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Linear estimation of design values

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A common task in statistical hydrology is the estimation of the design value (e.g., the design flood) from a small sample of observed values. This requires: (i) selecting a distribution function, $P(x)$, and inverting it to obtain the quantile function, x_P, i.e. the relation between the design value and the probability level P; (ii) estimating the parameters of this distribution using the available sample values. In most cases, the estimator of the design value (i.e., the value of x_P corresponding to a given probability level) turns out to be a nonlinear function of the sample values, due to nonlinearities in the relation between x_P and the parameters, and/or between the estimators of the parameters and the sample values (a notable exception is when a 2-parameter position-scale distribution is used, with parameters estimated by the method of L-moments). The presence of this nonlinearity between sample values and design-value estimators has detrimental effects on the efficiency and robustness of design-value estimators.

We propose here a family of estimators of the design value which may be expressed as linear combinations of the available sample values; these estimators are built by expressing x_P as a series of orthonormal polynomials of increasing degree in u_P, the quantile function of a suitably selected standardized base-distribution. The coefficients of this expansion are L-statistics (i.e., linear functions of the sample values) obtained as weighted averages of the sample values, where the weight attributed to the i-th value in the ordered sample depends on the powers of $u_{F(i)}$, where $F(i)$ is the empirical probability function. When the base-distribution is the uniform, one obtains $u_P = P$, and our expansion converges to Sillitto (Biometrika, 56(3), 641-650, 1969) expansion of the quantile function, with the standard L-moments as the coefficients of the expansion. The uniform distribution, however, is not suitable to represent extreme values, and Sillitto expansion is of limited practical utility. We use instead the Gumbel distribution as the base-distribution, with $u_P = -\log[-\log[P]]$; we obtain estimators of x_P which benefit in robustness and ease of use from the linearity with respect to the sample values, but share the flexibility of commonly used 3-parameter models. We demonstrate our approach with an extensive numerical experiment using several different parent distributions, parameterizations, and sample sizes.