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Human impact parameterization in global hydrological models improves estimates of monthly discharges and hydrological extremes: a multi-model validation study

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Human impacts on freshwater resources and hydrological features form the core of present-day water related hazards, like flooding, droughts, water scarcity, and water quality issues. Driven by the societal and scientific needs to correctly model such water related hazards a fair amount of resources has been invested over the past decades to represent human activities and their interactions with the hydrological cycle in global hydrological models (GHMs). Use of these GHMs – including the human dimension – is widespread, especially in water resources research.

Evaluation or comparative assessments of the ability of such GHMs to represent real-world hydrological conditions are, unfortunately, however often limited to (near-)natural river basins. Such studies are, therefore, not able to test the model representation of human activities and its associated impact on estimates of freshwater resources or assessments of hydrological extremes. Studies that did perform a validation exercise – including the human dimension and looking into managed catchments – either focused only on one hydrological model, and/or incorporated only a few data points (i.e. river basins) for validation. To date, a comprehensive comparative analysis that evaluates whether and where incorporating the human dimension actually improves the performance of different GHMs with respect to their representation of real-world hydrological conditions and extremes is missing. The absence of such study limits the potential benchmarking of GHMs and their outcomes in hydrological hazard and risk assessments significantly, potentially hampering incorporation of GHMs and their modelling results in actual policy making and decision support with respect to water resources management.

To address this issue, we evaluate in this study the performance of five state-of-the-art GHMs that include anthropogenic activities in their modelling scheme, with respect to their representation of monthly discharges and hydrological extremes. To this end, we compared their monthly discharge simulations under a naturalized and a time-dependent human impact simulation, with monthly GRDC river discharge observations of 2,412 stations over the period 1971–2010. Evaluation metrics that were used to assess the performance of the GHMs included the modified Kling-Gupta Efficiency index, and its individual parameters describing the linear correlation coefficient, the bias ratio, and the variability ratio, as well as indicators for hydrological extremes (Q90, Q10).

Our results show that inclusion of anthropogenic activities in the modelling framework generally enhances the overall performance of the GHMs studied, mainly driven by bias-improvements, and to a lesser extent due to changes in modelled hydrological variability. Whilst the inclusion of anthropogenic activities takes mainly effect in the managed catchments, a significant share of the (near-)natural catchments is influenced as well. To get estimates of hydrological extremes right, especially when looking at low-flows, inclusion of human activities is paramount. Whilst high-flow estimates are mainly decreased, impact of human activities on low-flows is ambiguous, i.e. due to the relative importance of the timing of return flows and reservoir operations. Even with inclusion of the human dimension we find, nevertheless, a persistent overestimation of hydrological extremes across all models, which should be accounted for in future assessments.