfall. For this type of precipitation, a slight increase was observed in the east of the CHJ and the extreme southeast of the CHS and CHQ. In contrast, heavy precipitation (≥40 mm/d, right figure) increased throughout the study area, except in some specific high-altitude areas. This increase in the rainfall volume, caused by heavy rainfall, reached values greater than 100% in some areas.

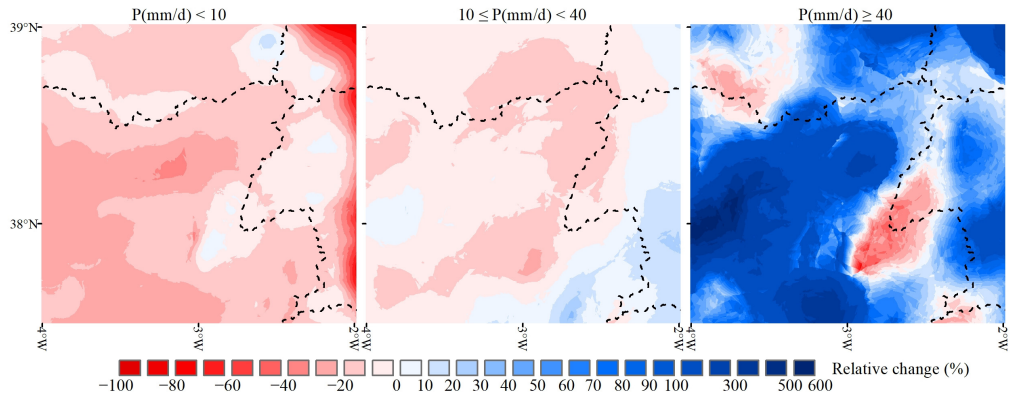

Figure 9. Relative changes in the volume of precipitation recorded between 1952–1986 and 1987–2021 according to the type of precipitation: (**left**), weak rainfall (<10 mm/d); (**center**), moderate rainfall (10–40 mm/d); and (**right**), heavy rainfall (≥40 mm/d).

Since rainfall is highly variable interannually, to be able to interpret the results obtained with more confidence, another analysis was carried out to evaluate the trend of rainfall according to its intensity. The first step was to analyze the trend in the volume of all rainfall and the number of days with precipitation for the study area as a whole (Figure S1). In this case, a decrease in both factors was observed, but with statistical significance only in the number of rainfall events. However, when the precipitation grouped by intensity intervals was analyzed, the results changed. Therefore, in the second stage, for each type of rainfall, the pluviometric stations were grouped according to whether they registered a negative or positive change between the two sub-periods (1952–1986 and 1987–2021), and their trend was analyzed for 1952–2021. Thus, the top of Figure 10 shows the average annual number of events and the volume of weak rainfall for 1952–2021 for the 299 stations that showed a negative change in Figure 9. The same analysis was performed for the 49 stations with a positive change between those periods (shown at the bottom). A strong trend toward a reduction in either the number of days or the volume of precipitation was observed, both with very strong statistical significance (99.99% confidence level), for the rainfall stations with a negative change between the sub-periods. For moderate precipitation (Figure 11), the results were similar, and a decrease in both variables was also observed for the 238 stations with a negative change, with strong statistical significance (95% confidence level). On the other hand, the 224 stations with a positive change in heavy precipitation showed a strong tendency toward an increase in both the volume and frequency of events, with very strong statistical significance (99% confidence level) (Figure S2).

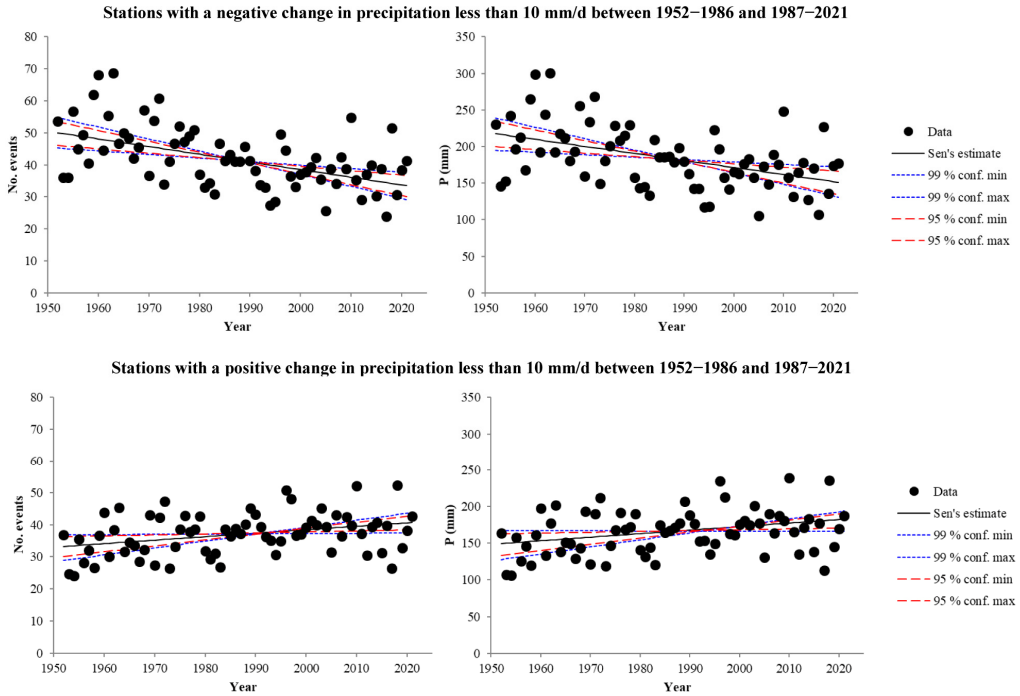

Figure 10. (**Top** graphs): slopes (Sen) and confidence intervals (95–99%) for the mean trend (1952–2021) in weak (<10 mm/d) rainfall daily events of all the stations that, according to Figure 9, showed a negative change between 1952–1986 and 1987–2021 (left, the number of rainy days; right, the mean precipitation per observatory and year for these days). (**Bottom** graphs): same test analyzing all the observatories that in Figure 9 showed a positive change between 1952–1986 and 1987–2021.

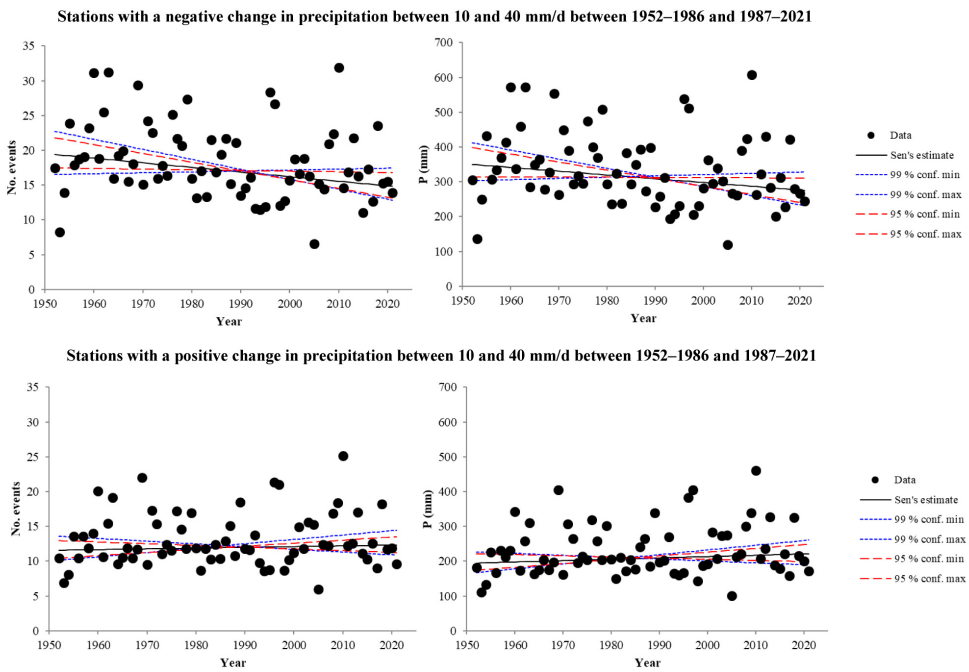

Figure 11. Same as the previous figure, but for moderate rainfall (between 10 and 40 mm/d).

3.4. Variations in the Length of Dry (Wet) Periods

Figure 12 displays the trend and the absolute and relative changes in the maximum length of dry periods, the annual mean length of dry periods, and the annual mean length of wet periods during 1952–2021. At the top, it can be seen that the CHQ was dominated by rainfall stations showing statistically significant increases in the maximum dry spell

duration, which accounted for 59% of the total number of stations in this basin. In the rest of the basins, this type of station represented approximately half of the CHQ value. However, the graphs of the change in the duration of these periods show a general increase in the entire study area, which was more pronounced in the CHQ than in the rest of the basins. Similarly, the graphs representing the trend and change in the average dry period (figures in the center) show a similar result, with approximately 60% of stations with statistically significant trends toward an increase in these dry periods in the CHQ and a smaller percentage in the rest of the basins. Finally, the duration of the wet period showed a clear tendency to decrease throughout the study area, except in the eastern part of the CHS. In this case, more than 70% of the pluviometric stations in all basins, except for the CHS, showed a trend toward the shortening of the wet period, reaching more than 80% in the CHQ.

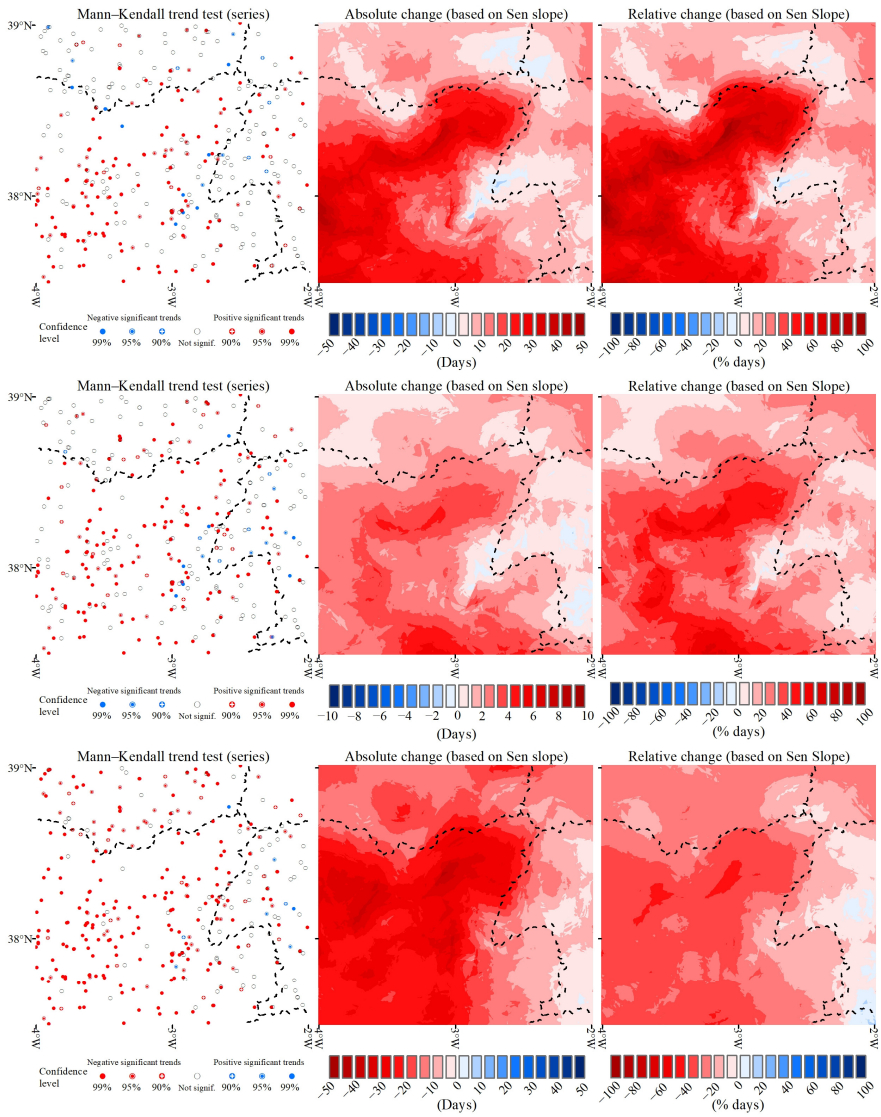

Figure 12. Trends and absolute and relative changes, in days, for the annual maximum length of dry periods (**top** graphs), the annual mean length of dry periods (**center** graphs), and the annual mean length of wet periods (**bottom** graphs) for 1952–2021.

3.5. Analysis of the Trend and Time Series of SPEI

In general terms, rainfall stations with a negative trend dominated in most of the territory and over the three time scales (3, 12, and 36 months), except in the eastern part of the CHS, where most of them showed no trend (Figure 13). With the 3-month SPEI,

50% of the observatories analyzed showed a significant negative trend, with the CHG and CHQ showing the highest percentages (78% and 52%, respectively). On the other hand, in the CHS, only 12% of the stations showed this tendency toward a decreasing SPEI. With the 12-month SPEI, this percentage rose to 62%, reaching the highest values for stations with a negative trend in the CHG (88%) and CHQ (68%). For the 36-month interval, 50% of stations showed a statistically significant negative trend, with 24% in the CHS (its highest value over the three time scales). Regarding absolute changes, most of the area under consideration and the three time scales were dominated by losses, with some minor differences: (1) the largest declines were found in the CHG and the eastern part of the CHQ; (2) positive changes were only observed in the eastern part of the CHS, where the areas showed slight increases.

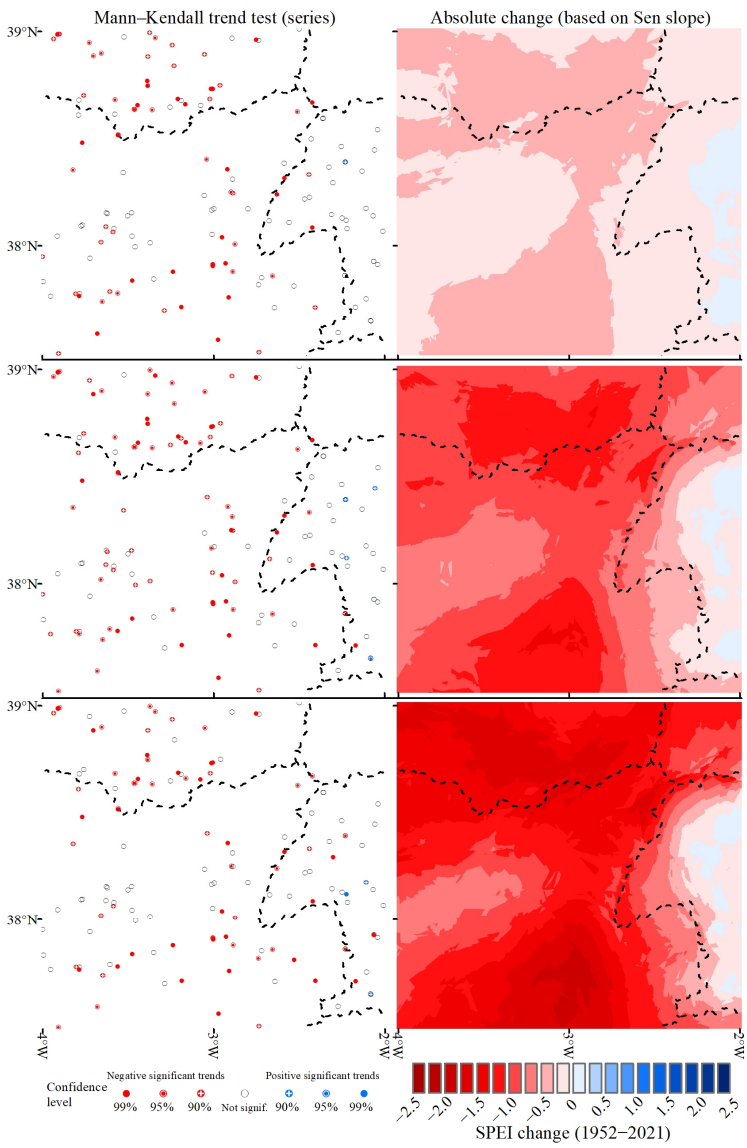

Figure 13. Trends and absolute changes in the standardized precipitation evapotranspiration index for 1952–2021 at the 3-month (**top**), 12-month (**middle**), and 36-month (**bottom**) time periods.

Figures 14 and 15 show the daily SPEI data series at medium- and long-term scales, differentiating between river basins. For the 12-month SPEI, it was generally observed that, from the 1960s to the 1980s, periods of positive SPEI dominated. After this, drought periods were more frequent in the four basins. In the mid-1990s and the 2000s, the lowest SPEI values were recorded, reaching −2 in some of the basins. For the long-term drought

data (36 months), this behavior was similar, although with less alternation between positive and negative SPEI periods. During the 1960s and 1970s, there was a clear predominance of positive SPEI values, while from the 1980s onward, negative values dominated. In this latter period, except in the CHS, there were long periods of drought in the remaining three basins, which were only interrupted by two shorter non-drought periods. In addition, from 2016 onward, these three basins experienced a strong drought, with SPEI values below −1. Understanding the impact of drought is more challenging in the short term. Indeed, the 3-month SPEI time series revealed significant variability across all basins, featuring a mix of positive and negative SPEI values, mainly in the final decades of the study period (Supplementary Figure S3).

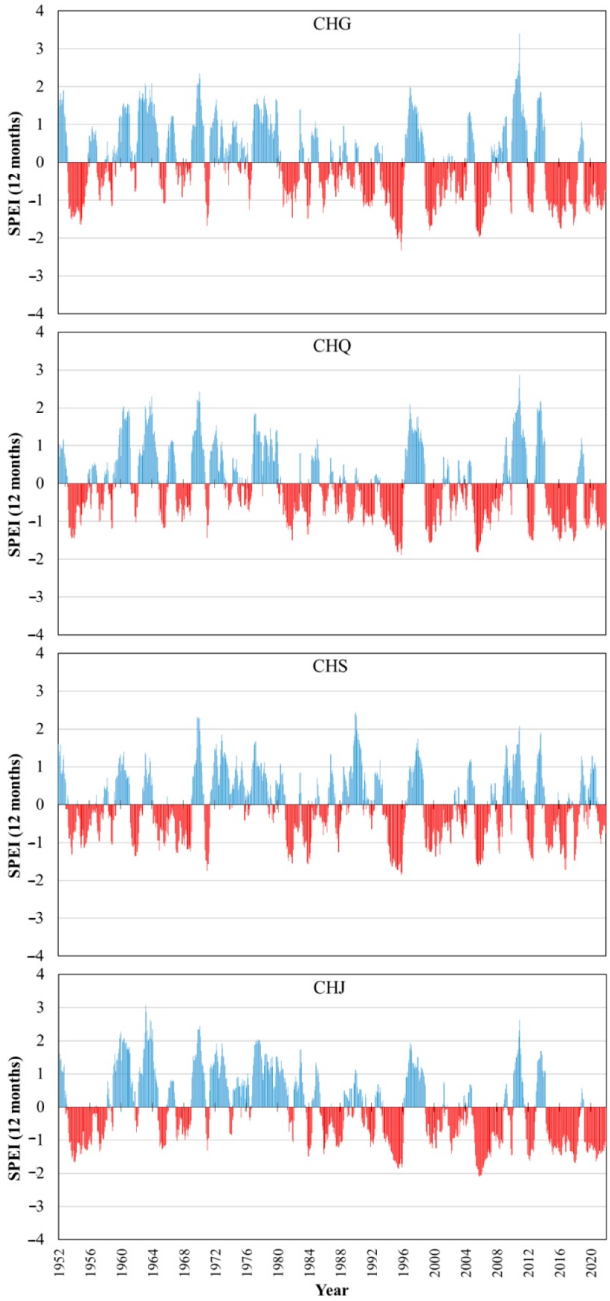

Figure 14. Evolution of the mean daily SPEI data (12-month time scale) for 1952–2021 and the CHG, CHQ, CHS, and CHJ weather stations. The color blue represents positive SPEI values, and red represents negative values.

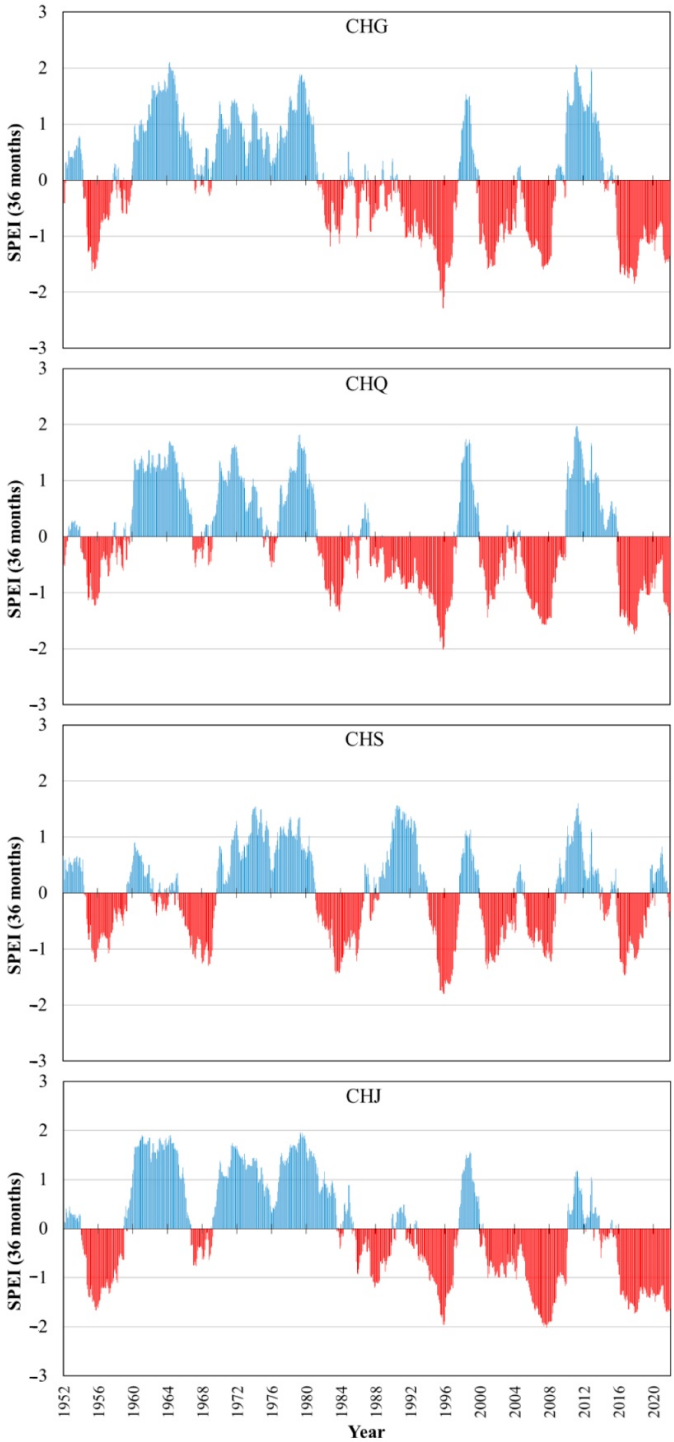

Figure 15. Same as the previous figure but for the 36-month time scale.

4. Discussion

The findings of this study, which were derived by analyzing the changes in precipitation over the last 70 years in a key recharge area for several of the most important rivers in the south and southeast of the Iberian Peninsula, show that the second half of this period was drier than the first half and that the patterns of rainfall changed, with a greater concentration of rainy days (fewer days with precipitation but greater intensity). The main findings related to the comparison of 1952–1986 and 1987–2021 are the following:

- The volume of precipitation recorded in the most recent period (1987–2021) was approximately 9% smaller than in the earlier period (1952–1986). In addition, the

reduction in the number of rainy days was 14%. This means that precipitation was concentrated in fewer days, resulting in more days with a high rainfall intensity.

- The changes were not the same across all seasons. Summer and winter were the seasons with the greatest changes in precipitation behavior. In these two seasons, the volume recorded in the most recent period was approximately 20% smaller than in the earlier one. As for the number of rainy days, the losses reached 28% in summer and 19% in winter. A decrease in precipitation in winter in the CHQ was detected in other studies, as well as a trend toward less precipitation [29]. Spring also showed declines in both the precipitation volume and number of rainy days, but with a lesser magnitude. On the other hand, autumn registered approximately 10% more rainfall in 1987–2021, with the same number of days. Thus, the rainfall regime changed mostly in summer and winter, which are traditionally the driest seasons in this region, producing even drier seasons [30]. On the other hand, more recently, autumn was wetter, although the frequency of days did not change, resulting in more intense precipitation. In this region and this season of the year, situations of intense rainfall in short periods are typical, which can cause severe damage to infrastructures and the population [31,32].
- The analysis of rainfall as a function of intensity revealed the importance of weak and moderate rainfall (<40 mm/d) in this area, both in volume and frequency. The presence of both in the most recent period was reduced, while heavy rainfall ($\geq$40 mm/d) was more frequent and contributed a larger rain volume in the same sub-period. Weak and moderate rainfalls play a fundamental role in the recharge of hydrological systems in Mediterranean regions. Their importance lies in their ability to infiltrate the soil effectively, which recharges subway aquifers and supplies fresh water to springs and wells throughout the year. In contrast, heavy rainfall, which is characterized by its high intensity, tends to cause runoff rather than infiltration. This means that rainwater flows rapidly over the ground surface, which can result in soil erosion and reduced aquifer recharge. While heavy rainfall can be beneficial in terms of refilling reservoirs and providing temporary relief in drought situations, it is not as effective for sustainable groundwater aquifer recharge. Although the classification of rainfall according to its intensity was used in other works [11] and is considered valid, the format of the rainfall data used (daily resolution) made it difficult to achieve a more accurate classification and may have masked some results.

A detailed analysis of rainfall intensity is essential for a complete understanding of the changes in rainfall patterns in the region studied. In the overall analysis, there was no clear trend toward a lower rainfall volume, although there was a trend toward a lower frequency of rainy days (Figure S1). This result coincides with other studies that indicate that no significant trend regarding a precipitation decrease was detected in the SE Iberian Peninsula [33]. However, although there was no overall decrease in the total amount of rainfall, the detailed data indicate that there were changes in the nature of the rainfall that affected rainfalls of different intensities. The lack of an obvious trend in the total rainfall volume could have been due to compensation between the different types of precipitation. For example, the significant decrease detected in weak and moderate precipitation could have been compensated for by the significant increase observed in heavy precipitation. This highlights the complexity of changes in rainfall patterns and emphasizes the need for a more detailed approach that considers rainfall intensity. Other detailed studies in areas of complex orography in the east of the Iberian Peninsula also showed the importance of analyzing precipitation according to its intensity in order to detect trends [11,12]. Without this perspective, important patterns that affect water resource management, agriculture, and other sectors that depend on water availability could be missed.

Consequently, a reduction in the number of rainy days results in longer dry periods and shorter wet periods. The analysis of the trends in both variables found statistically significant trends toward more arid conditions (longer average and maximum dry spells and shorter wet spells). The headwaters of the Guadalquivir River basin (CHQ) showed the largest number of rainfall stations with this trend, with a notable predominance over the

rest of the stations. In Mediterranean regions, the impact of dry and wet periods influences daily life, the economy, and environmental sustainability. In a region where agriculture is an essential part of the economy, dry periods can result in droughts that severely affect crops. In fact, a lack of rainfall can lead to a decrease in agricultural production [34]. In turn, water scarcity can lead to drinking water supply problems, as has already occurred several times in this region in recent years [35,36].

The results obtained from the analysis of precipitation, which indicate a decline in both the precipitation volume and the number of rainy days, together with an increase in temperature and its upward trend [37,38], suggest favorable conditions for drought. The decrease in rainfall effectiveness is also aggravated if the evapotranspiration losses increase due to the parallel increase in temperature. This negatively impacts the soil balance by extending the period without water reserves in the soil, which, in turn, increases the water requirements for agriculture [39,40].

The analysis of SPEI trends provided valuable information on the changing precipitation patterns in the region studied. One of the most noteworthy findings is the prevalence of a negative trend over most of the territory and over the three time scales analyzed (3, 12, and 36 months). This negative SPEI trend suggests a persistent decrease in precipitation levels, indicating an increasing risk of aridity. However, the presence of specific regional variations was evident, which justifies detailed studies such as this one. As an example, in the eastern part of the CHS, most of the rainfall stations did not show any significant trend, while in its western part, stations with a significant trend toward lower SPEI values predominated. In contrast, the observatories with a statistically significant downward trend were most prevalent in the CHG and CHQ over the three time scales analyzed. Moreover, in the case of the 12-month time scale, more than two-thirds of the stations in both basins showed a negative trend, reaching 88% in the CHG. These results are especially important in this last basin since they coincide with those obtained in another study that analyzed a different region containing the headwaters of several tributaries of the Guadiana River [12,41]. This situation of decreased precipitation and prolonged drought conditions in the headwaters of the eastern part of the CHG is a risk factor for the environmental sustainability of the Tablas de Daimiel National Park, which is situated downstream of both headwaters analyzed.

The area studied experienced a wet period between the 1970s and 1980s, reflecting favorable hydrological conditions. Then, periods with negative daily SPEI values dominated, indicating a greater frequency of drought events. A period of lower SPEI values occurred between 1990 and 2000. In more recent years, there was also a significant dry period. These results are similar for the 12- and 36-month time scales, although with smaller fluctuations between positive and negative values in the longer time scale, and for the CHG, CHQ, and CHJ. The analysis of the 3-month SPEI data revealed considerable variability, with alternating periods of predominantly positive and negative SPEI values. This variation highlights the complexities of understanding short-term drought effects, which are influenced by factors such as seasonal changes, extreme weather events, and climate anomalies. Nevertheless, a trend toward chronic drought conditions is clear, given the increasing imbalance toward longer dry spells in the longer time scales. These results coincide with those obtained in other studies, such as those carried out in Central and Southern Europe, the Eastern Mediterranean, and Western Asia [42]. In general, an increase in the frequency, severity, duration, and extent of drought is observed, with changes in precipitation being one of the main causes.

On the other hand, there have been several recent studies that point to possible changes in the general atmospheric circulation over the Iberian Peninsula that are related to climate change [43–45]. In particular, the greater expansion of the subtropical highs toward this area and the loss of rainfall associated with the zonal flows from the west are noted in these studies. This seems to be in line with the results obtained in the present study, particularly for the winter and summer cases.

5. Conclusions

This study revealed a precipitation decrease over 70 years in a key recharge area for several important rivers in the S and SE Iberian Peninsula. The precipitation waters captured by this enclave are of great importance for the economy and sustainability of the region; therefore, these results are important for those members of the government who are responsible for making decisions on the management of the water resources of the basins in question.

One of the key findings of this study is that the pattern of precipitation changed significantly during 1952–2021 in this mountainous area in the S and SE Iberian Peninsula, which includes the headwaters of several rivers of great importance for the region. A higher concentration of precipitation was observed over fewer days. Furthermore, a change in the precipitation patterns over time was noted, with an increasing number of days exhibiting high-intensity rainfall and a decreasing number of days with weak and moderate precipitation. In fact, weak and moderate precipitation, which are considered the most suitable for recharging water systems in mountainous areas, such as the one under study, were the most affected by these changes, showing a trend toward a reduction. On the other hand, heavy precipitation events significantly increased in frequency. This could have a significant impact on aquifer recharge, as such recharge will become increasingly less effective. This will have repercussions for the water supply, agriculture, and the sustainability of local ecosystems, and thus it is necessary to start planning for the future.

In the absence of such a study, the significance of the overall reduction in precipitation could be underestimated. However, a more refined analysis focusing on the precipitation intensity reveals important changes. A decrease in weak or moderate precipitation, as highlighted in this study, has profound ecological implications for the hydrological system and, consequently, for the well-being of communities. Similarly, an increase in torrential rainfall has implications for both the natural and social systems, often resulting in adverse effects. Therefore, understanding these dynamics is vital for societal adaptation and resilience.

Another key finding of this study was not only the concerning negative trends in precipitation but also the temporal and spatial variability associated with these patterns. The winter and summer seasons, which are characterized as the driest in the studied area, experienced the most pronounced impacts and significant losses.

The reduction in precipitation during these seasons raises concerns about potential water shortages in the region. With minimal water input into the system during winter and, mainly, summer, any decrease could have adverse effects across multiple sectors, ranging from agriculture to the provision of water for human consumption. It is crucial to note that the southern and southeastern parts of the Iberian Peninsula hold considerable importance as tourist destinations in the western Mediterranean, leading to a substantial increase in population and therefore an increase in water consumption during the summer months. This study also revealed the lengthening of the dry periods, which were more frequent in summer and winter in the study area, leading to more arid conditions. Given these circumstances, proactive planning becomes vital, as it appears that inputs during the already arid seasons will become less significant. This rationale should be extended to other water-dependent activities, such as agriculture, which is also vital for the inhabitants of the S and SE Iberian Peninsula.

Similarly, the use of a dense network of meteorological stations has made it possible to observe territorial differences. This detailed study methodology revealed a long-term chronic drought scenario, with a more pronounced effect in the Guadalquivir, Guadiana, and Júcar River basins. Recognizing the impact of drought on environmental sustainability, especially in ecologically sensitive areas, such as those analyzed in this study, the importance of the research is enhanced. In light of the revealed situation, strategic measures should be implemented to conserve biodiversity and improve the overall health of the studied ecosystem.

Finally, the results obtained here should be taken into account in the future water management of the Tablas de Daimiel National Park, which is a site of great ecological value located a few kilometers downstream of this enclave. This type of study provides a basis for water resource management and drought mitigation strategies that are more specific and adaptable to a changing climate.

Supplementary Materials: The supplementary information is available at https://www.mdpi.com/article/10.3390/atmos15020166/s1. Figure S1: Slopes (Sen) and confidence intervals (95–99%) for the mean trend (1952–2021) in precipitation daily events of all the stations in the study area (left, the number of rainy days; right, the mean precipitation per observatory and year for these days). Figure S2: Top graphs: slopes (Sen) and confidence intervals (95–99%) for the mean trend (1952–2021) in heavy ($\geq$40 mm/d) rainfall daily events of all the stations that, according to Figure 9, showed a negative change between 1952–1986 and 1987–2021 (left, the number of rainy days; right, the mean precipitation per observatory and year for these days). Bottom graphs: same test analyzing all the observatories that in Figure 9 showed a positive change between 1952–1986 and 1987–2021. Figure S3: Evolution of the mean daily SPEI data (3-month time scale) for 1952–2021 and the CHG, CHQ, CHS, and CHJ weather stations.

Author Contributions: Conceptualization, M.J.E., D.C., J.J.M. and R.N.; methodology, M.J.E., D.C., J.J.M. and R.N.; software, D.C. and J.J.M.; validation, M.J.E., D.C., J.J.M. and R.N.; formal analysis, D.C. and J.J.M.; investigation, M.J.E., D.C., J.J.M. and R.N.; resources, M.J.E. and R.N.; data curation, D.C. and J.J.M.; writing—original draft preparation, M.J.E., D.C. and J.J.M.; writing—review and editing, M.J.E., D.C., J.J.M. and R.N.; visualization, M.J.E., D.C., J.J.M. and R.N.; supervision, M.J.E. and R.N.; project administration, M.J.E. and R.N.; funding acquisition, M.J.E. and R.N. All authors have read and agreed to the published version of the manuscript.

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