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Klimafolgenstudie für das DVGW-Innovationsprogramm „Zukunftsstrategie Wasser“

Summary

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Summary

Climate change impacts water balance components in Germany and, therefore, is an important driver for changes in the water sector. These include, i.e., changes in mean temperatures and the severity of heat waves, but also changes in precipitation or groundwater recharge. Consequently, potential impacts on both, future water demand and water availability, need to be investigated.

In the past, numerous studies have been conducted based on single or small numbers of climate simulations. However, selecting a single simulation means rolling the dice on a result in the uncertainty space. This has been a major contributor to the producton of different results. The selection of climate simulations affects changes in precipitation and groundwater recharge more than changes in temperature. To assess the uncertainty in simulation results, this project uses a total of 70 climate simulations, each driving the water balance model mHM . We use two emission scenarios to represent different degrees of warming: RCP 2.6, with 21 climate simulations, represents a climate change mitigation scenario ("climate protection scenario"), while in the pessimistic RCP 8.5 (“business-as-usual” scenario), with 49 simulations used, is based on very strong future greenhouse gas emissions. In these climate model data, the systematic error was removed within the Helmholtz Climate Initiative and a spatial disaggregation to 1.2 x 1.2 km² was achieved with an external drift kriging.

The results for Germany show that the climate-induced changes also under the climate protection scenario proceed approximately until the middle of the century and stabilize thereafter, while under the “business-as-usual” scenario the changes proceed until the end of the century.

Based on the median of all RCP 2.6 and RCP 8.5 simulations, the average changes by the end of the century for Germany are as follows (2069-2098 compared to 1971-2000). It remains to be noted that regionally and seasonally different as well as opposite signals can develop:

- Mean annual temperature: RCP 2.6: +1.2 °C, RCP 8.5: +3.6 °C (1971-2000: 8.6 °C)
- Heat days: RCP 2.6: +3.5 d/a, RCP 8.5: +15.5 d/a (1971-2000: 5.8 d/a)
- Summer days: RCP 2.6: +9.3 d/a, RCP 8.5: +31.4 d/a (1971-2000: 29.3 d/a)
- Annual precipitation: RCP 2.6: +5.7 %, RCP 8.5: +15.3 % (1971-2000: 793.5 mm/a)
- Winter precipitation RCP 2.6: + 5.8 %, RCP 8.5: +30.2 % (1971-2000: 180.6 mm/winter)
- Actual evapotranspiration: RCP 2.6: +3.2 %, RCP 8.5: +9.5 % (1971-2000: 505.5 mm/a)
- Groundwater recharge: RCP 2.6: +12.4 %, RCP 8.5: +31.4 % (1971-2000: 129.4 mm/a)
- Mean annual discharge: RCP 2.6: +13.7 %, RCP 8.5: +29 %
- Annual dam inflow (>50km² EZG): RCP 2.6: +3.5 %, RCP 8.5: +10.3 %
- Agricultural drought duration April-June: RCP 2.6: +3.1 d/a, RCP 8.5: -0.5 d/a (1971-2000: 15.4 d/a)
- Agricultural drought duration July-September: RCP 2.6: +2.7 d/a, RCP 8.5: +11.4 d/a (1971-2000: 15.5 d/a)

- Mean annual hydrologic drought duration: RCP 2.6: -14 d/a, RCP 8.5: -14 d/a (1971-2000:58 d/a)

The ensemble strategy used here allows for a comprehensive evaluation of both the most likely development in the context of model uncertainties (median of changes across all climate simulations in a climate scenario) and the overall range (best case / worst case considerations) of possible changes under different climate change scenarios. The median of changes across all climate simulations represents the most likely development and is thus suitable as a benchmark for climate adaptation in water supply. According to this median, terrestrial water availability (precipitation minus actual evapotranspiration) increases slightly in both climate scenarios. The evaluation of all climate simulations shows a clear trend stability for temperature. In all simulations, e.g. the annual mean temperature and the summer days increase in the ten main catchments until the end of the century. The situation is different for the development of precipitation. Here, the most likely development is an increase in annual precipitation, but some climate simulations also include future precipitation decreases. These simulations are possible, but less likely. To classify the overall ensembles, a boxplot is shown for each of the ten main catchments in Germany in chapter 3.

The number of **summer days** in the historical period 1971-2000, which is the starting point for future changes in this evaluation, are distributed differently across Germany. Summer days tend to occur more frequently in Germany in a southerly direction and, just like temperatures, are also dependent on altitude above sea level. While the mean number of summer days in the catchments Eider, Schlei-Trave and Warnow-Peene is 14.6, 17.8 and 20.1, respectively, in the Rhine the mean is 32.1. In the Alpine region and the low mountain ranges, summer days occur only sporadically. For both scenarios, an increase of summer days by an average of +6 (Eider) to +12 (Danube) is estimated for the future time slice 2021-2050. After that, there is a stabilization of the changes under RCP 2.6 and a further increase of summer days under RCP 8.5. The largest increases are expected in the Upper Rhine Graben with more than 40 additional summer days. Also in the low mountain ranges and in the alpine region, summer days will increase in the future.

The **heat days** show a similar spatial distribution as the summer days. Regions with historically relatively many heat days are the Upper Rhine Graben and southeast Brandenburg. The increase of heat days shows a strong north-south gradient, which can be explained by the tendency of a stronger temperature increase in the south of Germany in summer. In general, it should be noted that the evaluation of the heat indicators are climatological indicators (averaged over 30 years). Individual years may show a significantly larger number of heat and summer days.

In general, it is shown that the **annual precipitation sum** also increases slightly with advancing warming. In the ensemble median under RCP 2.6 an increase of +4.5 % (Danube, Rhine) to +6.8 % (Odra river) is expected until 2050, after which inconsistent and only slight changes occur. In contrast, for the scenario RCP 8.5 an increase of the mean annual precipitation totals by about 11 % (Meuse) to almost 20 % in the Oder and Warnow-Peene catchment in the future time slice 2069-2098.

The precipitation changes are seasonally very different. In **summer**, the strongest median precipitation decreases are shown under the RCP 8.5 scenario of about -7 % (Rhine) to 9 % (Meuse) and slight increases in the Oder area of about -7 %. In **winter**, median precipitation increases are expected across all simulations. Under RCP 8.5, these increases are strongest at the Meuse (+27 %) and Warnow-Peene (+33 %) catchments.

In recent years, the increase in **evapotranspiration** has been discussed as the main driver of water balance change in Germany. Using the example of the Elbe catchment under RCP 8.5 until the end of the century, it is shown that the increase in actual evapotranspiration aET (+51 mm/a) simulated with mHM is less pronounced than PET (+61 mm/a). The aET has been essentially energy-limited in Germany in the past. However, with decreasing summer precipitation under climate change and more strongly drying soils in the vegetation period II (July-September), a water limitation of evaporation occurs increasingly in the future. Furthermore, it can be seen that the future annual atmospheric balance P-aET is positive in all considered catchments and thus terrestrially a slightly higher water availability will occur in the future.

As with winter precipitation, the median **annual groundwater recharge** increases with warming over 30-year periods, but the overall changes are small. In addition to the increase in precipitation, the decrease in frost and ice days also leads to higher infiltration. The changes calculated here on 30-year time periods represents average conditions. The extent to which multi-year groundwater recharge droughts could occur was not examined.

In the climate protection scenario RCP 2.6 as well as in the pessimistic business-as-usual scenario RCP 8.5, the **mean annual discharge** increases over all ten main catchments in Germany. Thereby, the discharge tends to increase with increasing temperatures in the median, whereby a spatial gradient is recognizable. While slight regional decreases can be seen in the southwest, the strongest increases in mean annual runoff are achieved in the northeast of Germany. Seasonally, this spatial gradient is also visible, especially in summer in the southwest with partly significantly decreasing discharges under strong climate change until the end of the century. In contrast, an area-wide increase in runoff is expected in winter. One possible explanation is the decrease in frost and ice days and the associated decrease in water storage in the form of snow cover. The results also show increasing median **annual reservoir inflows** with increasing warming. Again, for most reservoirs the overall range of ensembles includes simulations with decreasing annual reservoir inflows in the future, which is possible but not likely.

The changes in the **annual hydrological drought duration** under the climate protection scenario are negative in the median with low trend stability, while under the pessimistic business-as-usual scenario a clear prolongation of the days below the low water threshold is observed in southwestern Germany and a clear decrease in the northeast by the end of the century. This spatial pattern is found even more pronounced in summer, while the hydrological drought duration in the winter months is decreasing in all catchments. The change in **annual hydrological drought intensities** is small and decreasing in the climate protection scenario in the future. Only over the Rhine and Meuse basins, median annual low water deficits increase over the ensemble by the end of the century under the pessimistic business-as-usual scenario. These annual changes in hydrological drought intensity are driven by increases in summer and autumn, which are also reflected in the mean over the Danube catchment. In the growing season I from April to June, the changes in mean **agricultural drought duration** are small and not trend stable in both climate scenarios. A possible explanation lies in the opposing trends of increasing spring precipitation and simultaneously increasing temperatures. In contrast, in the vegetation period II from July to September, a stronger drying of the topsoil and a prolongation of the median agricultural drought duration are regularly observed until the end of the century in the pessimistic business-as-usual scenario. Regionally, only parts of the of the north-eastern part of Germany are excluded.

The **agricultural drought intensity** is a dimensionless measure to estimate the severity of a drought. The calculation includes the length of the drought period in two-year periods and the absolute drought as a negative deviation of the 20th percentile over time. The comparison of the two-year agricultural drought events shows that under both climate scenarios, greater intensities occur in the future over the total area of Germany. Furthermore, these occur more frequently and are more pronounced under the business-as-usual scenario. Overall, therefore, the probability of biennial drought events with greater intensities increases in Germany with increasing warming.

The **ratio of groundwater recharge to total runoff** changes little in both the annual and seasonal evaluations, with a slight shift toward surface runoff.

A condensed overview of results for this project was provided in **Marx et al (2022)**:

A. Marx, F. Boeing, and L. Samaniego. Zur Entwicklung des Wasserdargebotes im Kontext des Klimawandels: Ergebnisse des Forschungsprojekts „UFZ-Klimafolgenstudie“ für das DVGW Zukunftsprogramm Wasser. pages 16–21, Aug. 2022. https://www.dvgw.de/medien/dvgw/forschung/berichte/2208marx.pdf

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