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Modelling of Environmental Change Impacts on Water Resources and Hydrological Extremes in Germany

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von
Shaochun Huang

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Summary

Water resources, in terms of quantity and quality, are significantly influenced by environmental changes, especially by climate and land use changes. Germany has experienced notable climate change during the last century, with an increase in the annual average temperature of ca. 1°C and a moderate increase in annual precipitation of 9% between 1901 and 2000. The scenarios of climate change for Germany suggest an increase in the long-term average annual temperature and winter precipitation, whereas summer precipitation is likely to decrease. Regarding land use change, the implementation of the European Water Framework Directive requires predicting water quality characteristics resulting from planned land use changes at the scale of large regional river basins. This requirement is particularly crucial for the Elbe River in Germany, which was one of the most heavily polluted rivers in Europe by 1990 and experienced significant socio-economical changes from the early 1990s. Accordingly, in the context of the potential climate and land use changes in Germany and their intimate link to water resources, the main objectives of the present study are

1. to project climate change impacts on the seasonal dynamics of water fluxes and spatial changes in water balance components, as well as the future flood and low flow conditions for the five largest river basins (upper Danube, Ems, Elbe, Rhine and Weser) in Germany
2. to evaluate impacts of potential land use changes on water quality in terms of NO_3-N load in selected sub-regions of the Elbe basin; and
3. to investigate various sources of uncertainty in the projections.

In this study, the process-based eco-hydrological model SWIM (Soil and Water Integrated Model) was applied to simulate water fluxes, floods, low flows and nitrogen dynamics for meso- to macro-scale basins in Germany. SWIM was intensively calibrated and validated in advance using observed climate data and it could satisfactorily reproduce river discharge and nitrogen load in most of the studied gauges. For example, 26 out of 29 selected gauges in Germany have NSE (Nash-Sutcliffe efficiency) higher than 0.7, and 22 gauges have LNSE (Logarithmic Nash-Sutcliffe efficiency) higher than 0.7 for the period 1961 – 2000. The NO_3-N load was also reasonably simulated by SWIM with the NSE ranging from 0.52 to 0.7 for eight selected gauges in the Elbe region.

The climate scenarios generated by different Regional Climate Models (RCMs) were carefully selected for the study. The SWIM outputs driven by STAR (STAtistical Regional model) realizations were used for evaluating changes in the mean seasonal runoff and annual water balance components by the mid of 21st century. The projected daily discharges driven by scenarios produced by other models (CCLM, Cosmo-Climate Local Model, REMO, REgional Model, and WettReg, Wetterlagenbasierte Regionalisierungsmethode) were particularly used for the flood and low flow analysis. The land use scenarios were introduced based on the political incentives at the regional level.

In addition, the long-term trends of observed temperature extremes at the climate station Potsdam were analysed as a complimentary study to climate impact assessment. An important finding of this study shows that "cold" extremes have become less frequent and less severe than in the past and "warm" extremes have become more frequent and more severe. However, many changes are rather weak and not statistically significant, as the variability of temperature indices at the Potsdam station has been very strong.

In the context of climate change, the actual evapotransipration is likely to increase in most parts of Germany, while total runoff generation may decrease in south and east regions in the scenario period 2051-2060. Water discharge in all six studied large rivers (Ems, Weser, Saale, Danube, Main and Neckar) would be 8 – 30% lower in summer and autumn compared to the reference period (1961 – 1990), and the strongest decline is expected for the Saale, Danube and Neckar. Higher winter flow is expected in all of these rivers, and the increase is most significant for the Ems (about 18%).

No general pattern of changes in flood directions can be concluded according to the results driven by different RCMs, emission scenarios and multi-realizations. The results driven by the statistical-empirical model WettReg show a declining trend in the 50-year flood level for most rivers (especially in the northern Germany) under all climate scenarios. The simulations driven by dynamic models (CCLM and REMO) give various change directions depending on region, scenario and time period. The 50-year low flow is likely to occur more frequently in western, southern and central Germany after 2061 as suggested by more than 80% of the model runs. The current low flow period (from August to September) may be extended until the late autumn at the end of this century.

Land use and land management scenarios were applied to two meso-scale sub-basins in the Elbe basin (the sub-basin Weiße Elster and Unstrut). The modelling results show that increasing areas under winter rape, higher fertilizer rates, excluding cover crops and converting pasture to agriculture land would lead to higher NO_3-N loads, whereas lower fertilizer rates, set-aside of agricultural land and planting more maize instead of winter rape would reduce the NO_3-N load. Mineral fertilizers have a much stronger effect on the NO_3-N load than organic fertilizers. Cover crops, which play an important role in the reduction of nitrate losses from fields, should be maintained on cropland. The planting area of winter rape should not be increased significantly in areas, where environmental targets are important. As another energy plant, maize has a moderate effect on the water environment.

The uncertainty in estimating future high flows and, in particular, extreme floods remain high due to different RCM structures, emission scenarios and multi-realizations. In contrast, the projection of low flows under warmer climate conditions appears to be more pronounced and consistent. The largest source of uncertainty related to NO_3-N modelling originates from the input data on the agricultural management. However, the calibration of retention parameters can compensate the uncertainty in the input data to a certain extent.

The robust conclusion of this study is that most part of Germany is likely to experience lower water availability in summer and autumn under a warmer climate. The low flow season may extend to late autumn with more severe low flow conditions in western, southern and parts of central Germany at the end of this century. The NO_3-N load in rivers is significantly influenced by the agriculture management, especially crop types and mineral fertilizers applications. Hence, an optimal agricultural management is essential for the improvement of water quality in the context of the regional development plans for future.