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Estimation of sub-hourly DDF curves using scaling properties of hourly and sub-hourly data at partially gauged site

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Abstract

In urban drainage systems, knowledge of short-duration rainfall events can be considered as one of the most critical elements when their hydrological behaviour wants to be investigated. The temporal resolution of rainfall data usually available for practical applications is often lower than the data requested for the design procedures or mathematical models application, greatly affecting their reliability. Moreover, when high resolution rain gauges are available in the catchment, the registration period cannot be sufficiently long for obtaining practically usable statistical analyses. The present study proposes a method for estimating the distribution of sub-hourly extreme rainfalls at sites where data for time interval of interest do not exist, but rainfall data for longer duration are available. The proposed method is based on the "scale-invariance" (or "scaling") theory whose concepts imply that statistical properties of the extreme rainfall processes for different temporal scales are self-related by a scale-changing operator involving only the scale ratio. The methodology is applied to extreme rainfall data from a rain gauge network within the metropolitan area of Palermo (Italy). Following the application, it is shown that the statistical properties of the rainfall series have a simple scaling property over the range of duration 10 min–24 h. A simple parsimonious analytical formulation for the DDF curves, which embodies the scaling behaviour, is presented.

Keywords: Extreme rainfall; Scaling method; Statistical modelling; Short-duration events; Urban hydrology

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1. Introduction

In urban drainage systems, knowledge of short-duration rainfall events can be considered as one of the most critical elements when their hydrological behaviour wants to be investigated. For planning and design of various hydraulic structures, extreme rainfall for a given return period is required. In particular, rainfall extremes with high temporal resolution (1 h or shorter) are necessary for the design of drainage systems in urban catchments usually characterised by fast response. The temporal resolution of rainfall data usually available for practical applications is often lower than the data required for the design procedures or mathematical models application, greatly affecting their reliability. Moreover, when high resolution rain gauges are available in the catchment, the registration period cannot be sufficiently long for obtaining practically usable statistical analyses (partially gauged site). This would suggest that short-duration rainfall should be estimated using long-duration data (i.e., 1, 3, 6, 12, and 24 h) whose values are usually provided by the national hydrological services. Nguyen et al. (1998) proposed a method for estimating the distribution of short-duration extreme rainfalls at partially gauged sites based on the property of scale invariance of rainfall. The authors used general extreme value (GEV) distribution to estimate the extreme rainfall quantiles whose parameter scaling properties have been derived on the basis of regional rainfall frequency maps.

In addition, Menabde et al. (1999) demonstrated the simple scaling property for the annual maximum series of mean rainfall intensity through the examination of the moments scaling properties and the parameters scaling of an extreme value distribution fitted to the data.

In this work, a “scaling” approach for estimating the distribution of sub-hourly extreme rainfalls is presented with the aim of taking advantage both from high resolution raingauges with short functioning period and from low resolution raingauges with longer data samples (partially gauged catchments). The proposed approach is based on scaling properties of statistical characteristics and hydrological similarities between near raingauges.

2. Scaling theory

Let consider a continuous precipitation process $P(t)$ which represents the rain rate measured at time t at point space (e.g., raingauge station), and introduce the rainfall depth collected over a time duration d:

$$P_d(t) = \int_{t-d/2}^{t+d/2} P(\tau)\mathrm{d}\tau \qquad (1)$$

Since the probability of extreme events is usually examined, the maximum annual rainfall depth H_d can be considered defined as the maximum value of a moving average (with time span d) in a given year.