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Predicting river sediment yields through a novel Bayesian hierarchical model (BaHSYM)

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Soil erosion and the consequent transport of sediments into river systems dramatically influence, among others, the lifetime of reservoirs, the health of benthic ecosystems and the transfer of organic carbon and of particle-bound contaminants. Predicting and controlling sediment yields (SY) in rivers are thus tasks of enormous importance, but they are extremely difficult owing to the complexity and variability of the involved processes. Several modelling approaches have been developed to estimate SY at different scales, ranging from empirical to physical and from lumped to spatially distributed frameworks. Nevertheless, the very powerful technique of Bayesian hierarchical models has been overlooked in this field so far. Conceptually, these models extract information more efficiently from the data by pooling it across levels and groups. In doing so, they enable producing more accurate estimates, especially for unbalanced datasets, achieving optimal trade-offs between overfitting and underfitting as well as carrying out a deeper interpretation of results' significance and uncertainty. Given that the importance of different processes controlling erosion and sediment transfer varies in space and time, we hypothesize that SY can be modelled efficiently by carrying out a partial pooling of the information across different years, different catchments or clusters of similar catchments. To test this hypothesis, we developed a Bayesian hierarchical model framework to describe and predict yearly SY (BaHSYM) and applied it to very heterogeneous river catchments. The available sample comprises 30 Austrian catchments, located mostly in alpine regions but also in lowland agricultural areas, and characterized by a broad spectrum of mean discharge (1-256 m3/s), total area (135-10660 km2) and average slope (9-61%). For all of them, data of suspended solids loads were available for the period 2009-2014. We started with a fixed-effects model and upgraded it with partial pooling over two different group levels, namely single catchments and clusters of similar catchments, which we formed through a two-step procedure composed of Principal Component Analysis and Cluster Analysis. We validated the models via the leave-one-out cross-validation procedure (LOO). With a parsimonious linear model consisting of merely four variables (specific discharge, extreme discharge, mean altitude and a coefficient based on morphometric characteristics of the catchment), good performance criteria were achieved through partial pooling for temporal prediction (R2: 0.88, NSE: 0.71, mNSE: 0.50) and for spatial prediction (R2: 0.83, NSE: 0.75, mNSE: 0.49). Such results are very promising and confirm the great potential of this technique, which goes well beyond the estimation of SY. Since this technique enables investigating simultaneously the different significance of the explanatory variables for the whole sample and for specific groups, it can be applied e.g. to the study of the selective transfer of contaminants in catchments. Further, the fact that this type of models quantifies the uncertainty not only of the results but also of each model parameter makes it a very appealing tool to build the basis for risk assessment of pollution within river basin management.