Regional estimation method of rivers low flow from river basin characteristics

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Abstract: Low flow characteristics are usually estimated from flow gauge stations. However hydrological data are not always available at the site of interest: regional frequency analysis is commonly used for the estimation of flow characteristics at sites where little or no data exists. The study is applied to Tuscany rivers discharge dataset. The area is subdivided into homogeneous regions using an L-moments procedure. The low flow indices Q(7,2) and Q70 at ungauged basins are evaluated with deterministic (Inverse Weighted Distance) and geostatistical (Ordinary Kriging) methods. In order to improve the capability of low flow statistics in ungauged sites a multivariate model, based on geomorphoclimatic characteristics, is also assessed. For each sub-region a relation connecting low flow indices and geomorphoclimatic characteristics is found.

Keywords: regionalization, multivariate analysis, spatial interpolation; L-moments.

1. Introduction

Knowledge of low flow events frequency is required to plan water supply and irrigation systems and moreover to maintain amount and quality of water for wildlife. An estimation of the frequency at which low flow events of different severity might occur is therefore essential for effective water resource planning. Low flow regime is tightly dependent on the catchment hydrogeological feature and a detailed surface and groundwater catchment analysis is necessary for an accurate characterization. However on a practical perspective, although scientifically proven, statistical analysis is often applied to derive indices to characterize low flow regimes and as a measure for low flows. Particularly, low flow frequency behavior is typically characterized using a stochastic approach based on the characterization of some selecting indices (Gustard et al., 1992; Tasker, 1987) thus avoiding to address all the complicated day-to-day variations in the flow record.
Low flow indices can be easily evaluated at gauged sites from observed streamflow time series, but their reliability can be affected by poor and not accurate streamflow data. Sivapalan (2003) indicated that the prediction of surface water flows in ungauged basins is an urgent problem, of immediate relevance to society, dealing with questions such as the impacts of land use and climatic change, biodiversity and sustainable development. In the United States there have been numerous attempts to predict low flows using empirical equations based on catchment area, channel and meteo-climatic characteristics. Another approach to estimate low flow statistics in ungauged sites is the regional statistical analysis, widely used since long time and in different disciplines. It is the most widely used technique in flow estimation in ungauged sites or where few data are available (Riggs, 1973). Regionalization of streamflow characteristics is based on the premise that catchments with similar geology, topography, climate, vegetation, and soils would have similar streamflow responses. It consists of the identification of regional laws, applicable over a more or less wide area, a region, which generally use catchment characteristics as independent variables (Santhi et al., 2008).

2. Materials and Methods

The analysis is carried out on the discharge data recorded in several rivers in the Tuscany Region central Italy by Servizio Idrologico Regionale Toscano (Regional Hydrologic Service of Tuscany) during the period 1949-2008. The main rivers of the region are: Arno, Serchio, and Ombrone Grossetano. Moreover there are small basins of coastal rivers near the Tyrrhenian Sea and the upstream part of Tevere, Fiora and Magra watersheds. A dataset of 65 hydrometric stations is considered, excluding all the discontinuous series, with less than 3 years of data, and stations with long periods of inactivity. The dataset adequately represents the analysed territory.
The area is subdivided into different regions using the L-moments method applied to the 7-day annual minimum flows and to the Q70 annual series. The division into sub-regions was tested using discordancy and heterogeneity statistics (Hosking and Wallis, 1993). A unique region and a subdivision into three different sub-regions, following previous studies on rainfall extremes were considered. Finally a subdivision into five homogeneous sub-regions was undertaken by accounting for hydrological features. With this subdivision the regions are more homogeneous, and the subdivision follows hydrological and precipitation features (Rossi and Caporali, 2010).
An appropriate interpolation technique over the geographical space has to be established in order to determine low flow indices in ungauged sites. For each river section two interpolation techniques, one deterministic (Inverse Weighted Distance) and another one geostatistical (Ordinary Kriging) are applied using the data of the 65 locations of the database.
In order to improve the capability to predict low flow in ungauged sites, a novel multivariate analysis is carried out relating low flow indices and geomorphoclimatic characteristics. The analysis allow to estimate the parameters of a linear correlation between dependent low-flow characteristics and independent catchment and climatic variables. Using a Digital Elevation model (DEM) of the study area, the sub-watersheds for each hydrometric station is found. Each sub-watershed is characterized by means of:

- longest flow paths *FP* [km] (Tucci et al., 1995; Pyrce, 2004);
- topographic mean slope *Sl* [%] (Castellarin et al., 2004; Chokmani and Ouarda, 2004; Laaha and Bloeschl, 2006);
- mean elevation *Hmean* [m a.s.l.] (Gottshalck, 1985; Castellarin et al., 2004; Pyrce, 2004; Laaha and Bloeschl, 2006; Castiglioni et al., 2008; Viglione et al., 2006);
- difference between the maximum and the minimum elevation ΔH [m] (Castellarin et al., 2004; Laaha and Bloeschl, 2006; Vigilance et al., 2006);
- average value of Mean Annual Precipitation *MAP* [mm] (Castellation et al., 2004; Pryce, 2004; Lama and Bloeschl, 2006; Castiglioni et al., 2008; Viglione et al., 2006) available from previous studies (Caporali et al., 2008);
- mean soil permeability *SP* [%] calculated as the percentage of sand into the first 50 cm of the soil (Santhi el al, 2008, Castiglioni et al., 2008). This information is obtained from a pedological map of Tuscany Region cartographic website.

The regionalisation approach requires the development of a regional predictive model for Q70 and Q(7,2). To this aim, the natural logarithms of all geomorphoclimatic characteristics for the 65 sites were regressed against the corresponding Q70 and Q(7,2) values trough a least square mean error procedure. The linear model, used for its simplicity and for the good results it is able to give (Laaha and Bloeschl, 2006), has the form:

$$Q^{*} = a_1 + a_2 \ln(FP) + a_3 \ln(Sl) + a_4 \ln(Hmean) + a_5 \ln(\Delta H) +_6 \ln(MAP) + a_7 \ln(SP) \quad (1)$$

where Q^* is either Q70 or Q(7,2); *FP*, *SL*, *Hmean*, ΔH, *MAP* and *SP* are the explanatory variables of the model, the suitable set of geomorphic and climatic indices; a_i, for i = 0, 1,... , 7, are parameters. The optimal subset of explanatory variables and the estimates of a_i, with i = 0, 1,... , n for both the indices were identified through a least square mean error procedure. Logarithms allow to have variables values easier to be compared (Castellarin et al., 2004) and to have coefficients with a certain homogeneity as well as the same order of magnitude.

3. Results

The procedure is applied to the whole region and then to the other two proposed subdivisions. In Table 1 are summarized the values of the parameters for the different cases. In some subdivisions the equations are reduced eliminating some parameters that show a little correlation with the calculated index.

Index	Subdivision	Sub-region	a_1	a_2	a_3	a_4	a_5	a_6	a_7
Q(7,2)	Unique		-2.02	-5.48	-7.50	10.96	-7.34	1.27	-1.88
Q(7,2)	3 regions	Nord	-19.66	1.64	3.77	4.04		-3.05	1.90
		Centre	-17.80		0.85	2.77	-0.40	0.18	
		South	-5.44	0.13	1.19	0.12	0.69		
Q(7,2)	5 regions	North East	-26.84	3.66	3.07	7.04	-3.50	-4.72	4.93
		North West	-32.27	-3.15	0.98	5.05		-0.58	3.40
		Centre East	6.56	0.60	2.28	0.37		-1.07	-1.32
		Centre West	-21.57		2.33	3.96	-1.91	0.89	-0.38
		South	-5.14	0.19	1.48	0.09	0.60		
Q70	Unique		-19.01	-0.07	1.73	17.85	-4.16	-7.67	-0.63
Q70	3 regions	Nord	-12.53	7.09	7.33	30.67		-20.09	6.99
		Centre	-44.56		2.67	6.58	-1.12	0.90	
		South	-17.78	0.50	3.22	-0.18	2.85		
Q70	5 regions	North East	-22.34	11.34	-3.60	47.20	-0.08	-25.10	8.45
		North West	-80.38	-0.47	0.85	16.21		-6.81	3.14
		Centre East	-33.21	0.45	5.57	4.06		-0.05	0.68
		Centre West	-40.86		7.41	8.65	-5.35	2.26	-1.62
		South	-17.07	0.65	3.88	-0.27	2.66		

Table 1: Parameters of the considered multivariate model.

The models were validated through the calculation of the root mean square error RMSE. The RMSE is calculated for the three proposed subdivisions, for both the proposed low flow indices (Table 2) and, with a jackknife procedure, for the three interpolation methods.
Results for the multivariate analysis confirm the good properties of homogeneity of the final subdivision into 5 regions. For Q70 the RMSE varies from 7.80 with a unique region, to a mean value of 2.89 with the subdivision in three regions to reach a mean value of 1.53 with the subdivision in five regions.
In Figure 1 are shown the results of RMSE for the three interpolation techniques for the two selected indices and the subdivision into 5 regions. Comparing the results of multivariate analysis with the other two interpolation techniques it is possible to state that there is an improving of results especially for the northern regions.

4. Concluding remarks

A method of low flow regionalization is proposed and evaluated. In particular a procedure to evaluate low flow indices in ungauged basins is identified using a regional regression approach. The area is subdivided in 5 regions using an L-moments approach. This subdivision is verified using some interpolation techniques: Inverse Weighted Distance, Ordinary Kriging and a Multivariate Analysis. The results are validated using the jackknife method and calculating the RMSE – Root Mean Square Error for the different subdivisions and the different techniques. The multivariate analysis is the estimation method that performs best. It is able to solve the problems in the two northern regions: in these regions the considered low flows indices present a high variability that can be explained taking into account the geomorphoclimatic characteristics.

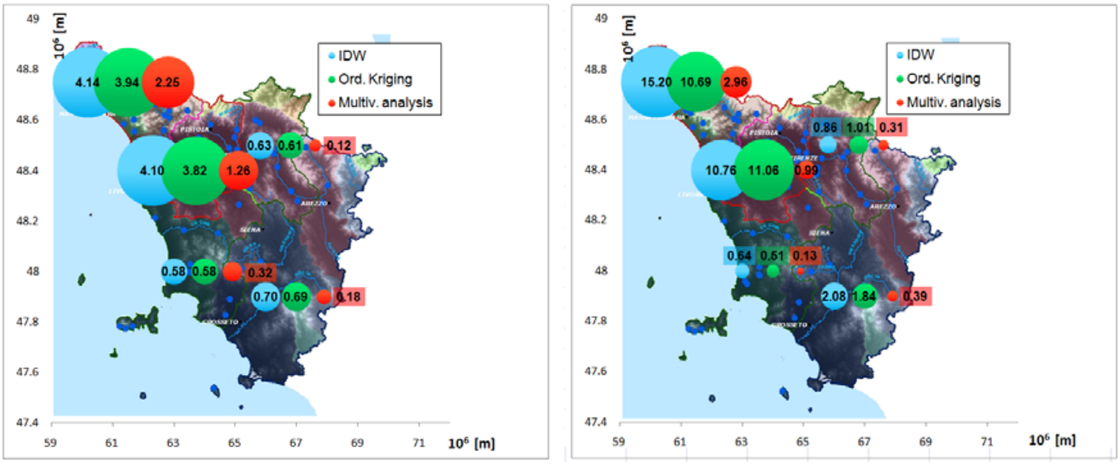

Figure 1: RMSE values for Q(7,2) (left) and Q70 (right) for the subdivision in 5 regions in the three considered interpolation techniques. The circumferences ray is proportional to the RMSE.

References

Caporali E., Cavigli E., Petrucci A. (2008) The index rainfall in the regional frequency analysis of extreme events in Tuscany (Italy), *Environmetrics*, 19, 714-724.

Castellarin A., Galeati G., Brandimarte L., Montanari A., Brath A. (2004) Regional flow-duration curves: reliability for ungauged basins, *Advances in Water Resources,* 27, 953–965.

Castiglioni S., Castellarin A., Montanari A. (2008) Stima delle portate di magra in siti non strumentati mediante tecniche di interpolazione spaziale, *Proc. 31° Convegno Nazionale di Idraulica e Costruzioni Idrauliche*.

Chokmani K., Ouarda T. B. M. J. (2004) Physiographical space-based kriging for regional flood frequency estimation at ungauged sites, *Water Resources Research,* 40, 1–12.

Gottschalk L., Tallaksen L. M., Perzynab G. (1997) Derivation of low flow distribution functions using recession curves, *Journal of Hydrology,* 194, 239–262.

Gustard A., Bullock A., Dixon J. M. (1992) *Low flow estimation in the United Kingdom* (IH Report No. 108). Institute of Hydrology, Wallingford, Oxon.

Laaha G., Bloeschl G. (2006) A comparison of low flow regionalization methods – catchment grouping, *Journal of Hydrology*, 323, 193–214.

Pyrce R. (2004) *Hydrological low flow indices and their uses*, Watershed Science Centre Report No. 04-2004. Trent University, Canada.

Rossi G., Caporali E. (2010). Regional analysis of low flow in Tuscany (Italy), in: *Global Change: Facing Risks and Threats to Water Resources. Friend 2010, Sixth World FRIEND - Flow Regimes from International Experimental and Network Data, Conference*, Servat E., Demuth S., Dezetter A., Daniell T. (Eds.) IAHS Publication 340, 135:141.

Riggs H. C. (1973) *Regional analysis of streamflow characteristics,* US Geological Survey Techniques of Water Resources, United States Government Printing office, Washington.

Santhi C., Allen P. M., Muttiah R. S., Arnold J. G., Tuppad P. (2008) Regional estimation of base flow for the conterminous United States by hydrologic landscape regions, *J. of Hydrology*, 351, 139-153.

Sivapalan M. (2003) Prediction in ungauged basins: a grand challenge for theoretical hydrology. *Hydrological Processes,* 17, 3163-3170.

Tasker G. D., (1987) A comparison of methods for estimating low flow characteristics of streams, *Water Resources Bulletin,* 23, 1077–1083.

Viglione A., Claps P., Laio F. (2006) Utilizzo di criteri di prossimità nell'analisi regionale del deflusso annuo, *Proc. XXX Convegno di Idraulica e Costruzioni Idrauliche.*