Spatially smooth estimation of low-flows: Canonical-Kriging and Top-Kriging

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ABSTRACT

We present an application of two techniques named TOP-KRIGING and Canonical Kriging or Physiographic-Space Based Interpolation (PSBI), to the problem of low-flow estimation for a broad geographical region located in northern-central Italy:

• the first technique, named Topological kriging or TOP-KRIGING (*Skøien et al. 2006*), estimates the variable of interest along river networks taking both the area and the nested nature of catchments into account (see Figure 2);

• the second one, Canonical Kriging or PSBI (*Castiglioni et al. 2009*), performs the spatial interpolation of the desired streamflow related variable in the bidimensional space of catchment descriptors, where the x and y coordinates of this space are derived from a set of n>1 catchment descriptors through the application of multivariate technique named Principal Component Analysis (see Figure 3).

This study focuses on a comparison between two innovative approaches to predict low-flows in ungauged basins at regional and basin scale. In the latter, we estimate the indices along the river network and compare the different database that is needed for the analysis.

Study Area

The study region includes the administrative regions of Marche and Abruzzo, in central Italy. The region consists of the catchments associated to 51 hydrometric stations, for which series of daily river flows are available (see Figure 1). We considered the following catchment descriptors: drainage area, A (km^2); main channel length, L (km); percentage of permeable area, P (%); maximum, mean and minimum elevations, H_{max}, H_{mean} and H_{min} (m a.s.l.); average elevation relative to H_{min}, $\Delta H = H_{mean} - H_{min}$ (m); Giandotti's concentration time, t_c (hours); and mean annual precipitation, MAP (mm).

We selected Metauro basin for the analysis at basin scale because in this catchment the number of hydrometric stations (7 for 1043.6 Km^2) enabled us to perform an extensive cross-validation and to interpret the results on the basis of physical reasoning.

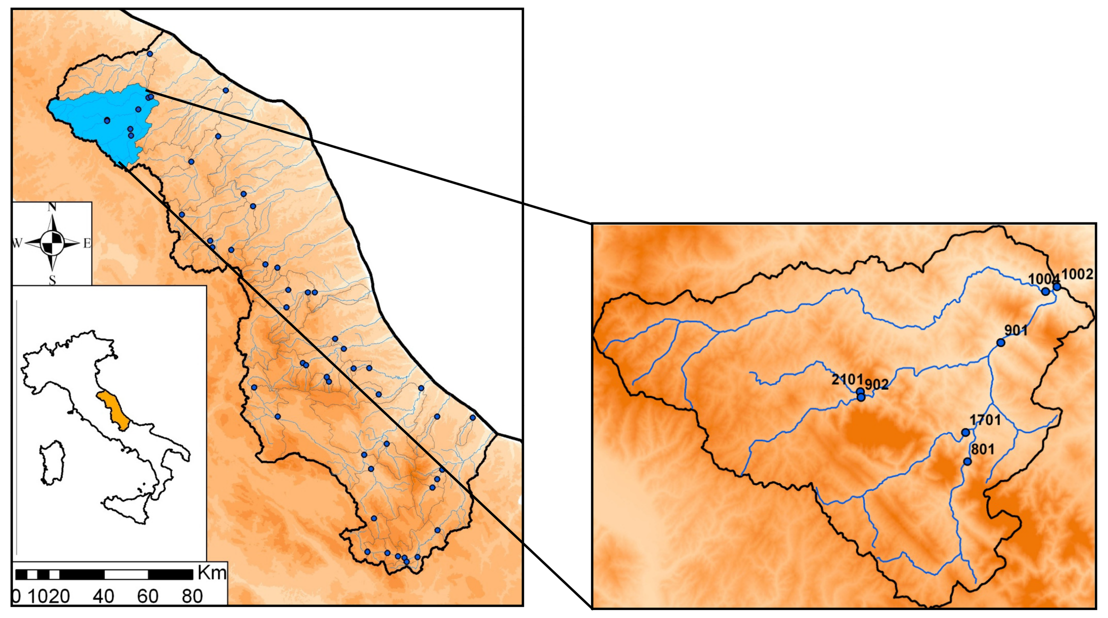


Figure 1. Study area: 51 hydrometric stations (left); Metauro basin (right)

TOP-KRIGING:

TOP-KRIGING advantages:

- consider both the area and the nested nature of catchments, so it is easier to apply since no catchment descriptors need to be determined;
- permit to estimate the streamflow variable along the river network only with the area and the nested structure of catchments.

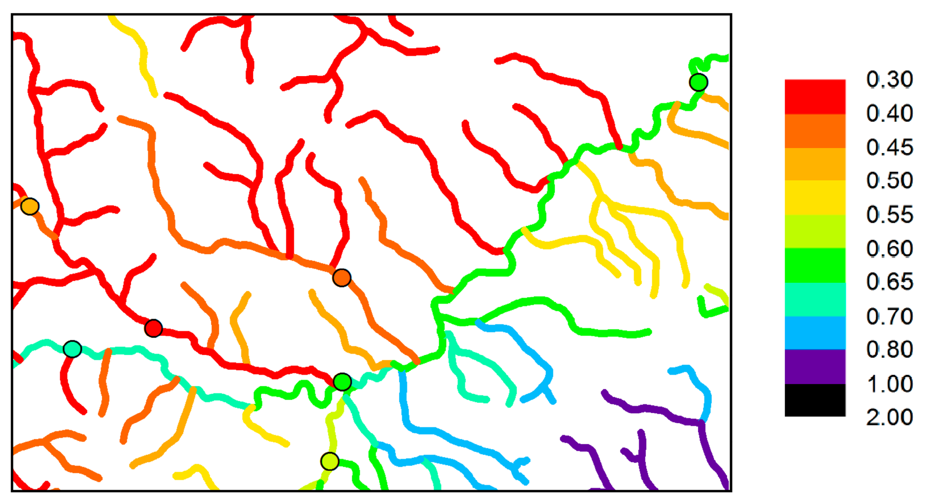


Figure 2. Example of estimation of streamflow (normalised specific 100-year flood [m^3/s/km^2], Mur region) along the river network with TOPKRIGING technique (Skøien et al., 2006)

Canonical Kriging or PSBI:

PSBI advantages:

- to determinate Physiographical-Space, considers geomorphological and climatic descriptors of each catchment which characterize each basins and affect the hydrological processes;
- the use of Physiographical-Space permits to apply other more complex techniques which use more coordinates of the space, for example kriging 3D, increasing the variance explained of original variables.

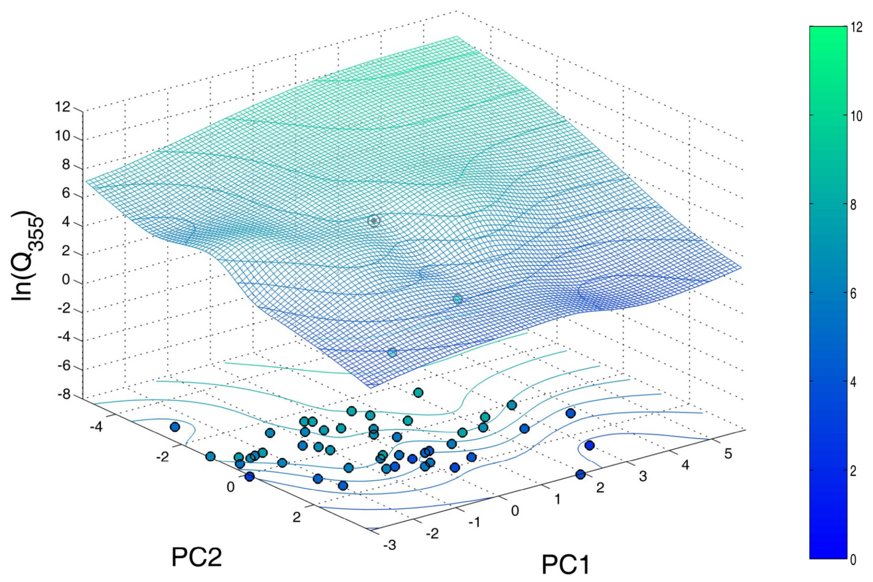


Figure 3. Example of cross-validation of PSBI: 3D representation of the surfaces generated in the physiographic space by the interpolation techniques (cross-validation site: River Aterno at L'Aquila).

Results and Conclusions: Regional Scale

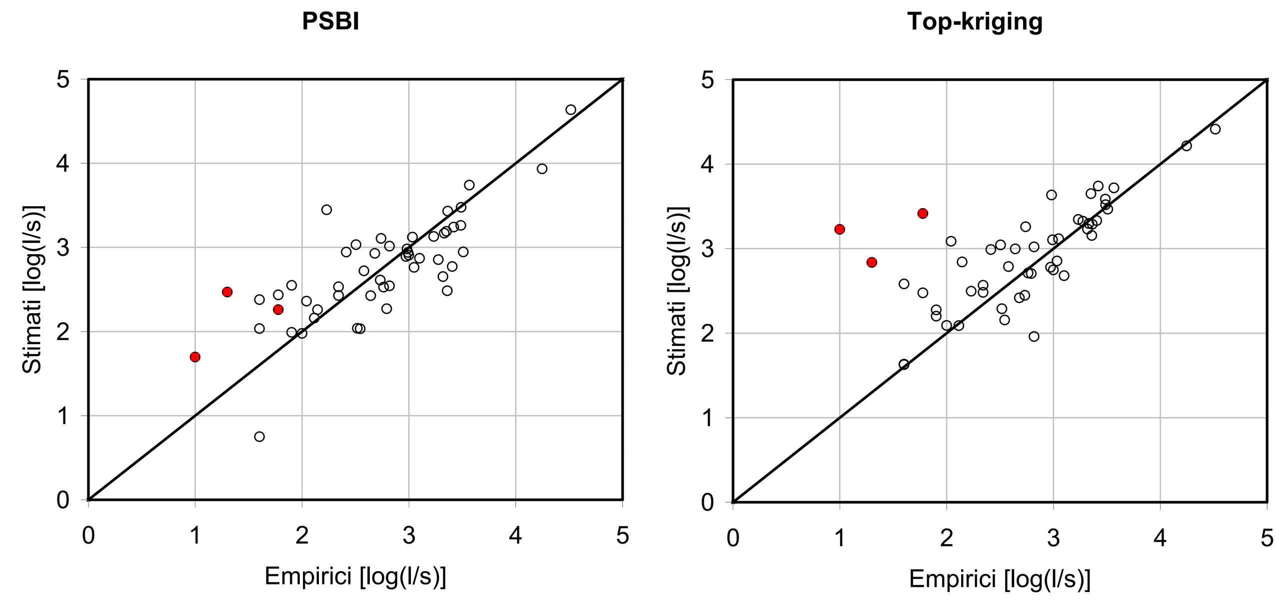
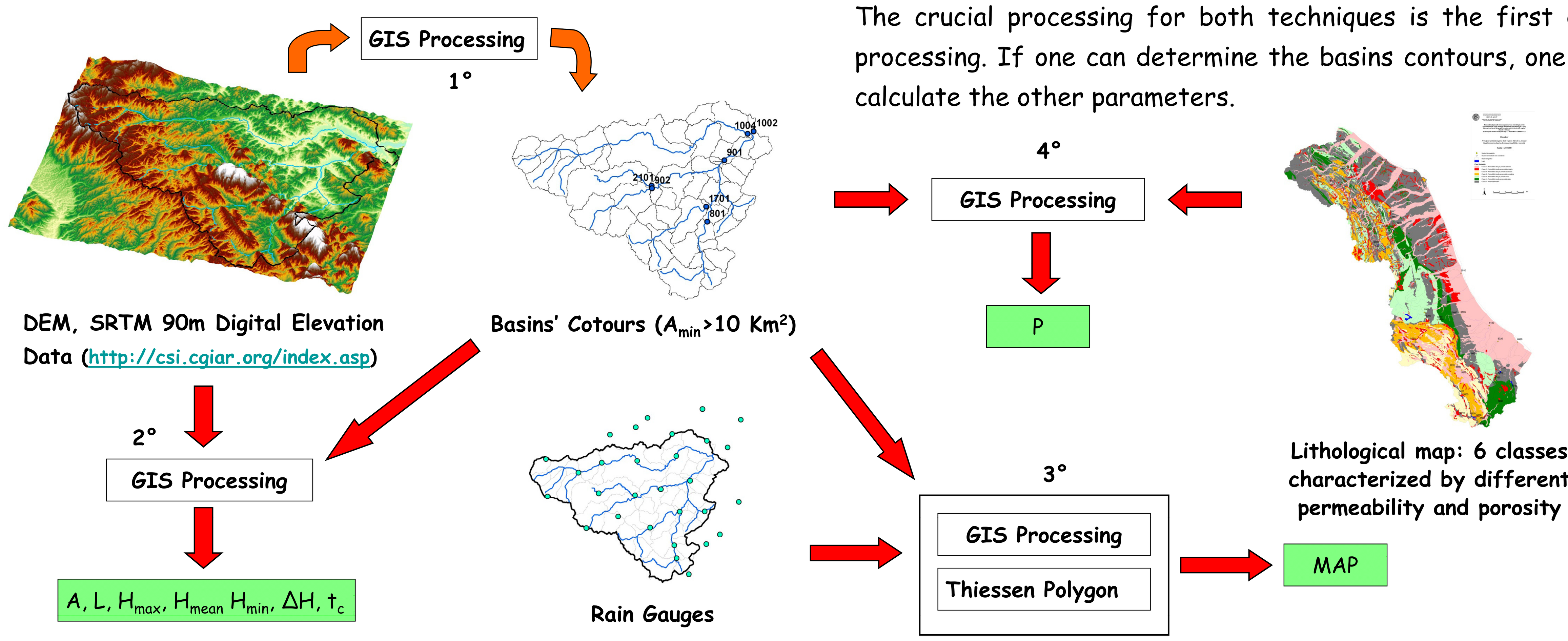


Figure 4 and 5. Cross-validation of spatial interpolation techniques: empirical vs. estimated values of Q_{355}.

The accuracy of estimation low flow index (Q_{355}, discharge associated with a duration of 355 days) for each methodology is evaluated using a jack-knife resampling procedure (*Castellarin et al.*, 2004).

PSBI and TOP-KRIGING showed similar performance. The cross-validation indicates that PSBI outperforms TOP-KRIGING in terms of MRE (mean relative error), MRE=1.09 and MRE=1.14 respectively, but the Nash-Sutcliffe Efficiency (*Nash and Sutcliffe*, 1970) obtained with TOP-KRIGING (E=0.90) is greater than that of PSBI (E=0.88). The results are illustrated in the scatterplots of Figures 4 and 5.

Results and Conclusions: Basin Scale (database)



The crucial processing for both techniques is the first GIS processing. If one can determine the basins contours, one can calculate the other parameters.

Results and Conclusions: Basin Scale (estimation along the river network)

This basin scale application shows that TOP-KRIGING and PSBI present complementary features. Top-kriging outperforms PSBI at larger river branches, while PSBI outperforms TOP-KRIGING for headwater catchments. This result is associated with the assumption of intrinsic stationarity of Top-kriging, i.e. similar low flows at close-by sites. PBSI, however, performs poorer at larger rivers. PBSI, like any multivariate technique, assumes a clear relationship between the low flow index and catchment processes represented by catchment characteristics. The aggregation of discharges at larger rivers leads to a mixing of different regimes and low-flow generating processes and therefore reduces the performance of multivariate techniques.

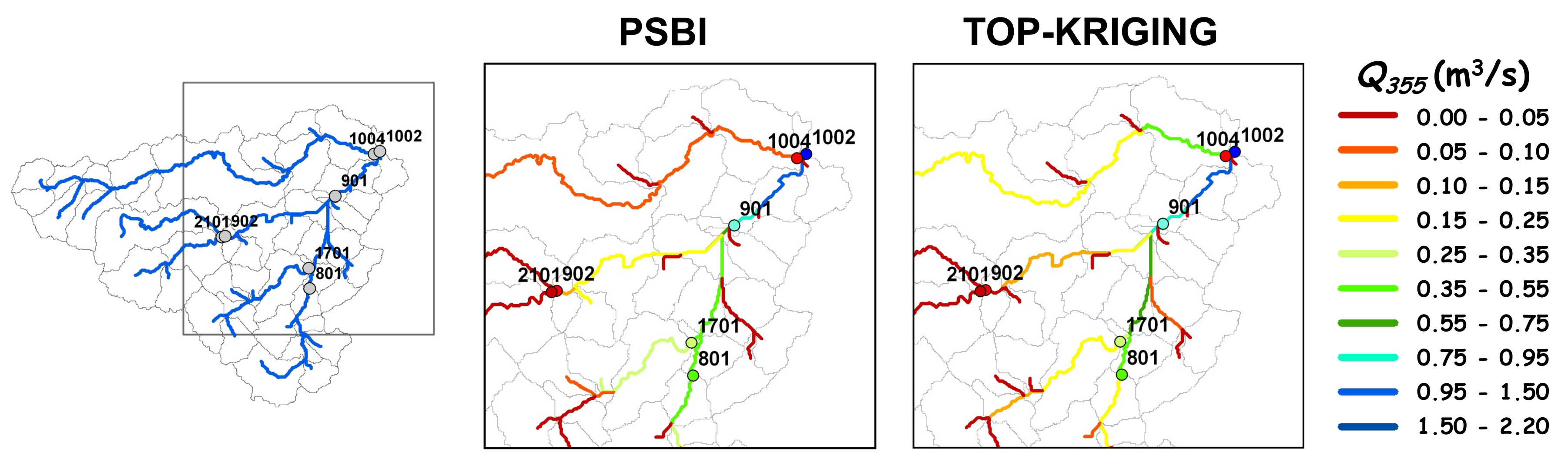


Figure 7 and 8. Comparison of techniques for estimating Q_{355} along the river network: the observed values are represented as colored dots, the estimated values are represented as colored lines.

Code	PSBI	Top-kriging
801	0.12	0.54
901	0.23	0.02
902	0.34	0.39
1002	1.20	0.01
1004	0.40	3.04
1701	0.10	0.52
2101	0.30	0.91
Mean Value	0.38	0.77

Table 2. Relative error in the estimation of Q_{355} along the river network for Metauro Basin.