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A new copula-based approach for the design of storm events: an application on the hill of Turin

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Abstract

Urban expansion and the increasing fraction of impervious surfaces have increased the risk of pluvial flash floods, typically triggered by short, intense precipitation (Cea et al., 2025). Traditional approaches for extreme rainfall analysis rely on design hyetographs of fixed shapes (e.g., Chicago, rectangular) derived from Intensity-Duration-Frequency (IDF) curves. While these tools ensure safety margins, they inherently average out maximum rainfall peaks and oversimplify natural dynamics such as temporal intermittency and actual storm morphology.

This study proposes a replicable methodology to estimate design storm events that are more representative of observed rainfall patterns compared to standard IDF-based approaches. The methodology is applied to the Turin hillside (Italy), an area characterized by steep slopes, dense urbanization, and a complex network of minor streams—often culverted—that are frequently omitted from standard flood hazard maps.

Extreme rainfall involves complex dependencies between duration, intensity, cumulative depth and max rainfall, which univariate approaches fail to capture (Grimaldi & Serinaldi, 2006). To overcome these limitations, we implement a multivariate framework based on Vine Copulas (Czado & Nagler, 2026; Salvadori et al., 2003). Independent rainfall events are first extracted from sub-hourly time series using the Inter-Event Time Definition (IETD) and Mean Annual Precipitation (MAP) criteria. Marginal distributions are then identified for each variable, while the dependence structure is modeled through a flexible

Vine Copula framework capable of capturing non-linear relationships and tail dependence.
The fitted model is used to simulate synthetic events and compute joint exceedance probabilities. The resulting multivariate return periods are compared with classical univariate ones, highlighting how accounting for variable dependence significantly alters the assessment of rainfall severity. This approach provides a robust tool for flood risk management, urban planning and hydrological design in complex urban environments.

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