Name:	Stefano Mallucci	Email:	stefano.mallucci@unitn.it
Institution:	University of Trento	Type (oral/poster)	Oral and Poster

Analysis and attribution of hydrological trends in the Adige River Basin (Italy)

Stefano Mallucci[1], Bruno Majone[2], and Alberto Bellin[2]

[1] University of Trento / Fondazione Edmund Mach, Center Agriculture Food Environment, San Michele all'Adige, Italy
[2] University of Trento, Department of Civil, Environmental and Mechanical Engineering, Trento, Italy

The relevant role of climate change on the observed alterations of the water cycle in snow-dominated regions is widely recognized, particularly in the European Alps (see e.g., *Beniston, 2003*). A number of contributions suggest that recent changes in the precipitation patterns and the contemporaneous rise of temperatures have led to rapid glaciers melting and intensification of evaporation with a consequent alteration of the typical Alpine hydrological regime (see e.g., *Birsan et al., 2005*). Furthermore, other pressure factors such as land use changes, hydropower and agricultural developments, increasing population and other anthropogenic stress factors are shown to drive important streamflow alterations in some Alpine catchments (see e.g., *Chiogna et al., 2016*) and their influence should be carefully quantified and separated from the climatic one. Disentangling climatic and human impacts on hydrological fluxes is a difficult task since they combine in a complex nonlinear manner. Here we propose a rigorous data-driven multi-method approach with the aim to identify drivers of hydrological changes in a large Alpine catchment. Statistical methods (i.e. Mann-Kendall trend tests, Sen's slope estimates, multivariate data analyses and Kriging algorithms) have been applied to assess the variability of hydro-meteorological variables both in time and space, identifying the associated local drivers' effects. The attribution of the observed alterations to their main causes was performed by providing evidences of consistency or inconsistency of different plausible hypotheses following the approach proposed by *Merz et al. (2012)*. In particular, we analyzed long-term time series of hydrological data in the Adige catchment, a large Alpine river basin located in the Southeastern Alps, North-East of Italy.

Daily precipitation as well as daily minimum, maximum and mean temperatures were first interpolated over a regular grid with size of 1 km and then spatially averaged by computing the arithmetic mean of the values at the cells contained within the catchment. A leave-one-out cross-validation procedure identified Kriging with the External drift (*Goovaerts, 1997*) with 16 neighbouring stations as the most suitable interpolation scheme for all the four interpolated variables (precipitation, mean, maximum and minimum temperature). This geostatistical interpolation provides both the conditional mean and the conditional variance, representing the most probable value and an estimate of uncertainty, respectively. In this study we evaluated the uncertainty introduced by the spatialization of point measurements, performing 5,000 Monte Carlo simulations of the precipitation time series associated to each grid cell of the study domain. Daily reference crop potential evapotranspiration (ET_0) was estimated by using the Hargreaves - Samani model (see e.g., *Hargreaves & Samani, 1985*). Potential evapotranspiration was then obtained by multiplying ET_0 by the crop coefficient K_c, depending on the site-specific vegetation and growth stage. In addition, following e.g., *Allen et al. (1998)*, a 30% reduction factor was applied in order to counterbalance the tendency of the Hargreaves - Samani model to overestimate ET_p under non-standard conditions. Therefore, climate-driven actual evapotranspiration AET_{clim} was computed by multiplying ET_p by a stress factor α (<1), reducing the potential evapotranspiration since it represents the upper limit of actual evapotranspiration.

At the sub-catchment scale the annual water budget assumes the following form:

$$P - Q - \alpha\, ET_p - W = 0 \tag{1}$$

where P [mm] is the precipitation total, Q [mm] is the streamflow volume, $\alpha\, ET_p$ is the climatic actual evapotranspiration and W is the water volume withdrawn from the catchment. We proposed to disentangle these two contributions by applying the water budget to the period 1920-1950, when water uses can be considered marginal such that $W \cong 0$ (*Zolezzi et al., 2009*). Consequently, α can be obtained by averaging Eq. (1) over the period 1920-1950:

$$\alpha = \frac{\bar{P} - \bar{Q}}{\overline{ET_p}} \tag{2}$$

where $\bar{P}$, $\bar{Q}$, $\overline{ET_p}$ are average hydrological fluxes in this period. The resulting α for the river basin closed at Trento is equal to 0.699.

The time series of P and ET_p were then aggregated over the drainage area of 4 selected sub-catchments (Adige at Trento and Bronzolo, Gadera at Mantana and Avisio at Soraga). Successively, trends of P, ET_p and Q were calculated by applying the Mann Kendall test (*Kendall, 1975*) with significance level of 0.1 and considering both annual and seasonal aggregations and a moving time window of 30 years. The width of the moving window was selected for mitigating the effects of small (temporal) scale fluctuations due to well know cyclic changes. The investigation of the uncertainty linked to the spatialization of the precipitation field revealed that the uncertainty bounds in the annual estimates of precipitation were narrow for all the investigated sub-catchments, being lower than the 1.5% of the average annual rainfall total.

The analyses evidenced temporal patterns differentiated within the river basin depending on the reciprocal strength of water uses and climate change. The attribution of the observed alterations to their main causes was made as rigorously as data availability allowed. At the headwaters positive trends in winter streamflow are detected at the gauging stations of Gadera at Mantana and Avisio at Soraga, despite an evident reduction of winter precipitation. Accurate trend attribution analysis (*Mallucci et al., submitted*) revealed that this change cannot be attributed to a shift of winter precipitation from solid to liquid, rather to a larger groundwater contribution triggered by a proportional increase of groundwater recharge in Autumn due to larger precipitations. This is the stigma of climate change, given that headwaters are only marginally impacted by agricultural activities and seasonal storage for hydropower is very limited. This effect vanishes as the drainage area increases moving downstream, with only a marginal increase of winter streamflow observed at the Bronzolo and Trento gauging stations. On the contrary, in the southern part of the river basin, decreasing winter snow is the main driver of streamflow reduction, possibly supplemented by increasing water uses in agriculture. The latter are mainly caused by an intense development of irrigated agriculture since the '70s in the drainage area of the Noce River, a tributary of the Adige. To summarize, in headwater basins the larger autumn precipitation entails increasing winter streamflow, whereas the reduction of winter snow implies decreasing summer streamflow but only at the large scale.

Acknowledgements

This research has been financially supported by the European Union 7th Framework Programme (Grant agreement no. 603629-ENV-2013-6.2.1-Globaqua).

References

Allen, R. G., Pereira L. S., Raes, D. Smith M., et al. Crop evapotranspiration guidelines for computing crop water requirements-fao irrigation and drainage paper 56, FAO (1998), Rome, 300(9), D05,109.
Beniston, M. Climatic change in mountain regions: a review of possible impacts, in Climate variability and change in high elevation regions: Past, present & future, Springer (2003), pp. 5–31.
Birsan, M.-V., Molnar, P., Burlando, P., and Pfaundler, M. Streamflow trends in Switzerland, Journal of Hydrology (2005), 314(1), 312–329.
Chiogna, G., Majone, B., Paoli, K. C., Diamantini, E., Stella, E., Mallucci, S., Lencioni, V., Zandonai, F., and Bellin, A. A review of hydrological and chemical stressors in the Adige catchment and its ecological status, Science of The Total Environment (2016), 540.
Destouni, G., Jaramillo, F., and Prieto, C. Hydroclimatic shifts driven by human water use for food and energy production, Nature Climate Change (2013), 3(3), 213–217.
Goovaerts, P. Geostatistics for natural resources evaluation, Oxford University Press on Demand (1997).
Kendall, M. Rank correlation methods (4th edn.) charles griffin (1975), San Francisco, CA, p. 8.
Mallucci, S., Majone, B., Bellin, A. Detection and attribution of hydrological changes in a large Alpine river basin, submitted to Journal of Hydrology.
Merz, B., Vorogushyn, S., Uhlemann, S., Delgado, J., Hundecha, Y. Hess opinions, More efforts and scientifc rigour are needed to attribute trends in food time series, Hydrology and Earth System Sciences (2012), 16(5):1379-87.
Pettitt, A. A non-parametric approach to the change-point problem, Applied statistics (1979), pp. 126–135.
Zolezzi, G., Bellin, A., Bruno, M., Maiolini, B., and Siviglia, A. Assessing hydrological alterations at multiple temporal scales: Adige river, italy, Water resources research (2009), 45(12).