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Analysis of Monthly Rainfall Trend in Calabria (Southern Italy) through the Application of Statistical and Graphical Techniques †

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Abstract: One of the most evident consequences of global atmospheric warming is the modification of the water cycle. Precipitation plays a crucial role in the process and its variations can affect water resources, natural environments and human activities. In this paper, an investigation of the temporal rainfall variability in the Calabria region (southern Italy) has been carried out using a homogeneous and gap-filled monthly rainfall dataset of 129 rain gauges with more than 50 years of observation in the period 1951–2006. Possible trends in monthly and annual rainfall values have been detected by means of the Mann–Kendall test and of a new graphical technique (Şen's method), which allows the trend identification of the low, medium and high values of a series. As a result, a different behavior of both the highest and the lowest rainfall values emerged among the five Rainfall Zones (RZs) that were considered in the analysis. Moreover, from the comparison of the trend methodologies, different trends results (increasing, decreasing, or trendless time series) have been identified. In particular, this study shows that the Şen's method could be successfully used in the evaluation of peak and low values of data for the trend analysis of rainfall values.

Keywords: rainfall; trend; Mann-Kendall; graphical techniques; Calabria

1. Introduction

The latest Assessment Report (AR5) issued by the Intergovernmental Panel on Climate Change [1] has highlighted the global impact of human activities on climate and the effects that such activities produce. The increase in CO_2 and greenhouse gases (methane and nitrous oxide) emissions in the atmosphere are believed to be the main cause of the global warming observed since the 1950s [1]. Indeed, rising Earth surface temperatures in the last century were evidenced according to the AR5. Within such a purview, several investigations has primarily focused on multiple analyses of meteorological, hydrological, and climatological variables based on different methodologies [2]. For example, long-term precipitation trends have been observed in several large areas of the world [3,4]. As regards the Mediterranean area, an alternation of extreme rainy periods and droughts or water shortages has been detected [5]. Furthermore, significant precipitation variability characterizes this area at regional scale [6,7], resulting from synoptic dynamics of hazardous events moving and evolving along the Mediterranean basin [8]. In Italy, numerous investigations carried out using long-term precipitation databases have detected a decreasing precipitation trend, even if rarely significant

[9]. The regions in which these trends were observed are principally located in southern Italy: Campania [10], Basilicata [11], Sicily [12] and Calabria [13]. These studies, principally based on non-parametric tests, as the Mann–Kendall [14,15] and the Spearman's rho tests [16], did not specify if low or high precipitation contributed to the detected trends. For this reason, Şen [17] proposed a new Innovative Trend Analysis (ITA) technique, which has found wide application in hydrology [18–20]. In this study, the monthly high quality rainfall series recorded in a region of southern Italy (Calabria) have been analyzed and the temporal changes of the different series have been detected using the ITA technique and the non-parametric Mann–Kendall test. In particular, the investigation was carried out considering five Rainfall Zones (RZs) of the study area, characterized by different climatic conditions. The application of ITA technique allowed to distinguish the trend of the low, medium and high precipitation monthly data.

2. Study Area and Data

Located at the toe of the Italian peninsula (Figure 1), Calabria is a region characterized by a typically Mediterranean climate, presenting sharp contrasts due to its position within the Mediterranean sea and its orography. Specifically, warm air currents coming from Africa and high temperatures affect the Ionian side, leading to short and heavy rainfall. The Tyrrhenian side, instead, is affected by western air current which causes temperatures to be milder and higher precipitation amount on the mountains than on the Ionian side. Cold and snowy winters and fresh summers with some precipitation are typical of the inner areas of the region [21]. The database used in this study was the one presented in [22]. The original precipitation series registered in the Calabria region from 1916, and stored by the Multi-Risk Functional Centre of the Regional Agency for Environment Protection, were checked to eliminate inhomogeneities from the data series and lack of data. As a result, the analysis focused on a total of 129 rainfall series (Figure 1) for the period 1951–2006, in order to study those rainfall series falling within the same time range and presenting the same length.

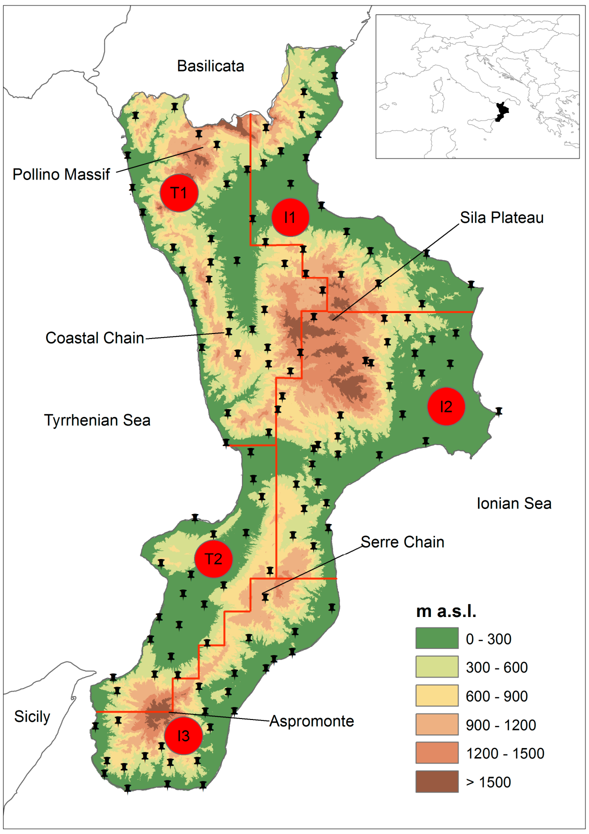

Figure 1. Localization of the selected 129 rain gauge stations and of the five Rainfall Zones on a DEM of Calabria.

Five distinct Rainfall Zones (RZs), presenting different climatic conditions, have been used [23]. Brunetti et al. [23] identified such zones by means of the application of the Principal Component Analysis, including varimax rotation of the principal components, to the correlation matrix of daily records. In particular, the analysis of the first 5 Empirical Orthogonal Functions, which explained 90% of the total variance, had led to the identification of 5 RZs: the North-Western Zone of the Tyrrhenian side (T1) with 31 rain gauges; the South Zone of the Tyrrhenian side (T2) with 21 rain gauges; the North Zone of the Ionian side (I1) with 21 rain gauges; the Central Zone of the Ionian side (I2) with 31 rain gauges; the South Zone of the Ionian side (I3) with 25 rain gauges (Figure 1).

3. Methods

In order to evaluate the possible existence of temporal tendencies, the rainfall series were analysed for trends with the well-known non-parametric Mann–Kendall (MK) test [14,15]. With the aim to specify how low or high precipitation contribute to the detected trends, the ITA method has been applied. This methodology, proposed by Şen [17], has the main advantage that it does not require any assumptions (e.g., serial correlation, non-normality, sample number etc.) as in case of the MK test and other methods. First, the time series is divided into two equal parts, which are separately sorted in ascending order. Then, the first and the second half of the time series are located on the x-axis and on the y-axis, respectively, of a Cartesian coordinate system. If the data are collected on the 1:1 ideal line (45° line), there is no trend in the time series. If data are located on the upper triangular area of the ideal line, an increasing trend in the time series exists. If data are accumulated in the lower triangular area of the 1:1 line, there is a decreasing trend in the time series [17,20]. In the following application, the series were divided into two 28-years sub-series: 1951–1978 and 1979–2006.

4. Results and Discussion

Due to the results of the PCA, for each RZ an average rainfall series has been evaluated for every time-scale. Results of the trend analysis for the five RZs are summarized in Table 1 for yearly and monthly time-scales. The slopes of the trends were calculated by least square linear fitting, and the statistical significance was assessed applying the Mann-Kendall test with three different confidence levels (α = 10%, 5% and 1%).

Table 1. Results of the Mann–Kendall test for yearly and monthly precipitation. Asterisks indicate the significant results obtained through a two-tailed test: 10% (*), 5% (**) and 1% (***).

	I1	I2	I3	T1	T2
	mm/Decade	mm/Decade	mm/Decade	mm/Decade	mm/Decade
Year	−33.8 ***	−53.2 ***	−41.5 **	−45.8 ***	−30.9 **
January	−6.9 *	−8.3 *	−2.9	−14.8 **	−9.9 ***
February	−4.0	−7.0	−3.6	−13.0 **	−5.3
March	−5.8 *	−8.8 **	−9.3 **	−7.4 *	−7.6 *
April	3.2	2.9	0.8	1.5	4.2
May	−2.8	−3.5	−2.8	−4.2	−2.6
June	0.7	−1.5	−0.2	−1.3	−1.1
July	1.7	2.0	0.5	1.5	1.9
August	2.8	2.7	1.1	0.6	2.0
September	0.5	4.7	5.8	3.2 *	3.7
October	−15.2 ***	−24.1 **	−28.6 **	−5.5	−16.4 **
November	−10.4 *	−14.9	−6.2	−6.0	−3.6
December	2.4	2.6	3.8	−0.3	3.8

Regarding the yearly aggregation, the first row of Table 1 clearly shows that the trend is always negative and significant, with the highest rate in RZs I2 (−53.2 mm/decade; SL = 0.01) and T1 (−45.8 mm/decade; SL = 0.01). For the monthly aggregations, a negative trend is present in October, especially on the Ionian side of the region (RZs: I1, I2 and I3) with a maximum rate of −28.6 mm/decade (SL = 0.05) in RZ I3 (Table 1). The negative tendency is also shown with lower rates in March (significant in all the RZs), January (significant in I1, I2, T1, and T2), February (significant only in T1), November (significant only in I1). Table 1 also reveals that summer months often show positive trends, but with low rates and significance only in September (in RZ T1, with a rate of +3.2 mm/decade).

The application of the ITA approach to the five RZs (Figures 2–6) permits to put in evidence the contributions to the trends above described by the low and high precipitation values. The clear negative tendency detected in October is due to the peak values, particularly evident in RZs I2, I3 and T2 (Figures 3, 4 and 6). As an example, in RZ I3 (Figure 4) the highest values in October are about 700 mm and about 280 mm for the periods 1951–1978 and 1979–2006, respectively. Always in October, the contribution to the negative trend in RZ T1 seems to come from the low-medium precipitation. The trends detected in March for all the RZs through Mann-Kendall test are confirmed by the ITA approach which explains also the lower rates. In fact, for the same month the ITA technique shows opposite behaviors of low, medium and high rainfall. For RZs I1, I2, I3, T2 negative trends appear for the low precipitation and an opposite tendency is shown for the high precipitation. As an example, in RZ T2 (Figure 6) a peak value of about 300 mm is observed for the period 1979–2006; this value is higher than the peak of the previous period (about 210 mm). On the contrary, the lowest value for the 1951–1978 period is about 30 mm, while the lowest one for the more recent period is about 0 mm. In RZ T1 the negative trend is more clear for the medium-high precipitation.

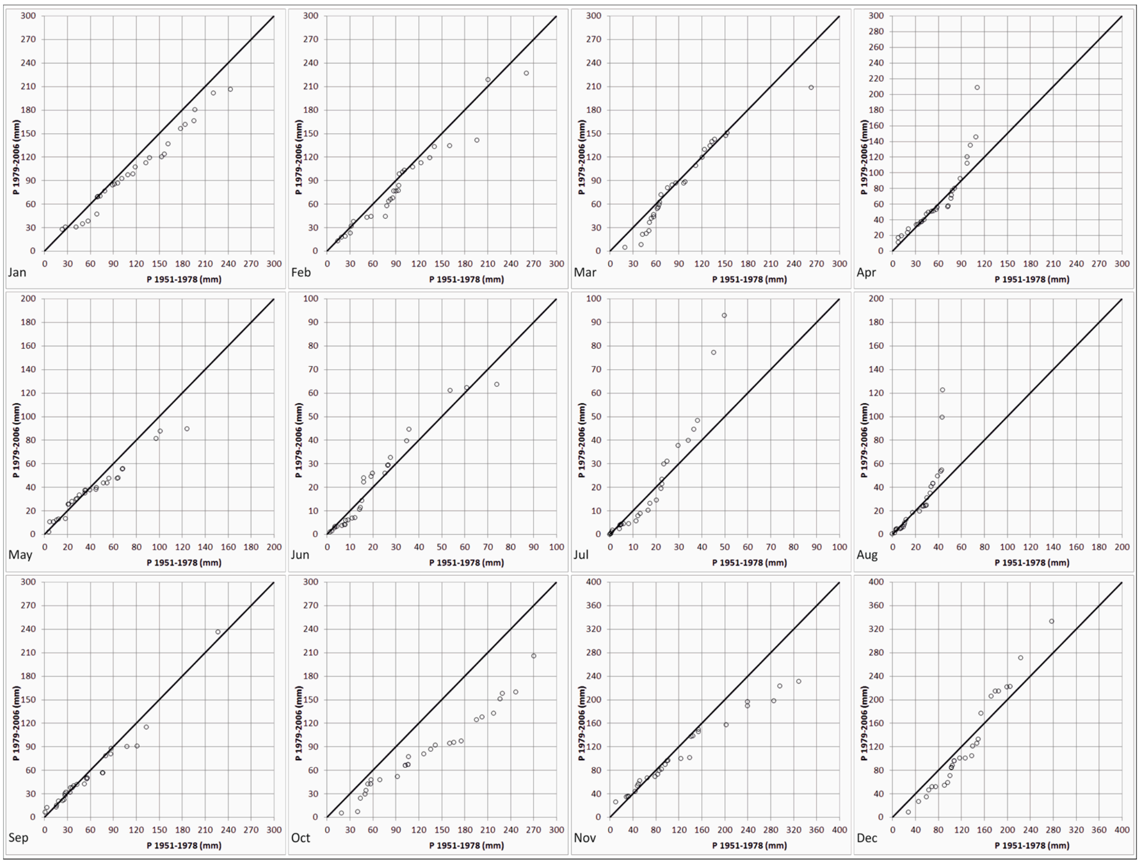

Figure 2. Results of the ITA method for the Rainfall Zone I1 for the period 1951–2006.

In January the significant negative trends detected for the RZs I2, T1, T2 (Table 1) seem to be caused by the low-medium precipitation (Figures 3, 5 and 6). Also for this month, some positive trends appear for the peak values. On the contrary, the significant negative trend for RZ I1 (Table 1) is mainly due to the medium-high precipitation (Figure 2). In February, the only significant trend is present in RZ T1 (Table 1) and the application of the ITA method indicated that this behavior is caused by the medium-high precipitation (Figure 5).

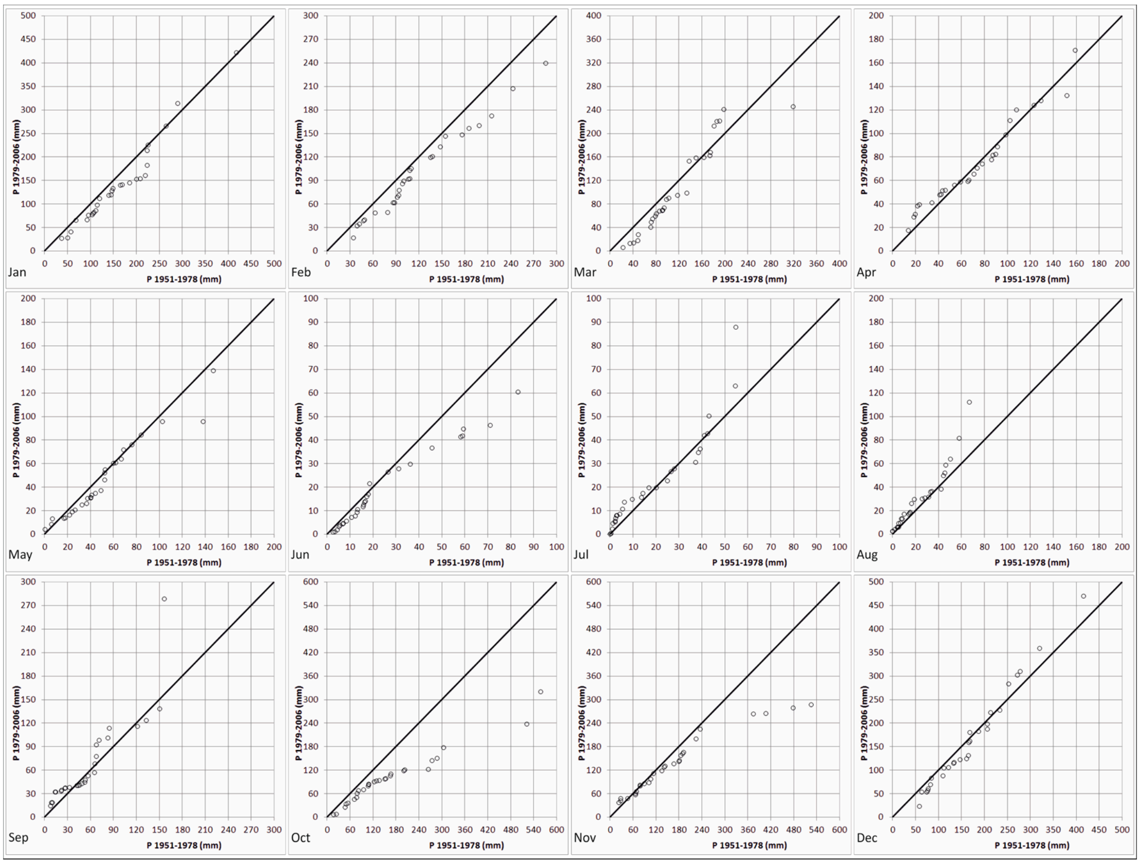

Figure 3. Results of the ITA method for the Rainfall Zone I2 for the period 1951–2006.

The decreasing trend in November, significant only for the RZ I1 (Table 1), can be observed also in the results of the ITA technique, in particular for the peak values on the Ionian side of the region (Figures 2–4). The positive trends of the summer and spring months, significant only in September in RZ T1 (+3.2 mm/decade), in accordance to the Mann-Kendall test results (Table 1), are detected also in April, July and August for the highest values in RZs I1, I2 and T1 (Figures 2, 3 and 5). As an example, in August RZ I1 (Figure 2) shows the highest value for the period 1979–2006 of about 120 mm, that is higher than the peak of the previous period (about 40 mm). December is the only winter month with a non-uniform behavior in the region: the positive, but not significant (Table 1), trends are clear for the highest precipitation values in RZs I1 and I2, while opposite trends are shown in RZs I3, T1 and T2.

Considering separately the different RZs, the application of the ITA method has allowed to consider the behavior of the low and the high precipitation distributions with different results. In RZ I1 (Figure 2) the lowest precipitation values reveal decreasing trends, but with different degrees, in March, June, July, October, December. In RZ I2 (Figure 3), some months (January and March) evidence a not uniform trend: negative for the low precipitation values and opposite for the high ones. In RZ I3 the distribution of the low precipitation values clearly shows decreasing trends in March and evident positive tendencies in April and August (Figure 4). In RZ T1 (Figure 5), considering the lowest monthly values, a decreasing trend can be detected in January, October and December, while there is an increasing trend in April and July. In RZ T2 all the months, with the exception of October and April, reveal opposite tendencies considering the highest and the lowest values (Figure 6). As example, January shows a negative trend for low values and a positive tendency for the high ones. On the contrary, in November, the lowest values increase while the highest ones decrease.

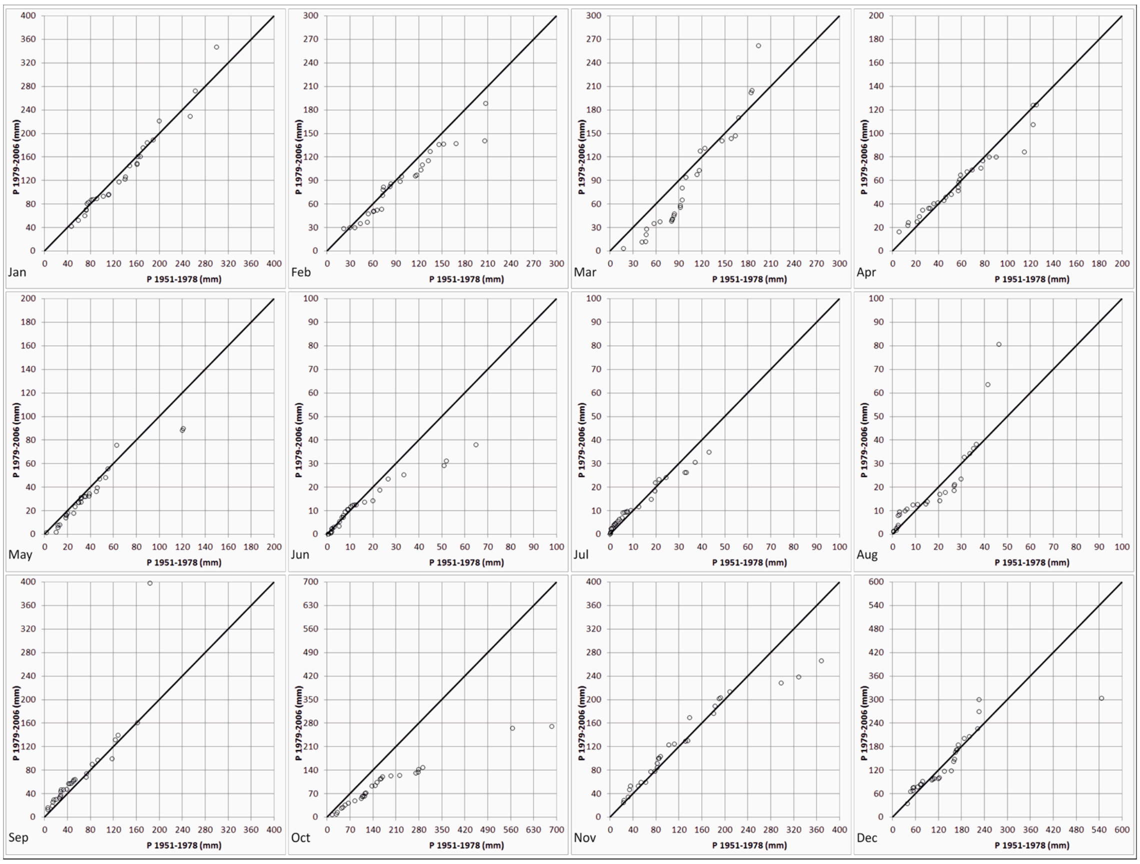

Figure 4. Results of the ITA method for the Rainfall Zone I3 for the period 1951–2006.

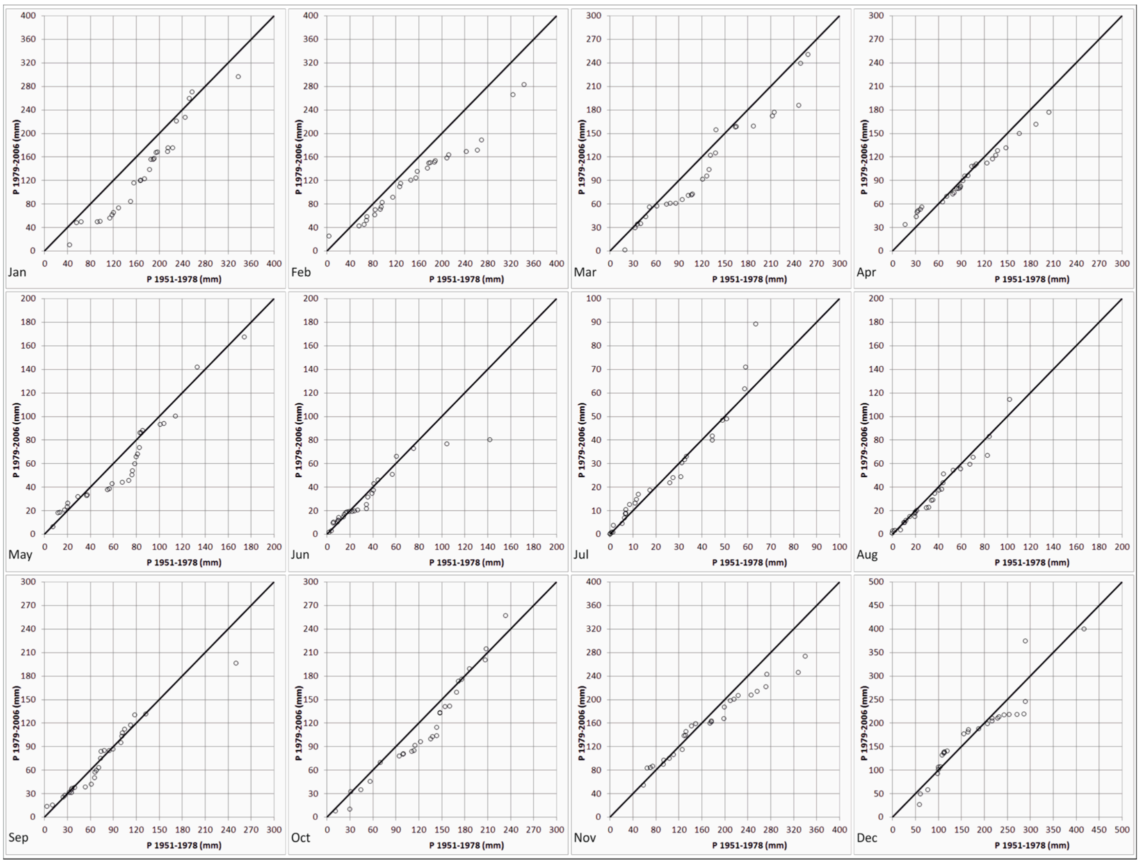

Figure 5. Results of the ITA method for the Rainfall Zone T1 for the period 1951–2006.

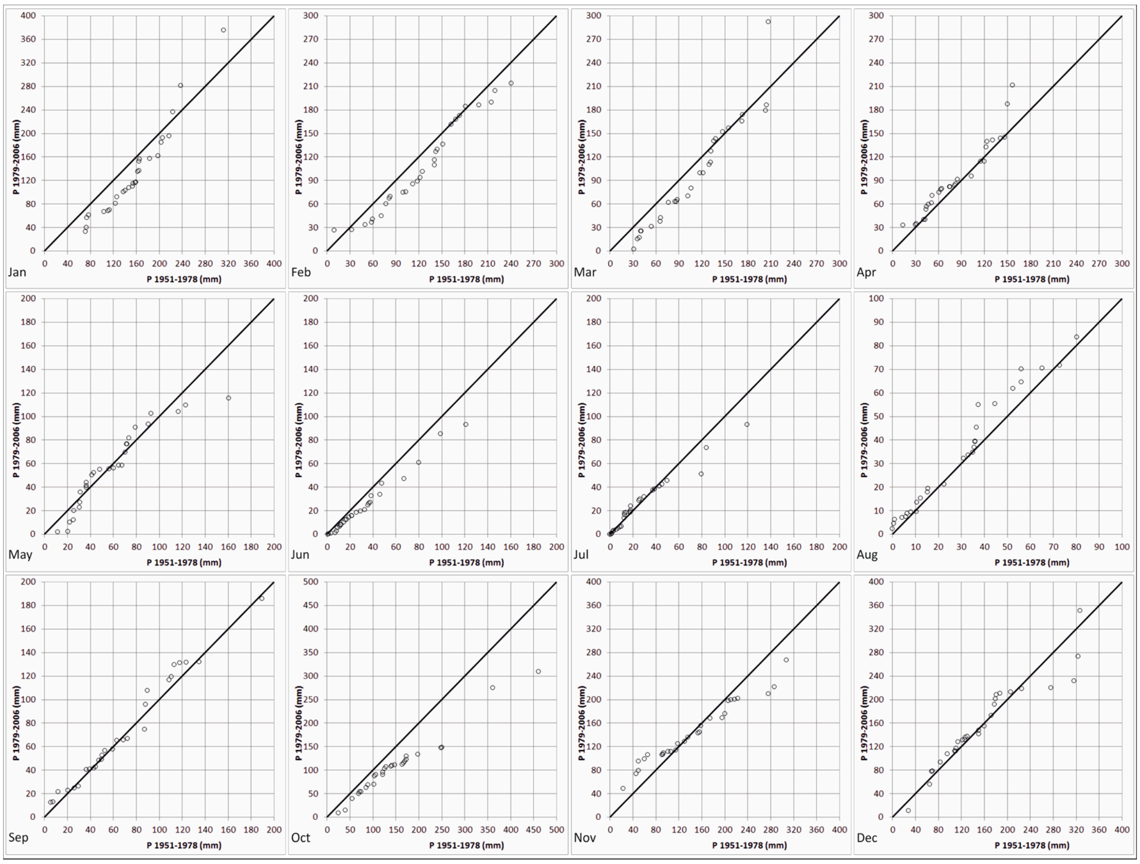

Figure 6. Results of the ITA method for the Rainfall Zone T2 for the period 1951–2006.

The results obtained by means of the ITA method partially confirm the outcomes of previous analyses [22–26], carried out through other methodologies applied to daily precipitation. In particular, the ITA method showed that the negative trends in autumn and winter months, evidenced also in the cited previous studies, are mainly due to the high precipitation for the autumn months and to the low precipitation for the winter ones. These results are clearer for the RZs I1, I2 and T2. On the contrary, the positive tendency in summer months, even if lowly evidenced, is due to the high values of the monthly rainfall, especially for the RZs I1 and I2.

5. Conclusions

Trend analysis provides a view for meteorological, hydrological, and climatological variables from past observations to future changes. Usually, the most used methods for trend detection allow researchers to analyze general tendencies of climatic variables but they do not make it possible to identify significant sub-trends of low and high values. In this paper, a graphical technique, based on the innovative trend analysis (ITA) proposed by Şen [17], was applied to a high quality dataset of monthly rainfall registered in southern Italy (Calabria region). Results were compared with the ones obtained through the application of the well-known Mann-Kendall test. The analysis evidenced different trends for the various months and the five Rainfall Zones in which the entire region was subdivided.

Moreover, the several results obtained for the low and high values highlight the difficulty to consider a unique tendency for the rainfall data. In particular, the Calabrian territory showed different rainfall trends between the two sides of the region, the Ionian and the Tyrrhenian sides. This behavior can be due to the particular orography of Calabria and its position at the center of the Mediterranean basin which both lead to higher yearly precipitation on the west side and intense rainstorms affecting mainly the east side. The results of the ITA method can be useful in the water management, which pays particular attention to the behavior of the low precipitation monthly data.

Moreover, it may be considered a first step towards the development of statistical methods for estimating precipitation variable having short- or long-term records.

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