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## MAKAHO: An interactive cartographic Tool for Trend Analysis of hydrological extremes in France

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Analysing the significance of trends in hydrological variables across different components of the streamflow regime, from low flows to high flows, provides an overview of the state of a region in the context of ongoing global changes. This information is crucial for decision-making regarding adaptation but also for evaluating hydrological projections.

MAKAHO (Mann-Kendall Analysis of Hydrological Observations) is an interactive cartographic visualization system designed to examine trends in hydrometric observations from the 232 stations belonging to the French Reference Hydrometric Network (Giuntoli et al., 2013). These stations show a high measurement quality, time series with a historical depth of over 30 years, and they crucially gauge near-natural catchments. The statistical test used for trend detection is a variant of the Mann-Kendall test accounting for first-order autocorrelation. The trend slope is provided by the Theil-Sen estimator.

The hydrological situation in France shows a marked contrast between the northern and southern regions. Between 1968 and 2020, 22 % of stations show a significantly trend in the annual maximum daily streamflow at the 90 % confidence level. Of these stations, 27 % exhibit an upward trend, with an average increase of 13 % per decade. Almost all of these stations are located in the northern part of the country.

This north-south divide is also visible for low flows, with the demarcation line extending further north. 39 % of stations show a decreasing trend in the annual minimum monthly discharge, with an average intensity of about 11 % per decade. The signal in the northern part of the country is less significant. The duration of low flows has significantly increased in the south, particularly in the southwest, with an average of more than ten days per decade, reaching almost a month in extreme cases.

The tool, developed using the R Shiny library, takes the form of an online graphical interface (<https://makaho.sk8.inrae.fr/>). It enables direct communication with the R Exstat package (<https://github.com/super-lou/EXstat>), which is essential for data aggregation and trend analysis. Calculations are performed on the fly, allowing greater customisation of analyses. MAKACHO users can choose the analysis period, the hydrological variable (from low flows to high flows), display time series for the variable of interest and extract summary sheets for a set of hydrometric stations. The interactive map and graphs allow switching from an overview to a detailed view of the results for each station. MAKACHO has been designed based on previous research projects involving stakeholders to encourage water managers to develop robust strategies for adapting to climate change and has received financial support from the French Ministry of Ecology.

Giuntoli, I., Renard, B., Vidal, J.-P., and Bard, A. (2013). Low flows in France and their relationship to large-scale climate indices. *Journal of Hydrology*, 482:105–118. <https://doi.org/10.1016/j.jhydrol.2012.12.038>