# A parsimonious approach for regional design rainfall estimation: the case study of Athens

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ABSTRACT

Design rainfall estimation at the regional scale is the cornerstone of hydrological design against flooding, particularly essential for ungauged areas. We devise a parsimonious and flexible methodology for regional estimation of rainfall extremes for time scales of minutes up to a few days and any return period, i.e. producing the ombrian curves. Estimation of the distribution parameters is performed by an advanced regional pooling approach employing knowable (K-) moments that allow reliable high-order moment estimation and handling of space dependence; which is non-negligible in homogenous regions. The regionalization approach is based on elevation, which is often sufficient to explain the rainfall variability within a generally homogenous climatic region. The methodology is effectively applied in the Attica region, comprising Athens and its surrounding basins.

## 1. Introduction and Methodology

Design rainfall for engineering applications is conveniently obtained from ombrian (from the Greek word 'όμβρος' meaning rainfall) curves, i.e. mathematical relationships linking rainfall intensity to timescale and return period, usually known as 'intensity-duration-frequency' curves. Koutsoyiannis (2021) recently developed a framework for integrating typical ombrian curves to stochastic models of the multi-scale rainfall intensity. The framework can be applied at any time scale, arbitrarily large, yet for large time scales the mathematics are more involved, while these scales are less relevant to flood analyses. Here, we apply the framework only for small time scales to produce the ombrian curves for the Attica region.

Under some simplifying assumptions (Koutsoyiannis, 2021), the rainfall intensity $x$ for small timescales $k$ (of the order of minutes to a few days) and return period $T$ is given by the following relationships; the first (Equation (1)) valid for return period estimated from series of rainfall exceedances and the second (Equation (2)) from series of annual maxima (where $\Delta$ = 1 year):

$$x = \lambda \frac{(T/\beta)^{\xi} - 1}{(1 + k/\alpha)^{\eta}}, \qquad \xi > 0 \tag{1}$$

$$x = \lambda \frac{(-(\beta/\Delta)\ln(1 - \Delta/T))^{-\xi} - 1}{(1 + k/\alpha)^{\eta}}, \qquad \xi > 0 \tag{2}$$

where $\lambda$ an intensity scale parameter in units of $x$ (e.g., mm/h), $\beta$ a timescale parameter in units of the return period (e.g., years), $\alpha$ a timescale parameter in units of timescale (e.g., h) with $\alpha \geq 0$, $\eta$ a dimensionless parameter with $0 < \eta < 1$, and $\xi > 0$ the tail index of the process.

The parameter estimation is based on a two-step procedure. The timescale parameters are estimated following the Koutsoyiannis et al. (1998) procedure, whereas the distribution parameters are estimated by a novel regional pooling approach. Two groups of stations were identified: (a) group A comprising 9 stations with lower on average annual maxima at the daily scale which are generally located at elevation <160 m and (b) group B comprising 5 stations with higher on average annual maxima at the daily scale which are generally located at elevation >160 m. After standardization of the stations' 24 h annual maxima by their group mean, the parameters of the pooled maxima distribution are estimated using only the first set of non-central K-moments (Koutsoyiannis, 2019) that is not impacted by the effect of space dependence, unlike higher moments (Koutsoyiannis, 2021, Iliopoulou et al. 2022). For the given stations that exhibit significant spatial correlation this correspond to the first16 non-central K-moments.

To regionalize the scale parameter $\lambda$ to any region of interest, e.g. a sub-basin within the studied area, the following relationship is applied:

$$\lambda = f_A\,\lambda_A + f_B\,\lambda_B \tag{3}$$

where $f_A$ the ratio of the area's extent that lies at elevation < 160 m to the total extent and $f_B$ the ratio of the area's extent that lies at elevation ≥ 160 m to the total extent, and $\lambda_A, \lambda_B$ the scale parameters of the two groups.

## 2. Results and Discussion

The parameter estimates are shown in Table 1 for both elevation groups, while an example of the fitting of the model to two stations representative of groups A and B respectively, is shown in Figure 1. It is seen that the empirical distribution functions are generally in good agreement with the theoretical ones.

**Table 1.** Ombrian parameters $\alpha$, $\eta$, $\xi$, $\lambda$ and $\beta$ for Equations (1)-(2).

| Parameters | $\alpha$ (h) | $\eta$ (-) | $\xi$ (-) | $\lambda$ (mm/h) | $\beta$ (years) |
|---|---|---|---|---|---|
| Elevation group A | 0.1 | 0.73 | 0.07 | 445 | 0.07 |
| Elevation group B | 0.1 | 0.73 | 0.07 | 579 | 0.07 |

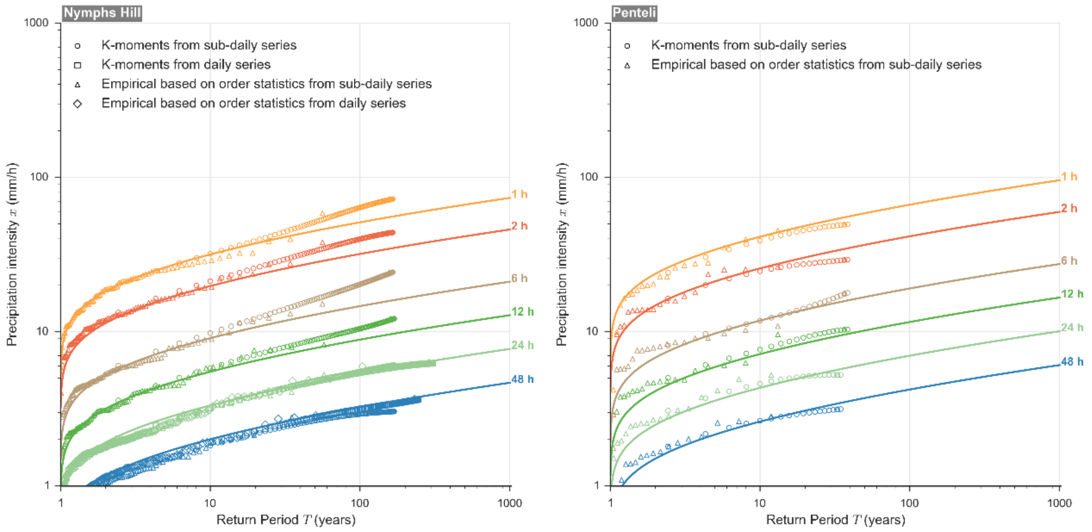


**Fig. 1.** Theoretical and empirical distributions of annual maximum intensities at 1 h to 48 h scales (depending on the available samples) from the daily and sub-daily stations at (a) Nymphs Hill (group A) and (b) the sub-daily station at Penteli (group B). The empirical intensities plotted based on order statistics are also shown for validation.

The ombrian curves for any region within the given area are derived based on the four common parameters and the regionally varying parameter which is obtained as a result of the region's elevation distribution (Equation (3)). In this way the framework is parsimonious and easy to apply at the basin scale, without the need for further spatial interpolation. Its merits are further discussed in the context of a new regional flood hazard assessment framework for the Attica region.


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