

Application of an Event-Based Approach to Assess Bivariate Rainfall Models in Two Italian Climates [†]

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Abstract

The assessment of non-stationarity in the rainfall process is still a major research topic in the field of applied hydrology. The water cycle is affected by several characteristics of this process: rainfall volume, wet weather duration, their mutual association, and the annual number of events. The method used to sample rainfall variables from the time series may or may not suitably account for their variability. Herein, the rainfall process is analyzed using a bivariate event-based approach, with reference to two rainfall time series recorded at short time steps in different Italian climates. Trends are also estimated.

Keywords: rainfall time series; rainfall volume; wet weather duration; variable association; bivariate trend analysis; Italian climates

1. Introduction

The impact of climate change on the rainfall process has long been debated, and a vast body of research exists on this topic [1–7]. Nevertheless, non-stationarities are strongly dependent on the method used to sample the rainfall volumes from the continuous time series (total rainfall volumes referred to calendar intervals, annual maxima of rainfall volumes referred to a constant duration, inter event time definition used to separate rainfall events) and its parameterization. In Northern Italy, for instance, when total annual rainfall depths are analyzed, discordant and statistically non-significant trends are often estimated [6]. In contrast, when individual independent rainfall events are sampled by using an inter event time definition, the rainfall depth may show different trends, whose statistical significance depends on the season [7]. Furthermore, trend analyses often focus only on the non-stationarity in the rainfall depth. Several stochastic properties of the rainfall process, however, have a remarkable impact on the water cycle, such as (i) the variability of the wet weather duration, (ii) strength of the dependence structure relating the rainfall depth to the wet weather duration, and (iii) the number of events per year. Seasonality of all these items may play a crucial role as well. The event-based approach allows researchers to investigate the natural variability of multiple properties of the rainfall process at different time scales and their trends. In addition, the event-based approach makes it possible to develop analytical probabilistic models [8,9] or Monte Carlo simulation procedures [7], which can straightforwardly assess the impacts of multiple non-stationarities in the rainfall process on the runoff process. Nonetheless, few studies have used this approach until now. The event-based approach needs extended and high-quality rainfall time series recorded



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at a small time step, which are seldom available. In this work, two rainfall time series recorded in different Italian climates are analyzed by an event-based approach to assess the variability of multiple rainfall variables and their trends.

2. Materials and Methods

Main characteristics of the rain gauges and of the rainfall time series used in this study are listed in Table 1. Brescia ITAS is placed in Northern Italy at the transition between the Po Plain and the Alpine mountain range. The climate is humid with a mean annual rainfall of about 1000 mm. The rainfall regime is temperate, featuring two maxima (spring and autumn) and two minima (summer and winter). Messina is placed in Southern Italy along the eastern coast of the island of Sicily. The climate is dry with a mean annual rainfall of about 850 mm. The rainfall regime is Mediterranean, featuring a maximum in winter and a minimum in summer.

Table 1. Analyzed rainfall time series and characteristics of the rain gauges.

Rain Gauge	Climate ¹	Latitude	Longitude	Elevation	Consistency	Time Step
Brescia ITAS	Cfa	45.5333°	10.2194°	150 MASL	2004–2024	10 min
Messina	Csa	38.2587°	15.5614°	421 MASL	2003–2023	10 min

¹ Updated Köppen–Geiger climate classification: Cfa = temperate, without dry season, hot summer; Csa = temperate, dry and hot summer [10].

Individual independent rainfall events were sampled from the continuous time series using a minimum inter event dry period and a volume threshold, herein referred to as Inter Event Time Definition (IETD) and Initial Abstraction (IA), respectively (see details in [9,11]). Thus, each rainfall event can be characterized by multiple random variables, whose mutual associations can be investigated. In this study, the rainfall volume v , the wet weather duration d , and their association strength τ were analyzed. Events were aggregated according to calendar years to compute the annual mean values of v and d , the annual values of τ , by means of the Kendall rank correlation coefficient, and the total annual number of events μ . Linear trends were then assessed by using the Theil–Sen estimators for intercept and slope. These estimators have been demonstrated to be more robust than the traditional least squares regression when outliers exist [12]. To evaluate the trend significance, Theil tests for the slope of the regression line were conducted [12]. Stationarity, that is, a linear regression slope equal to zero, was assumed to be the null hypothesis.

3. Results and Discussion

Aiming at spanning the full range of possible rainfalls, both series were analyzed using low values of the sampling parameters: IETD equal to 3 h and IA equal to 2 mm. As can be seen in Figures 1 and 2, both time series surprisingly revealed similar results in terms of all analyzed variables, which span the same ranges in the two climates. For instance, the estimated mean annual rainfall volumes proved to be close, as for Brescia it was estimated in 972 mm (in agreement with historical data), whereas for Messina it was estimated in 970 mm (larger than expected). Trends were generally decreasing for all variables except for the annual mean of v in Brescia ITAS, as shown in Table 2. However, only those of d and τ in the Messina series appeared to be statistically significant (p -values less than 5%). It should be noted that decreasing trends in the association strength τ can have a remarkable impact on flood frequency, owing to the more frequent occurrence of events with large volume and short duration [7]. This impact may be further emphasized by the decrease in the wet weather duration d .

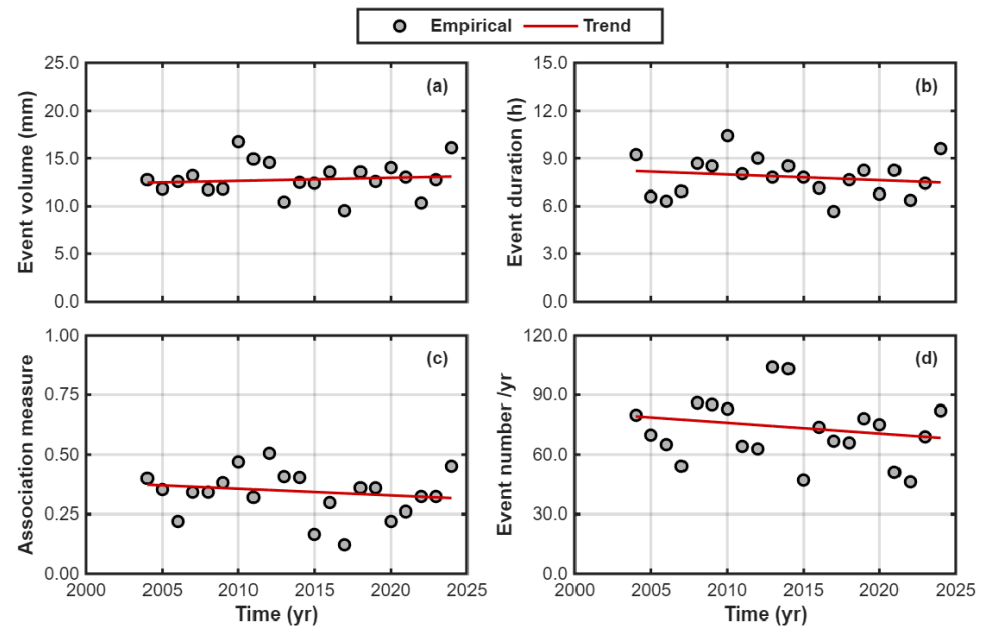


Figure 1. Bivariate event-based analysis of the Brescia ITAS series (IETD = 3 h, IA = 2 mm): (a) rainfall volume v , (b) wet weather duration d , (c) association τ between rainfall volume and wet weather duration, and (d) number of individual independent events per year μ .

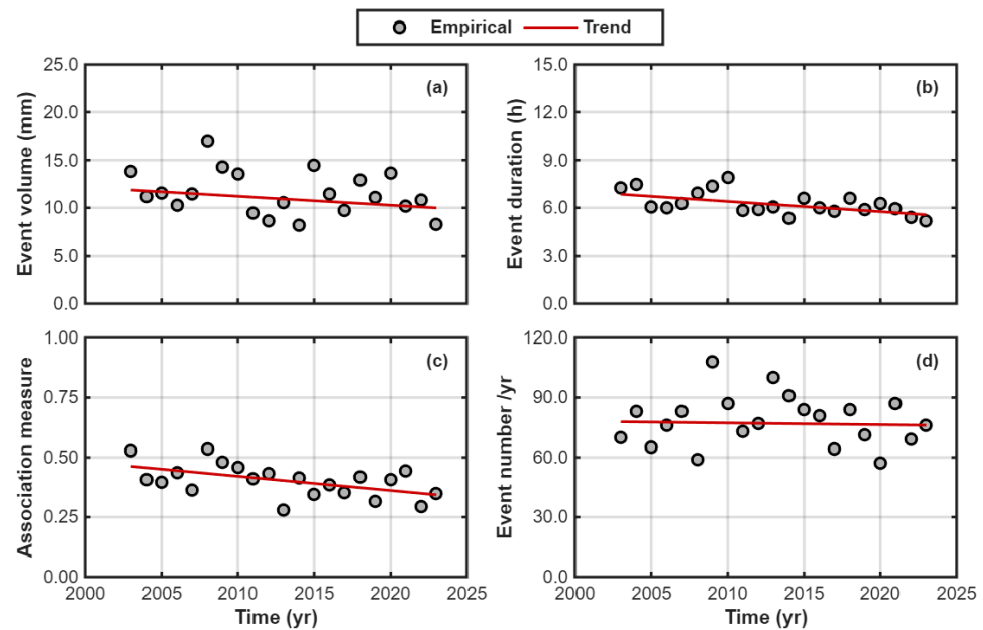


Figure 2. Bivariate event-based analysis of the Messina series (IETD = 3 h, IA = 2 mm): (a) rainfall volume v , (b) wet weather duration d , (c) association τ between rainfall volume and wet weather duration, and (d) number of individual independent events per year μ .

Table 2. Trends of analyzed rainfall variables and statistical significance of the stationarity tests, expressed as percentage p -values reported in *italics* within brackets (IETD = 3 h, IA = 2 mm).

Rain Gauge	v (mm 10^{-2} yr $^{-1}$)	d (h 10^{-2} yr $^{-1}$)	τ (10^{-2} yr $^{-1}$)	μ (10^{-2} yr $^{-1}$)
Brescia ITAS	3.2 (62.9%)	−3.6 (50.7%)	−0.3 (46.9%)	−54.4 (39.8%)
Messina	−9.4 (14.7%)	−6.5 (0.9%)	−0.6 (3.5%)	−8.7 (80.9%)

4. Conclusions

The event-based approach has demonstrated to be an effective strategy to investigate multiple aspects of the rainfall process, including potential trends and their significance. Most of the trends analyzed in this work were found to be statistically non-significant. However, further efforts must be taken to increase the series length in order to better investigate this issue. Seasonality is an additional direction that the research should address.

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Data Availability Statement: Time series can be freely downloaded at (Brescia ITAS) <https://www.arpalombardia.it/temi-ambientali/meteo-e-clima/form-richiesta-dati> last accessed on 25 September 2025, (Messina) http://www.sias.regione.sicilia.it/frameset_dati.htm last accessed on 17 September 2025.

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