Frequency analysis of short-duration rainfall extremes in Liguria (Italy)

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Highlights

- A network of 51 stations in the Ligurian territory with at least 10 years of complete recordings (sub and super hourly durations) are examined.
- The reliability of IDF equations is tested with respect to direct statistical analysis.
- The proposed IDF formulation contributes to improve the reliability of the sub-hourly design storm depth estimation.

Introduction

The characterization of high intensity and short-duration rainfall is crucial in the field of urban hydrology since the hydrologic response of an urban catchment is generally impulsive and is depleted within the sub-hourly period. On the other hand the design storm depth estimation is more complicated when one refers to short storm durations with respect to the 1-24 hours' intervals. The scale invariance assumption (Burlando and Rosso, 1996) has been shown to be often not consistent with the statistical behaviours of short-duration extreme rainfalls; in particular, Marani (2003) shows that the variance of the rainfall data decreases more rapidly when referring to short durations with respect to what is observed for longer storms. Short-duration rainfall data are rarely available and generally the length of the sub-hourly data series is significantly lower with respect to the canonical ones. In this framework, the main objective of this research is to define the suitable form of the Intensity Duration Frequency (IDF) equation in order to better fit the transition in the scaling regime of rainfall.

Methodology

Rainfall datasets

The study region includes the administrative Region of Liguria, in northern Italy. The database of extreme rainfall consists of the annual maxima series of precipitation with durations equal to 5, 10, 20, 30, 40 and 50 min (sub-hourly durations); 1, 3, 6, 12 and 24 hours (canonical durations). These data were obtained from the network of rain gauges in charge of the Regional Environment Protection Agency (ARPAL) in the period 1930 – 2018. The study considered the rain gauge stations with at least 10 years of complete (sub and super hourly durations) recordings thus resulting in a set of 51 rain gauge stations, thus resulting in 769 years of observation for the sub-hourly durations and 2603 for the canonical ones.

The Intensity-Duration-Frequency curve

Two well-known IDF formulations, namely IDF1 and IDF2, are used in the absence of scale invariance assumption in the following form:

$$\boldsymbol{IDF1}: i(T,d) = a \cdot d^{b-1}$$

$$\boldsymbol{IDF2}: i(T,d) = a \cdot (d+c)^{-b} \cdot d$$

where $i(T,d)$ is the T-ennal quantile of the rainfall intensity for a duration d; where a, b and c are the parameters fitted according to the least square method, independently for each return period T, by using quantiles estimated by direct analysis referred to the canonical durations.
Two different formulations of IDF curves that are characterized by a three parameters formulation in the sub-hourly intervals and a two parameters formulation for the super-hourly intervals, are investigated in the present study. The proposed IDF curves, namely IDF3 and IDF4, are defined, according to the scale invariance assumption, in the average form as follow:

$$\boldsymbol{IDF3}, \boldsymbol{IDF4}: i(d) = \begin{cases} i_0 \cdot (1 + Bd)^{\beta} & for\ d \leq 1 hour \\ a_1 \cdot d^{n-1} & for\ d > 1\ hour \end{cases}$$

where i_0, B and β are three parameters in the field of sub-hourly duration, a_1 is the expected value of the maximum annual rainfall depth for the hourly duration and n is the scale exponent according to the scale invariance approach in the field of the canonical duration.
The frequency growth factor K(T) is used then as a simple multiplicative factor of the above defined average relations and it has been evaluated in the field of the canonical durations according to the General Extreme Value distribution model.
In the IDF3 approach the estimation of the parameters is carried out by requiring that the overall average intensity-duration function (i.e. referred to sub and super hourly durations) is continuous and derivable for the duration equal to 1 hour, thus the IDF3 formulation requires the estimation of the parameter a_1 and n in the field of canonical durations while as for the sub-hourly curve the formulation shows a single parameter B to be estimated. The parameters estimation is carried out with the least square method.
In the IDF4 approach the estimation of the parameters is carried out by requiring that the overall average intensity-duration function is continuous for the duration equal to 1 hour. Furthermore, for the parameters' estimation the average rainfall intensity equation is formulated in a dimensionless form, $i_d(d)$, by referring to the expected value a_1:

$$i_d(d) = \frac{(1+Bd)^{\beta}}{(1+B)^{\beta}}$$

The parameters B and β are estimated by using the least square method with respect to the observed sub-hour rainfall intensity made dimensionless with respect to the expected value $\widehat{a_1}$ of the hour rainfall depth of the electronic series. The third parameter i_0 is then evaluated by imposing the continuity for the 1-hour duration.

Error metrics

The capability of the different IDF equations to provide a reliable estimate of the short-duration design storm depth was tested by computing the relative error, $\varepsilon_j(-)$, for each *j*-th rain gauge and the sub-hourly duration of 10, 20, 30, 40 and 50 minutes and the averaged root mean square error, $\overline{\mathrm{RMSE}}$ (averaged over the whole rain gauges and sub-hourly durations). These reliability indicators are computed by comparing the rainfall depth estimated through the specific IDF functions with the one estimated through the direct statistical analysis according to the procedure illustrated in Di Baldassare et al. (2006).

Results and discussion

The proposed IDF equations have been estimated for the 51 rain gauges stations, by providing the complete set of parameters for each equation. The reliability analysis is here discussed for a sub-set of sites selected according with the following specific requirements:

- The ratio between the expected values a_1 and $\widehat{a_1}$ should be close to one;

- The number of data observed in the complete series should be greater than 24 years;
- The number of data observed in the electronic series should be greater than 15 years.

A sub-set of 13 rain gauges station complies with the above-mentioned specific requirements. Figure 1 shows the comparison between the $\overline{\mathrm{RMSE}}$ values of the different IDF equations assessed for the return period equal to 5, 10 and 20 years. The IDF2, IDF3, IDF4 curves show a similar behavior dictated by the similar analytical form and turn out to have a minor index error than IDF1, for which large quantile overestimations can be expected as the duration decreases and the IDF4 is the curve that best suits the data.

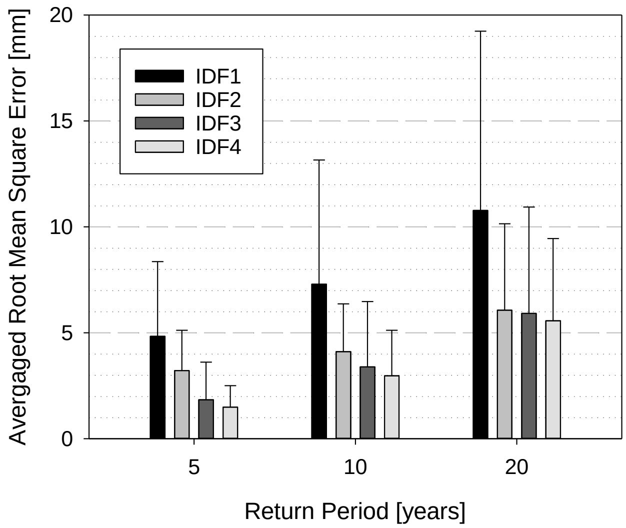

Figure 1. Comparison between the averaged Root Mean Square values of the different IDF equations assessed for the return period equal to 5, 10 and 20 years. The standard deviation associated with each estimated error is also reported.

Conclusions and future work

IDF 3 and IDF4 (characterized by the three-parameter in the sub-hourly field) provide the most interesting outcomes for the selected rain gauge stations confirming the previous literature results (*Di Baldassare et al.*, 2006). In particular the IDF4 form allows to account for the different length of the sub-hourly and canonical data series and eventually for the different expected value of the 1-hour depth in the field of the overall canonical data series with respect to the more recent sub-hourly data series. The proposed methodology will be extended to a large number of sites in order to better exploit the available information at the regional scale and consequently improve the understanding of involved processes.

References

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