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Procedia Engineering 162 (2016) 32 – 38

Procedia Engineering

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International Conference on Efficient & Sustainable Water Systems Management toward Worth Living Development, 2nd EWaS 2016

Trends in the daily precipitation categories of Calabria (southern Italy)

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Abstract

This study presents an analysis of daily rainfall categories over a region of southern Italy using a set of daily homogenous precipitation series for the period 1916–2006. Six daily rainfall categories have been considered: Light, 0–4 mm/day; Light-Moderate, 4–16 mm/day; Moderate-Heavy, 16–32 mm/day; Heavy, 32–64 mm/day; Heavy-Torrential, 64–128 mm/day; Torrential, 128-up mm/day. Results showed that Light-Moderate, Moderate-Heavy and Heavy rainfall are the main contributors to the total annual rainfall. Moreover, a trend analysis through the Mann-Kendall test showed a decreasing trend of the higher categories and an increasing trend of the weaker categories.

Peer-review under responsibility of the organizing committee of the EWaS2 International Conference on Efficient & Sustainable Water Systems Management toward Worth Living Development

Keywords: Daily Rainfall; Rainfall Categories; Trend; Mann-Kendall; Calabria

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Peer-review under responsibility of the organizing committee of the EWaS2 International Conference on Efficient & Sustainable Water Systems Management toward Worth Living Development
doi:10.1016/j.proeng.2016.11.008

1. Introduction

Due to the considerable environmental impacts of climate change, research in the past century has focused on precipitation trend analysis. In particular, change in extreme events can impact on natural environments, and human activities, as well as human health and safety. Extreme events represent a key aspect of climatic analyses and it is now widely accepted that changes in total precipitation can be associated with changes in the frequency of precipitation events, the amount of precipitation per event, or a combination of both [1]. In order to improve the understanding of the precipitation behavior of a region, daily precipitation series must be analyzed [2]. Numerous studies on precipitation variability have been undertaken all over the world using various statistical procedures and have evidenced a positive trend in daily precipitation intensity and a tendency toward higher frequencies of heavy and extreme rainfall in USA [3,4], in Australia [5], in New Zealand [6,7], in South Africa [8], and in the UK [9]. [10] conducted a coherent study of the full-scale of daily rainfall categories over the Mediterranean in order to assess the paradoxical behavior characterized by an increase in extreme rainfall in spite of a decrease in the totals. Unfortunately, there are few studies based on daily rainfall series in Italy, probably due to the lack of high-quality long daily rainfall series. In northern Italy, the results of an analysis on six daily rainfall series [2] showed a significant decreasing trend in the annual number of wet days and an increasing tendency in the mean and maximum precipitation heights related to one day, with a generalized increasing tendency for the number of dry days following and followed by wet days. Similar results have been obtained by a stochastic approach analysis of some rain gauges in Calabria, southern Italy [11,12]. An increase in heavy precipitation has been detected simultaneously with a decreasing trend in total precipitation in a wider area of northern Italy [13].

In this study, the daily rainfall series recorded in the Calabria region (southern Italy) have been analysed by classifying the events into different rainfall categories, following the classification proposed by [10]. In particular, for each category, the presence of any significant trend has been detected using the non-parametric Mann–Kendall test. The aim of this study is to analyze if the decrease in the rainfall totals, evidenced in previous studies [14-18], is also confirmed for the extreme rainfall.

2. Study area and data

Calabria is in the farthest south of the Italian peninsula, with an area of 15080 km^2 and a perimeter of about 818 km (Fig. 1). Because of its geographic position and its mountainous nature, Calabria presents high climatic contrasts. In fact, Calabria has a typical summer subtropical climate, also known as Mediterranean climate. Particularly, the Ionian side of Calabria is influenced by warm currents coming from Africa, which cause high temperatures with short and heavy precipitation. By contrast, the Tyrrhenian side is influenced by western air currents and presents milder temperatures and many orographic precipitation. In the inland zones, colder winters with snow and fresher summers with some precipitation are observed [19].

In this paper a daily homogeneous and complete database, with 129 rainfall series for the 1916–2006 period (Fig. 1), has been used [20].

3. Methodology

As suggested by [10] six daily rainfall categories have been considered: Light (A) 0–4 mm/day, Light-Moderate (B) 4–16 mm/day; Moderate-Heavy (C1) 16–32 mm/day; Heavy (C2) 32–64 mm/day; Heavy-Torrential (D1) 64–128 mm/day; and Torrential (D2) 128-up mm/day. However, due to the characteristics of rainfall intensity in Calabria, in some applications of this study, another class (D1+D2: 64-up mm/day) has been used.

First, for each rain gauge and for each year, the percentage of the annual amount of each daily rainfall category, and the annual number of daily rainfall events falling within each class, have been computed. Then, each of these annual series was analyzed for trends, and statistical significance assessed through the well-known Mann-Kendall non-parametric test [21,22].

4. Results and discussion

The contributions (as a percentage of the total annual amounts) of each of the previously defined daily rainfall categories for the period 1916–2006 are shown in Table 1. A natural separation among the categories contributions is evident. At a regional scale, class B (4–16 mm/day) provides the maximum contribution to the yearly amount with an average value of 31%. It is immediately followed by the classes C1 (28.3%) and C2 (21.8%). Low contributions derive from the classes D1 (9.6%), A (6.1%) and D2 (3.1%).

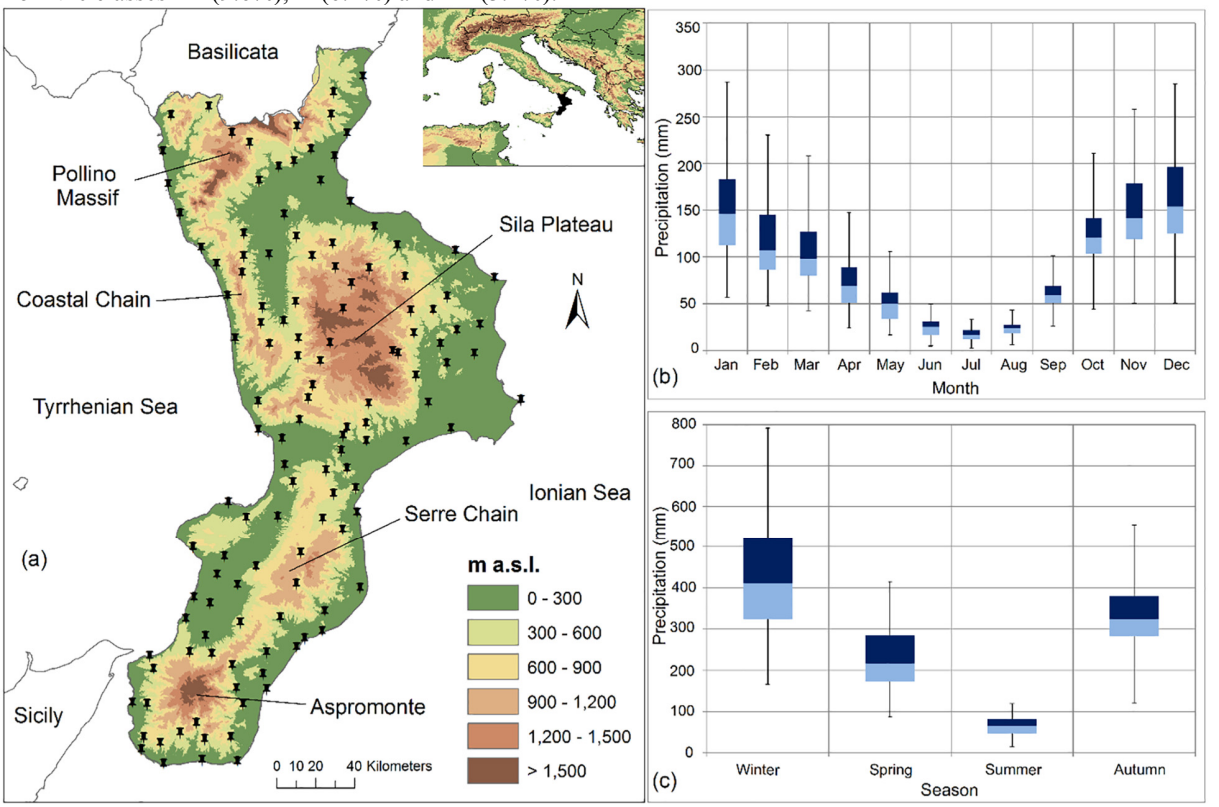

Fig. 1. (a) Location of the selected stations on a Digital Elevation Model (DEM) of Calabria; (b) regional monthly precipitation distribution; and (c) regional seasonal precipitation distribution.

In order to analyze the temporal evolution of the contributions (as a percentage of the total annual amounts) of the daily rainfall categories, the observation period has been divided in three different sub-periods (1917-1946, 1947-1976 and 1977-2006). Results show a clear difference between the higher categories (C2, D1 and D2), which present decreasing values, and the lower categories (A, B), whose contributions, on the contrary, increase with time (Table 1). The Moderate-Heavy category (C1) at regional scale does not show a clear trend (Table 1).

Table 1. Average values of the annual contributions (as percentages of the total annual amounts) for each daily rainfall category for the Calabria region. The results are described for the entire observation period and for three 30-year sub-periods.

Time period	Rainfall Category					
	A	B	C1	C2	D1	D2
1916-2006	6.1	31.0	28.3	21.8	9.6	3.2
1917-1946	5.0	28.7	28.3	23.0	10.9	4.1

1947-1976	6.9	31.7	27.8	21.1	9.5	3.0
1977-2006	6.5	32.7	28.8	21.4	8.3	2.3

A detailed trend analysis has been conducted by applying the Mann-Kendall test to the rainfall series of each rain gauge. All tests have been performed at a 5% significance level (SL). Fig. 2a shows the results of the trend detection referring to the contributions of each rainfall class to the total annual amounts of each rain gauge. Diffuse positive significant trends were detected for the lowest rainfall categories (A and B). A negative trend, also often significant, has been detected for the highest rainfall categories, in particular for the class (D1+D2) which refers to daily rainfall greater than 64 mm. The Mann-Kendall test was also applied to the annual number of daily rainfall events falling within each category (Fig. 2b).

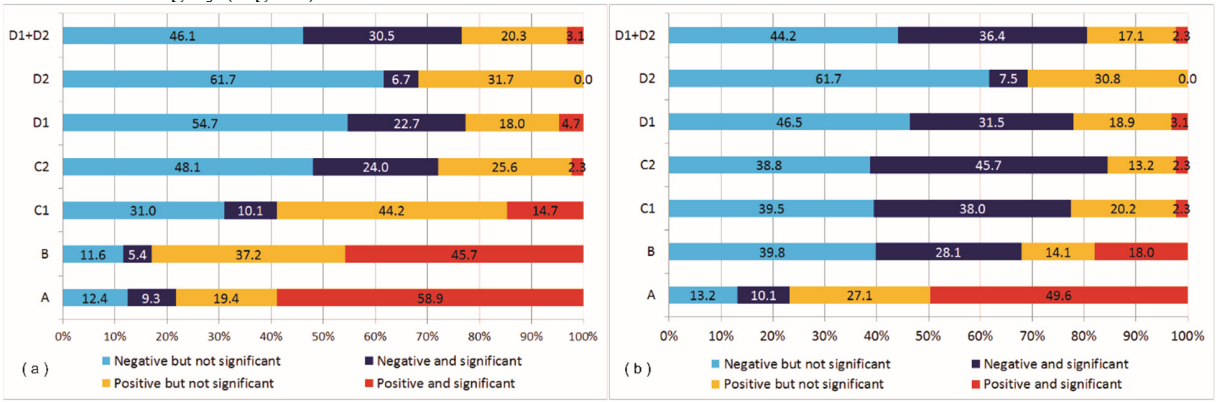

Fig. 2. Results of the Mann-Kendall test applied (a) to the annual contributions (as percentages of the total annual amounts) of each of the daily rainfall categories and (b) to the daily rainfall events falling within each class of the daily rainfall. The x axis represents the percentages of the series presenting positive or negative (significant or not significant) trends (SL: 5%), the y axis represents the different rainfall categories.

As a result, at a regional scale, the lowest category (daily rainfall less than 4 mm/day) shows a diffuse positive trend, while a more diffused negative trend has been detected for all the other rainfall categories and, in particular, for the Moderate Heavy (C1) and Heavy (C2) ones. The upper class (D1+D2) shows a more marked negative trend than the Heavy-Torrential (D1) and Torrential (D2) classes. The dissimilar behavior is due to the different sample which, for the class (D1+D2) is given by the sum of the samples of the other two classes.

To analyze the existence of changes in the tendencies over the study period, the running approach [20] was applied to both the annual contributions (as percentages of the yearly amount) and the numbers of rainy days (as days/10 years) referred to the different rainfall categories, and to the whole study area (Fig. 3 and 4, respectively). Unfortunately, due to the low number of data falling within the highest categories, the running approach can be significantly applied only to the first four categories.

In both the figures some negative and significant trends appear for the highest rainfall classes (C1 and C2) when the entire observation period is considered. When the beginning year of the analysis is more recent, the trend is not significant and often presents an opposite sign. By contrast, some positive and significant trends have been detected for the rainfall classes A and B. In particular, for the contributions to the annual amounts (Fig. 3), the rainfall class A shows a positive and significant trend from the first years of the data sets. Some negative and significant trends appear for the same class A only in the period 1950-1960. The rainfall class B shows trends with a lower significance and a higher entity especially for long time windows starting from the early years of the time domain.

Very interesting results have been obtained for the rainy days (Fig. 4) and in particular, for the rainfall classes A and B, which showed significant results alternatively negative and positive up to values greater than ±20 days/years. The running approach revealed that there is a slight modification in the behavior of the rainy days in the 1950s and 1960s. Indeed, the trend analyses starting in these decades present opposite trend signs with regards to the one evaluated for the whole data set, both for the lower and higher precipitation categories. This opposite behavior,

emerging in the 1950s and 1960s, could indicate a step change in the time series, as other studies have also evidenced [20]. The opposite trend sign can also be explained by the NAO, which is the most significant driver of climate variability in the middle and high latitudes of the Northern Hemisphere, and therefore in Calabria [15,23]. In effect, since the early 1970s the strengthening of the NAO has accompanied the warming and has caused more frequent and persistent anticyclones over the southern part of Europe [24].

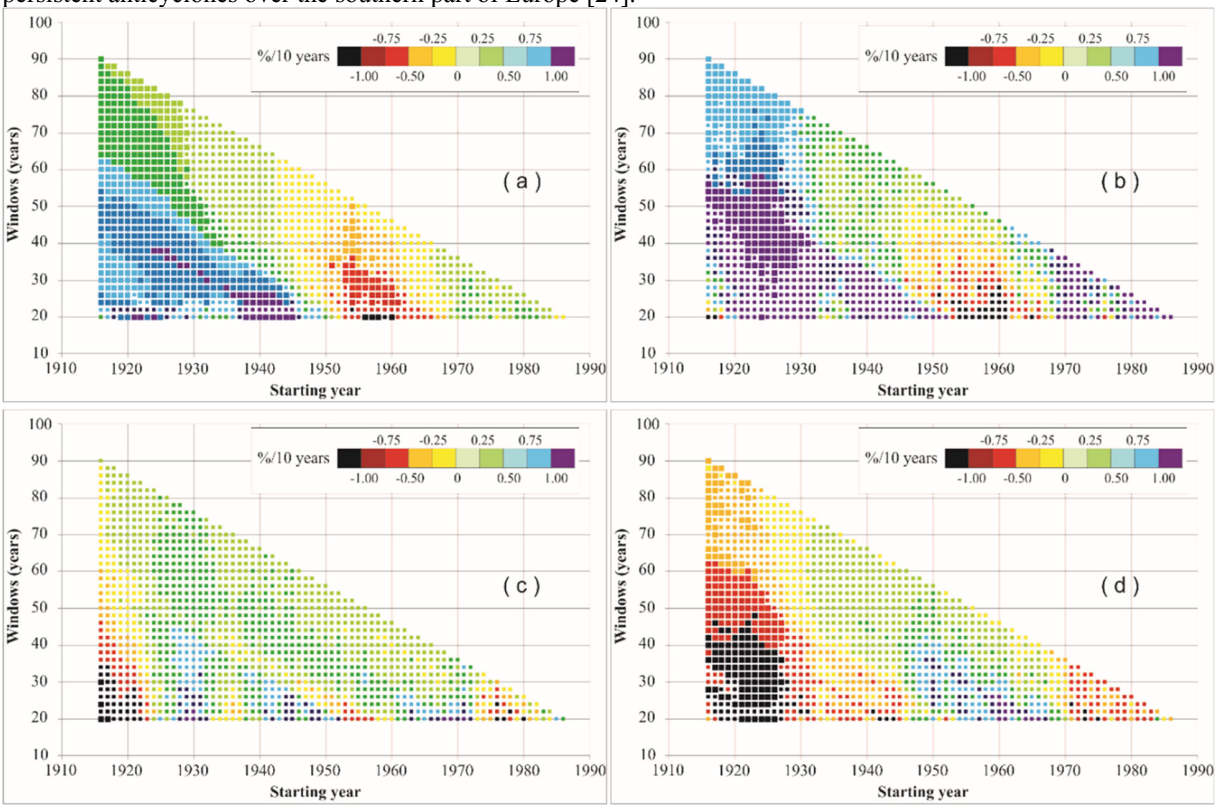

Fig. 3. Running trend analysis for the annual contributions (as percentages of the total annual amounts) of the daily rainfall categories A (a), B (b) C1 (c) and C2 (d) for the entire Calabria region. The y axis represents the window width, and the x axis represents the first year of the window over which the trend is calculated. Squares dimension indicates the significance level of the trend: large squares $p < 0.05$, small squares otherwise.

These results of the trend analysis confirmed the ones obtained by [20], who had shown, in Calabria, a positive (negative) trend in the contribution of low (heavy) precipitation events over the entire observation period. [20] also evidenced the strongest contribution to the negative trend in high-intensity categories coming from the winter season and the strong positive and significant trend in wet days emerging in April and in the summer months, which could explain the positive trend of the lowest category. The results of this study are also consistent with the conclusions of other authors [25-27] who have detected no significant trend in the number and in the magnitude of extreme events in other parts of Europe.

The results obtained in this study are important because the paradoxical behavior characterized by an increase in extreme rainfall in spite of a decrease in the totals [10] does not appear in the Calabria region. In fact, while different studies highlighted the reduction in Calabria of the yearly rainfall [e.g. 14,15,23], the results of this study do not evidence an increase in extreme rainfall. The differences between results obtained in this study and those obtained in [10] is probably due to the different rainfall database. In fact, [10] used a rainfall database of 42 stations, as proposed by [28], with less than 30% of rain gauges in southern Italy, where generally an opposite rainfall extreme behavior to northern Italy is present. Such a different daily behavior, already evidenced in several previous studies [e.g. 20], could

originate in the fact that a positive change in precipitation magnitude in southern Italy can be due to multi-day extreme precipitation rather than to single-day precipitation, as [29] evidenced.

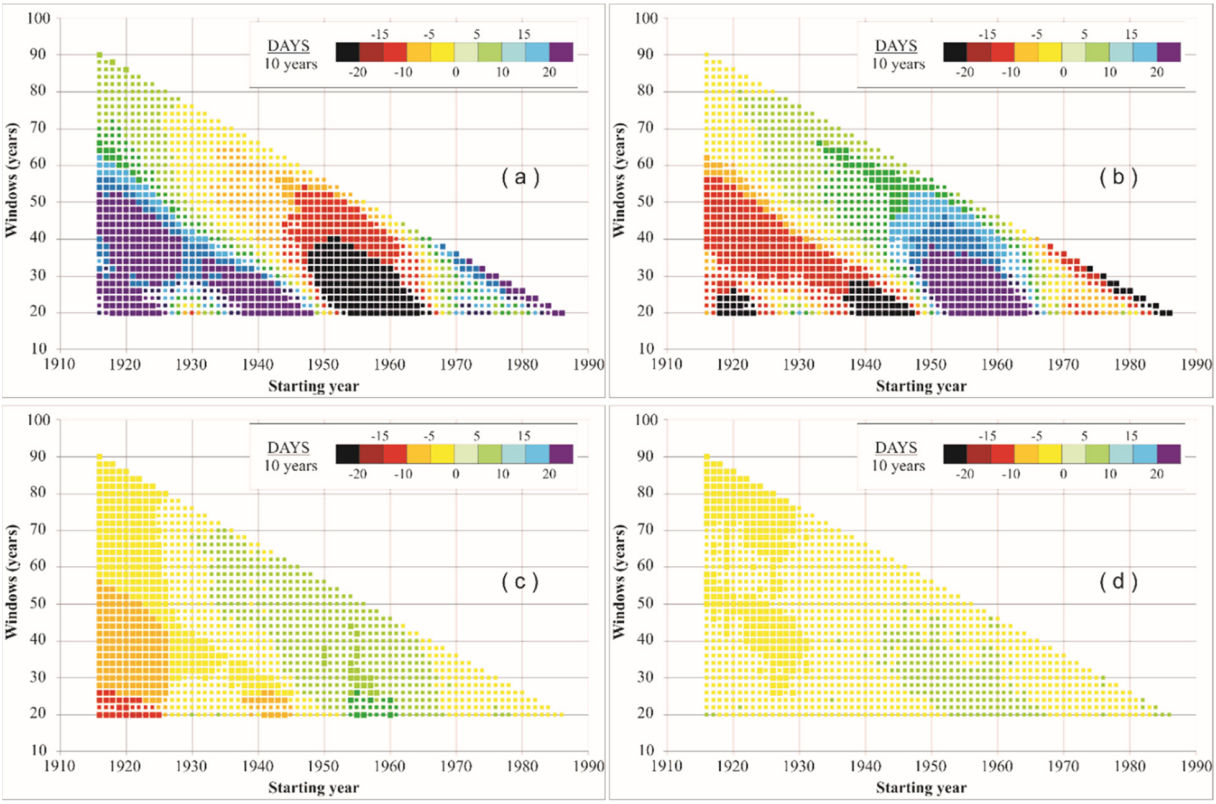

Fig. 4. Running trend analysis for the daily rainfall events falling within the same class of the daily rainfall A (a), B (b) C1 (c) and C2 (d) for the entire Calabria region. The y axis represents the window width, and the x axis represents the first year of the window over which the trend is calculated. Squares dimension indicates the significance level of the trend: large squares $p < 0.05$, small squares otherwise.

5. Conclusions

Several authors [10,13,27] detected a paradoxical increase of extreme rainfall, in spite of a decrease in the totals, in different areas of the Mediterranean basin. Instead, other analyses [20,25-27] have detected no significant trend in the number and in the magnitude of extreme events in other parts of Europe. In this study the spatial and temporal rainfall distributions in the Calabria region (southern Italy) were analyzed considering the rainfall categories, as classified by [10]. The results showed that in this region the highest rainfall categories do not show particular trends. The most significant trends appear only for the lowest classes, as confirmed by the running approach. In fact, the lowest rainfall classes show positive trends especially for long time windows starting from the early years of the time domain. Similar results were obtained for the rainy days events falling within the various rainfall classes.

The results of this study confirm that the paradoxical increase of extreme rainfall in spite of a decrease in the totals is not present in this part of southern Italy. The different trend behavior of extreme rainfall in the Mediterranean basin suggests that a detailed regional analysis, such as the one proposed here, is always necessary. In fact, as [30] suggested, no generalized changes can been detected in the daily rainfall regime across the Mediterranean basin, since the results depend on the density of the observation, of the study period, and of the area analyzed.

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