Climate Change Impact on Water Resources Explorer

While adaptation to changing water resources due to climate change is necessary everywhere, information about their potential future changes has not been easily accessible to most climate change adaptation processes. The interactive web application Climate Change Impact of Water Resources (CCIWR) Explorer presents the output of a multi-model ensemble (MME) of global hydrological models. It covers all land areas of the globe except Antarctica, based on a state-of-the-art MME of global hydrological models that was generated using the ISIMIP3b protocol (Gosling et al. 2024).

The Explorer provides state-of-the-art information suitable for supporting local to regional participatory climate change adaptation processes around the world. The CCIWR Explorer is unique in that it may support decisions on climate change adaptation that take stakeholder risk aversion into account. Not only does it show the projected MME median future change in total water resources, groundwater resources, and evapotranspiration, either in the four seasons or annually, it also shows which fraction of the ensemble members project a change that stakeholders consider to be hazardous. Two map views as well as "Local Insights", percentile boxes showing the range of future changes in individual 0.5° grid cells, are provided.

In the following, the CCIWR Explorer is described; a short **tutorial** helps the users to familiarize themselves with its usage.

Citation

The CCIWR Explorer has been developed by AGEOCE in collaboration with the Goethe University Frankfurt.

When using the CCIWR Explorer, please include the following citation:

Attard, G., Müller, L., Bardonnet, J., Kneier, F., Döll, P. (2025) Explorer for Climate Change Impact on Water Resources, Version 1.0,
available from https://ee-gwp.projects.earthengine.app/view/cciwr-explorer.

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1 What type of information is provided by the CCIWR Explorer?

The web application visualizes potential future changes in water resources under three greenhouse gas emissions scenarios: low emissions (SSP1-2.6), high emissions (SSP3-7.0), and very high emissions (SSP5-8.5). For more information regarding representative concentration pathways, the reader may refer to this article. Table 1 gives an overview of the information provided.

Table 1: Data presented by the CCIWR Explorer as obtained from ISIMIP3b (Gosling et al., 2024). All combinations of variables, season, future time period, and greenhouse gas emissions scenario are provided, where each relative change is quantified by a GHM MME of (a maximum of) 20 ensemble members (4 global hydrological models x 5 global climate models). Each global hydrological model is driven by the bias-adjusted output of five global climate models.

Variables	Total water resources, groundwater recharge, actual evapotranspiration
Annual or seasonal aggregation	Annual, December to February, March to May, June to August, September to November
Percent changes from 1985-2014 until	2016-2045, 2041-2070, 2071-2100
Greenhouse gas emissions scenarios	SSP1-2.6 (low), SSP3-7.0 (high), SSP5-8.5 (very high)
Global climate models	mpi-esm-2-hr, ukesm1-0-ll, mri-esm2-0, gfdl-esm4, ipsl-cm6a-lr
Global hydrological models	JULES-ES-VN6P3, WaterGAP 2.2e, CWatM, MIROC-INTEG-LAND

For the reference period (1985–2014), the impact of temporally varying water use and artificial reservoirs is considered. However, in simulations for 2015–2100, direct human impacts on water resources and land cover are held constant at 2015 levels. This ensures that changes between the reference and future periods reflect climate change impacts only (see Table 2.3 of ISIMIP3b Protocol). The Explorer provides relative changes between the reference period and three future 30-year periods (Table 1).

The application presents changes in three key variables across 0.5° x 0.5° grid cells (~55 km x 55 km at the equator):

1. **Total water resources**: Total runoff (**qtot**).
2. **Groundwater resources**: Diffuse groundwater recharge (**qr**, except **qrd** for the WaterGAP global hydrological model),
3. **Actual evapotranspiration**: Total evapotranspiration (**evap-total**).

For each grid cell, the projected relative changes in these variables, computed by up to 20 multi-model ensemble (MME) members, are visualized. The MME was generated by driving four global hydrological models (Table 1) with bias-adjusted outputs from five global climate models (Table 1). While the three GHMs WaterGAP 2.2e, CWatM, and MIROC-INTEG-LAND provided all three variables, JULES-ES-VN6P3 did not provide diffuse groundwater recharge. Each GHM had been driven by the bias-adjusted output of five CMIP6 global climate models, each of which had computed climate variables impacted by three greenhouse gas emission (or rather concentration) scenarios (Table 1). To avoid large relative changes arising from very small absolute values, an MME member is excluded from the MME if its variable value for the reference period is smaller than 5 mm/year for the yearly analysis and 1 mm/season for the seasonal analysis.

Model output data were downloaded from the ISIMIP repository. For the reference period 1985-2014, the experiments with the specifier “historical_histsoc_default” were selected, and for the period 2015-2100 the experiments with the specifiers “ssp12670_2015soc-from-histsoc_default”, “ssp370_2015soc-from-histsoc_default”, and “ssp585_2015soc-from-histsoc_default” (https://www.isimip.org/outputdata/). This results in a maximum of 20 MME members (in short “models”) for each of the three greenhouse gas emissions scenarios.

2 How is the information provided?

The MME of projected changes is presented in the form of 1) global maps and 2) percentile box plots for a selected grid cell (“Local Insights”). The latter is displayed when clicking on a specific grid cell on the global maps. The user selects the contents of the maps and the Local Insights diagram using the interface on the left-hand side of the screen. To find locations on the maps, you can increase the transparency of the layers by clicking on “Layers” and moving the slider, and you can type in the location name in the search bar in the header. For optimal identifiability of the change classes, set transparency to zero.

🗺️ **Global map showing the median change**: This global map describes the median relative change of a variable of interest, for a given SSP, projection period, and seasonality.

🗺️ **Global map showing the share of models exceeding a threshold**: This global map describes the percentage of MME members (here: “models”) for which the relative change of the variable exceeds a certain value defined by the user. For example, select “below” and “-20%” if you wish to see the fraction of MME members that project a decrease of more than 20%. Or select “above” and “10%” to show the fraction of MME members that project an increase of more than 10%.

📈 **Local Insight plots**: They present percentile boxes with projected changes in a grid cell (selected by the user) between the periods 1985-2014 and the three future periods. The percentile boxes show the distribution of projected changes of a variable across the MME (Müller and Döll, 2024). They display the 10th, 30th, 50th (median), 70th, and 90th percentiles of the changes (Figure 1). For example, if the 10th percentile (P10) equals -25%, then 90% of the MME members compute a change that is larger than -25%, and 10% a change that is smaller than -25%, i.e., a decrease of more than 25%. The number of included MME members is indicated at the bottom of the plot. You can enlarge the graph by clicking on (icon) and then download either the graph in png or svg format, or as csv text file that lists the exact percentage changes that more than 10% (P10), 30% (P30), 50% (median P50), 70% (P70) and 90% of all “models” (ensemble members) exceed.

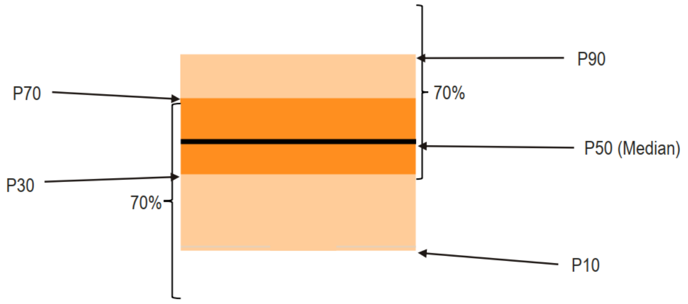

Figure 1: Schematic of a percentile box

3 How is the provided information best utilized for informing local climate change adaptation processes?

Climate change adaptation is challenging due to the large uncertainties about the future. These uncertainties need to be embraced and not neglected when executing (participatory) climate change adaptation processes (Döll and Romero-Lankao 2017).

To support participatory processes for climate change adaptation concerning water resources, e.g., in a city or county, we recommend downloading the percentile box plots for the grid cell that contains the location of interest. Regarding the three provided variables, we suggest selecting at least the variable total water resources and its long-term changes on annual and seasonal time scales.

If groundwater resources are important for human water supply, or if they are a source of streamflow — particularly during the dry season — and thus relevant to the well-being of river biota, we recommend analyzing changes in annual groundwater resources. Changes in seasonal groundwater resources are relevant in the case of small aquifers with low water storage capacity. Changes in actual evapotranspiration can help to understand the impact of climate change on vegetation. As potential evapotranspiration will increase in the future, a decrease in actual evapotranspiration indicates stress for the vegetation.

In a participatory climate change adaptation process, selected percentile box plots should be presented to the stakeholders (Müller and Döll 2024). This helps the stakeholders identify the future changes they wish to adapt to, depending on their risk aversion. For example, in the case of a high risk aversion towards reduced water availability, they may want to adapt to the P10 change of groundwater resources (e.g., -25%), while they may want to adapt to the P30 change (e.g., -15%) in the case of a moderate risk aversion.

The range of potential future changes can also serve as an input to local water resources management models that combine the range of changes with local information on, e.g., water demand (Kneier et al. 2021) or the acceptance of certain adaptation measures (Müller et al. 2024).

4 Tutorial

To familiarize yourself with the usage of the CCIWR Explorer, we suggest finalizing two tasks with questions to determine whether you can extract the correct information. You may complete the tutorial in an interactive online version available at

https://fkneier.github.io/Tutorial-for-CCIWR-Explorer/.

Alternatively, you may note your answers to the eight questions and then compare them to the correct answers provided at the end of this document.

Task 1: Explore how renewable groundwater resources in Central America, particularly in Honduras, El Salvador, and Nicaragua, are expected to change in the future. How are renewable groundwater resources (i.e., mean annual/yearly groundwater recharge) projected to change between 1985-2014 and 2041-2070 under the high-emissions scenario SSP 3 (RCP 7.0)? What impact would climate change mitigation have, i.e., if the low-emissions scenario SSP1 (RCP2.6) were to become a reality?
To find locations on the map, you can adjust the transparency of the layers by clicking on "Layers" and moving the slider.

1.1 Considering the median of the simulated changes, climate change mitigation (i.e., SSP1-2.6) is projected to lead to a smaller decrease in renewable groundwater resources than SSP3-7.0) in this region. Yes or no?

1.2 Under the high-emissions scenario SSP 3 (RCP 7.0), more than 80% of all "models" (i.e., ensemble members) project a decrease in renewable groundwater resources by more than 50% in most of the region. Yes or no?

1.3 Under the high-emissions scenario SSP 3 (RCP 7.0), more than 80% of all "models" (i.e., ensemble members) project a decrease in renewable groundwater resources across most of the region. Yes or no?

Task 2: Explore future changes in total runoff in Ulaanbataar, the capital of Mongolia.

2.1 Under the very-high-emissions scenario SSP 5 (RCP 8.5),
30% of all ensemble members project a decrease in the yearly total runoff until the period 2041-2070 of more than x%. 18% or 27%?

50% of all ensemble members predict either a decrease or an increase of up to x%. 8% or 13%?

2.2 How does this change when considering total runoff in the summer (JJA)?
30% of all ensemble members project a decrease in the total summer runoff until the period 2041-2070 of more than x%. 24% or 33%?

50% of all ensemble members predict either an increase of more than 7% or a decrease of more than 7% (?)

2.3 Does the range of projected summer runoff changes (i.e., the projection uncertainty) decrease for the period 2071-2100 as compared to the period 2041-2070? Yes or no?

Data sources and license

The CCIWR Explorer is made available through a Google Earth Engine App built in the context of an academic research project. The usage of this explorer shall respect Google Earth Engine Terms of Service. In particular, the commercial use of the explorer is prohibited.

The underlying data can be delivered under a commercial license according to your specifications (NetCDF, GeoTIFF, Zarr).

Contact

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References

- Döll, P., Romero-Lankao, P. (2017): How to embrace uncertainty in participatory climate change risk management – A roadmap. Earth`s Future, 5, 18-36. https://doi.org/10.1002/2016EF000411
- Gosling S. N., Müller Schmied H., Bradley A., Burek P., Gedney N., Grillakis M., Guillaumot L., Hanasaki N., Ito A., Kou-Giesbrecht S., Koutroulis A., Nishina K., Otta K., Sahu R.-K., Satoh Y., Schewe J. (2024): ISIMIP3b Simulation Data from the Global Water Sector (v1.3). ISIMIP Repository. https://doi.org/10.48364/ISIMIP.230418.3
- Müller, L., Czymai, M., Blättel-Mink, B., Döll, P. (2024): How to assess conditions for the acceptance of climate change adaptation measures by applying implementation probability Bayesian Networks in participatory processes. Environmental Modelling & Software 181: 106188. https://doi.org/10.1016/j.envsoft.2024.106188.
- Müller, L., and Döll, P. (2024): Quantifying and communicating uncertain climate change hazards in participatory climate change adaptation processes. Geosci. Commun., 7/2, 121–144. https://doi.org/10.5194/gc-7-121-2024
- Kneier, F., Woltersdorf, L., Peiris, T.A., Döll, P. (2023): Participatory Bayesian Network modeling of climate change risks and adaptation regarding water supply: Integration of multi-model ensemble hazard estimates and local expert knowledge. Environmental Modelling and Software, 168, 105764. https://doi.org/10.1016/j.envsoft.2023.105764.

Correct answers in tutorial

1.1: yes, 1.2: no; 1.3: yes; 2.1: 18%/8%, 2.2: 24%/a decrease of more than 7%; 2.3: no