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Regional analysis of short duration precipitation annual maxima in Liguria (Italy)

EDISON HEREDIA-CALDERON & FRANCO SICCARDI

Institute of Hydraulics, University of Genova, Montallegro 1, I-16145 Genova, Italy

Abstract Two regionalization methodologies are applied to the short duration yearly maxima of intense rainfall in the Mediterranean area of Liguria (Italy). The study area is often subject to flash flooding due to the presence of a number of small basins with quick response times. Reliable analysis of intense rainfall of short duration is therefore very important. In the present work, a hierarchical regionalization approach based on the Two Component Extreme Value (TCEV) distribution and a flood index approach using the L-moments is applied. The first method is applied for five periods of time considering several hypotheses of homogeneous regions based on physical factors. The results are verified by Monte-Carlo experiments, and the growth curves for all durations are compared with observations using the Kolmogorov-Smirnov test. The second method is applied to data of 24 h duration and five distributions are applied and compared. Index rainfall is then characterized in space by correlation analysis and is found to be scale invariant with duration.

INTRODUCTION

It is known that regional techniques offer the ability to reduce significantly the uncertainties in quantile estimation of extreme events. One of the most attractive types of regionalization methodologies is the flood index type of approach (Benson *et al.*, 1962). Flood index regionalization applied to intense rainfall is concerned with four main issues: (a) definition of candidate regions, (b) homogeneity testing for the regions, (c) the choice of the probability distribution for the proposed region, and (d) the characterization of the scale factor called index rainfall.

The basic assumptions of this approach are the homogeneity of the rainfall series and the existence of climatological and/or geographically homogeneous regions. A homogeneous region is a group of sites producing data from a unique probability distribution except for a scale factor. A quantile is defined by:

$$X_i(F) = \mu_i X_i'(F) \tag{1}$$

where $X_i(F)$ is the inverse at site CDF, μ_i is the sample mean at site i (index rainfall) and $X_i'(F)$ is the inverse regional CDF (growth curve).

STUDY AREA AND DATABASE

The study area is located in the northwestern part of Italy. It covers about 20 000 km^2 including all the Liguria region and part of Piedmont (Fig. 1). The area is characterized by the presence of a complex morphology with the influence of the Pre-Alps and

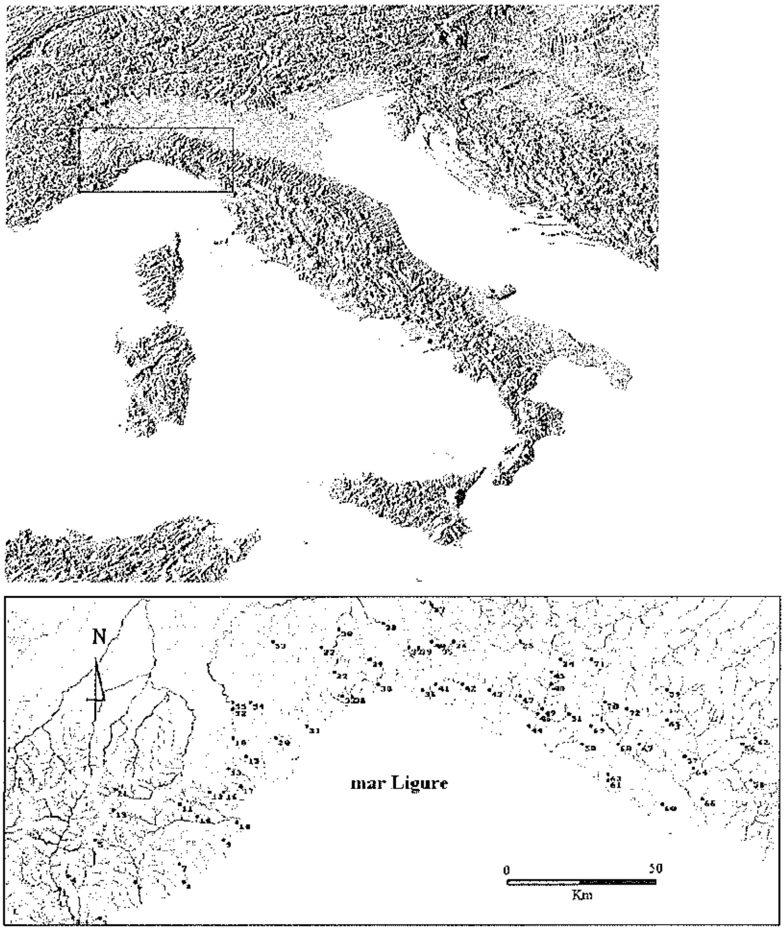

Fig. 1 Location of the study area.

Apeninian hills which are located near the Thyrrenian Sea. As a consequence several small basins exist in the area either draining towards the Thyrrenian sea or towards the Po River basin.

Annual series of precipitation maxima for five durations of 1, 3, 6, 12 and 24 h were obtained for all the available stations in the study area. From this database, only 73 stations with more than 35 years of observation were considered, giving about 3000 pluviometer-years of data.

STUDY OVERVIEW

Hierarchical approach to regionalization

Regional analysis of short duration extreme precipitation is performed first by using a hierarchical regionalization approach with the Two Component Extreme Value (TCEV) probability distribution. The TCEV distribution (Rossi *et al.*, 1984) is characterized by the CDF:

$$F_X(x) = \exp\left\{-\Lambda_1 \exp\left[-\frac{x}{\theta_1}\right] - \Lambda_2 \exp\left[-\frac{x}{\theta_2}\right]\right\} \tag{2}$$

$$F_X(y) = \exp\left\{-\exp[-y] - \Lambda_* \exp\left[-\frac{y}{\theta_*}\right]\right\} \tag{3}$$

with parameters $\Lambda_1 > 0$, $\Lambda_2 > 0$, $\theta_2 > \theta_1$ in equation (2), or by equation(3) with the reduced variable $Y = (X/\theta_1 - \ln \Lambda_1)$ and parameters $\theta_* = \theta_2/\theta_1$ and $\Lambda_* = \Lambda_2/\Lambda_1^{1/\theta^*}$.

The index rainfall considered is the site mean of the yearly maxima. Parameter estimation is based on the hierarchical methodology proposed by Fiorentino *et al.* (1987) and Gabriele & Arnell (1991). According to this approach, parameters θ_* and Λ_* are estimated by the maximum likelihood method in homogeneous regions with respect to the skewness coefficient *CS*, while the parameter Λ_1 is estimated using data from homogeneous subregions with respect to the coefficient of variation, *CV*, inside each of the homogeneous regions as shown schematically in Fig. 2. Homogeneity tests are performed by generating 15 000 series with lengths similar to the sample data, using Monte-Carlo simulations, and comparing sample and generated *CS* and *CV* for several hypotheses of homogeneous regions based on physical considerations. First, a unique region is defined. In a second hypothesis, basins draining to the Thyrrenian Sea are considered as part of the same region while those draining to the Po River are

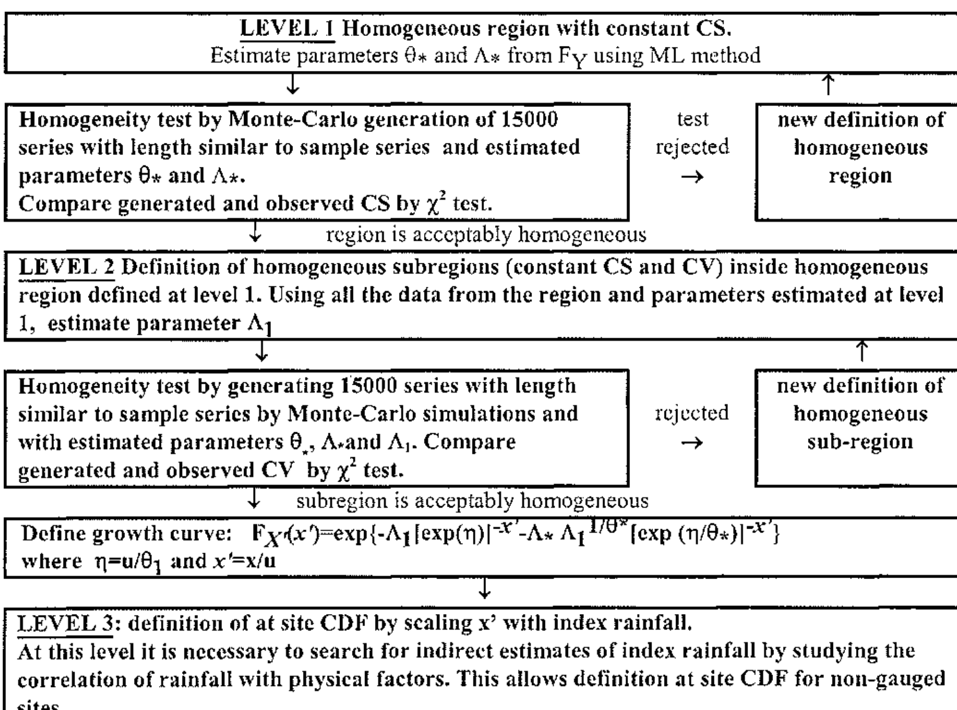

Fig. 2 Hierarchical approach of regionalization with the TCEV distribution.

believed to form a second subregion. The third hypothesis considers morphology and orientation of the main mountainous chains to form three subregions representing the western, central and eastern part of the area.

The resulting dimensionless regional frequency functions, or so-called "growth curves" are verified by Monte-Carlo experiments for all durations and compared with observations using the Kolmogorov-Smirnov test (Fig. 4(a)).

Regionalization using L-moments

The second method based on the L-moments (Hosking & Wallis, 1993) is applied to data of 24 h duration for several candidate distributions including GEV, Pareto, Wakeby and Pearson III, as well as the TCEV. The procedure is schematized in Fig. 3. L-moments are the linear combination of probability weighted moments PWM (Landwehr & Matalas, 1979; Greenwood *et al.*, 1979) defined by:

$$\beta_r = E\{X[1-F(X)]\}^r \qquad r = 0, 1, 2, 3, 4 \tag{4}$$

and the L-moments (λ) and L-moment ratios (τ) are the quantities:

$$\lambda_{r+1} = \sum_{k=0}^{r} p^{*}_{r,k}\beta_k \tag{5}$$

$$\tau_r = \frac{\lambda_r}{\lambda_2} \qquad r = 3,4, \ldots \tag{6}$$

where:

$$p^{*}_{r,k} = (-1)^{r-k}\binom{k}{r}\binom{r+k}{k}$$

L-moments ratios are analogous to the coefficient of variation, skewness and kurtosis

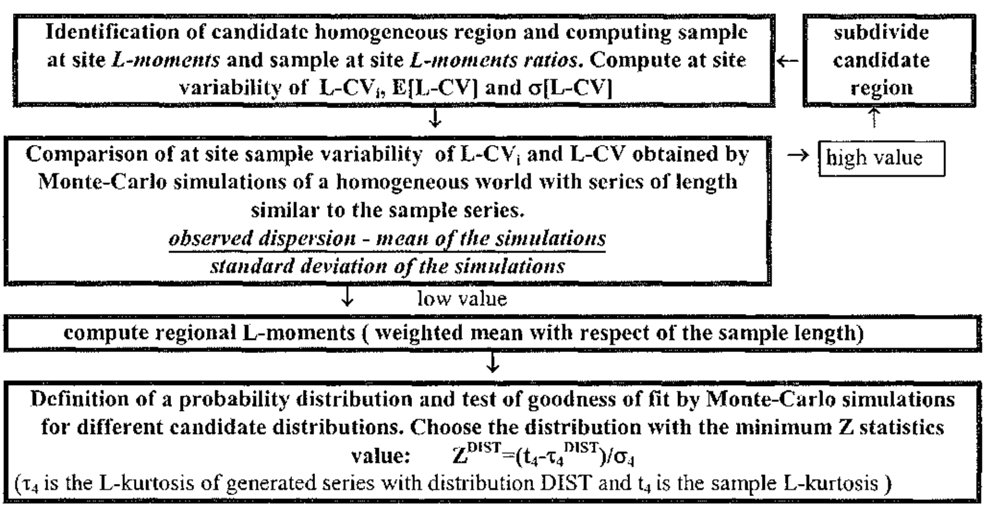

Fig. 3 Regionalization with a flood index method using L-moments.

(τ_2 = L-*CV*, τ_3 = L-*CS*; τ_4 = L-kurtosis). Parameter estimation is similar to the classical method of moments.

A test based on the L-kurtosis coefficient is used to compare the descriptive performance of the theoretical probability distributions. Figure 4(b) shows the three distributions accepted at the 5% significance level according to the procedure suggested by Hosking & Wallis (1993).

Characterization of index rainfall

Duration Regional growth curves computed for five time periods are very similar for all three hypotheses analysed. Furthermore, from the study of index rainfall with duration it was found that the following law holds (Heredia-Calderon, 1997):

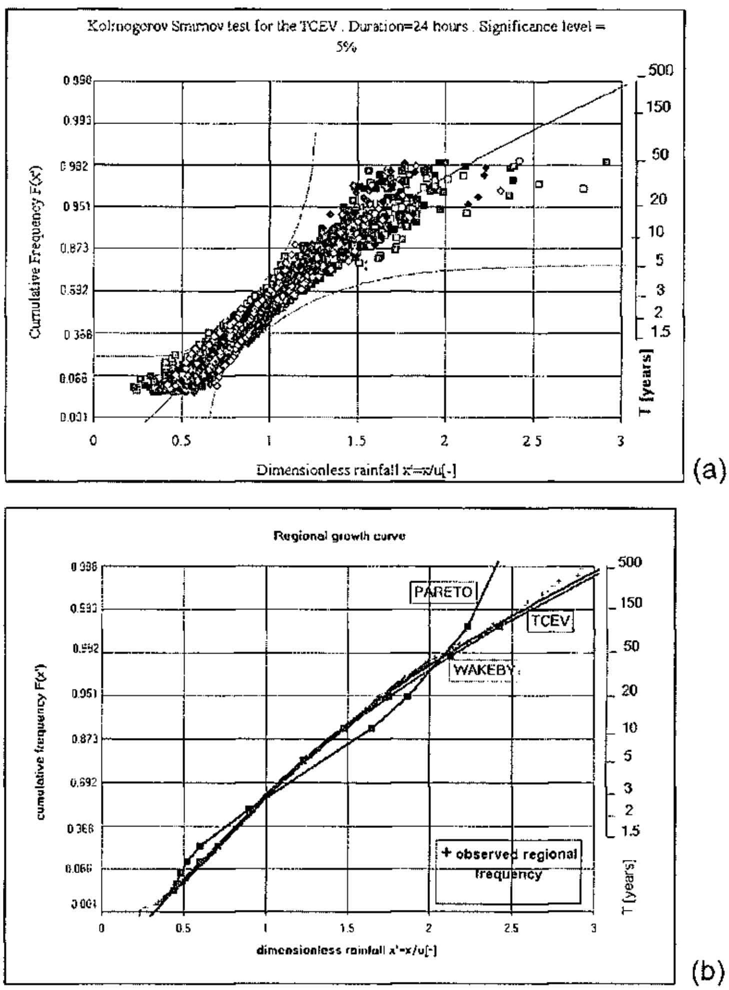

Fig. 4 (a) Kolmogorov test for the TCEV regional growth curve found with the hierarchical approach. (b) Comparison of TCEV, Pareto and Wakeby distributions with observed dimensionless frequency. In both figures **u** stands for the index rainfall or at site mean.

$$E\,[h_{\lambda D}] \stackrel{d}{=} E\,[g(\lambda)\,h_D] \tag{7}$$

where h_D and $h_{\lambda D}$ are the rainfall depths of duration D and λD, the symbol $E[.]$ is the expectation operator and the scaling law is of the form $g(\lambda) = \lambda^{\theta}$.

Mandelbrot (1981) defines this law as "asymptotically scaling". For the study area the asymptotically scaling law corresponds to:

$$\frac{E[h_D]}{E[h_{24}]} = 1.01\left(\frac{D}{24}\right)^{0.369} \tag{8}$$

meaning that extreme rainfall is scale invariant with duration in the study area. The scaling law is verified by two properties, linearity of the log-log plot of the scale values (Fig. 5) and linear variation of the exponent with the order of moments. Both were verified by the data (Fig. 6).

Space distribution of index rainfall A study of the spatial distribution of the index rainfall is performed by analysing the departure of the index rainfall from the regional mean. The departure from the mean is considered to be composed of a deterministic part depending on observable factors, and a stochastic part depending on non-observed factors and observational errors (Heredia-Calderon, 1997). It is

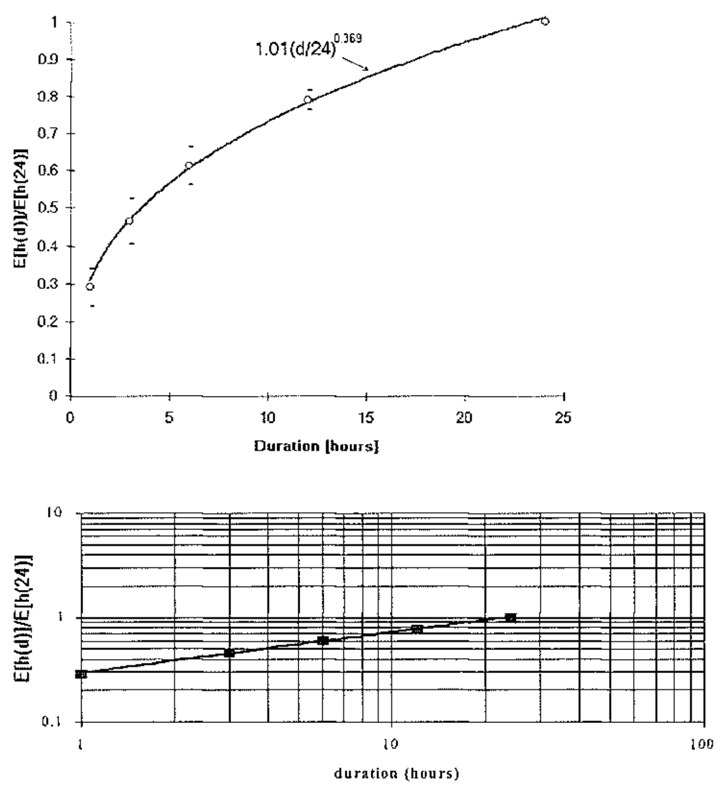

Fig. 5 Scaling law of index rainfall with duration.

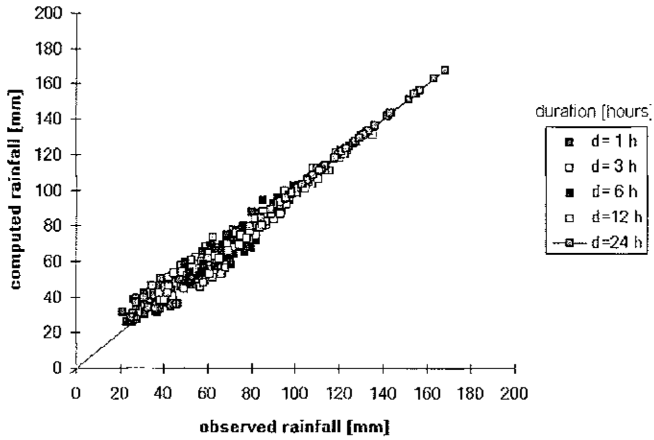

Fig. 6 Comparison of observed and computed index rainfall. Computed rainfall is obtained from the 24 h duration rainfall and the scaling law.

found that precipitation is higher in the centre of the Ligurian Gulf where a "convergence zone" seems to exist. The correlation of the computed deviations from the regional mean with altitude, distance from the sea and distance from the convergence zone along the coast line were analysed (Figs 7 and 8). There is a high correlation of index rainfall values with the distance along the coast. On the contrary, altitude and distance from the sea show low correlation (less than 0.7).

RESULTS AND CONCLUSIONS

The results of the regional analysis performed can be summarized as follows:

– The study area was found to be homogeneous. By comparing theoretical and observed growth curves for all durations it is evident that dimensionless frequency curves are independent of duration for the study area. Consequently, a study of index rainfall with duration was performed and as a result index rainfall was found to be scale invariant with duration.

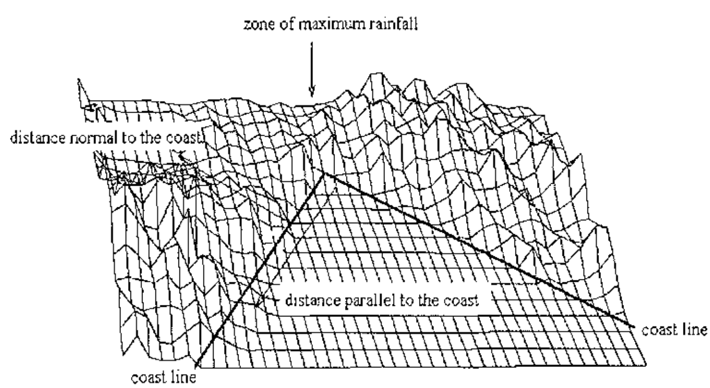

Fig. 7 Schematization of the analysis of index rainfall distribution in space.

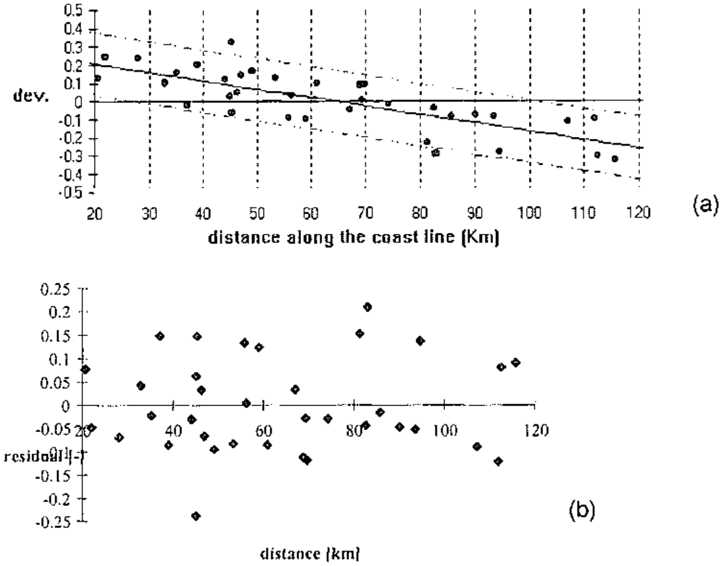

Fig. 8 (a) Deviation of index rainfall from regional mean as a function of the distance from the convergence zone. (b) Residuals diagram (correlation $r = 0$).

– Comparison of several distribution functions with observed frequency distributions shows that mixed distributions such as Wakeby and TCEV best describe the statistics of the extreme rainfall in the area.

Another interesting conclusion exists regarding the spatial distribution of index rainfall. By correlation analysis, it was found to be independent of altitude and distance from the sea, whereas there is evidence that it is significantly dependent on the distance measured along the coast line, from a convergence zone in the centre of the Ligurian gulf. This result seems to confirm the importance of meteorological considerations for storm dynamics in the Mediterranean zone.

Further analysis of these findings and their relationship with the physics of the processes are the focus of on-going research.

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