Impact of Climate Change on the Hydraulic Risk Downstream the Eugui Dam (Northern Spain) Quantifying Flood Losses

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ABSTRACT

Floods are expected to increase in frequency and magnitude on average in Europe (Alfieri et al., 2015). Therefore, hydrological dam safety may also decrease in the future, as floods are the main hydrological load in dams. In a previous study, the impact of climate change on expected maxima reservoir water levels was quantified at the Eugui Dam (Spain). However, this study focuses on the impact of climate change on the outflow discharges at the Eugui Dam (Spain), also quantifying the expected changes in direct flood losses in buildings in the Metropolitan Area of Pamplona located downstream of the dam.

1. Data and Case Study

The case study is the River Arga that crosses the city of Pamplona in Northern Spain with a catchment area of about 510 km^2. The Eugui Dam is upstream Pamplona with a catchment area of about 69 km^2 (Figure 1).

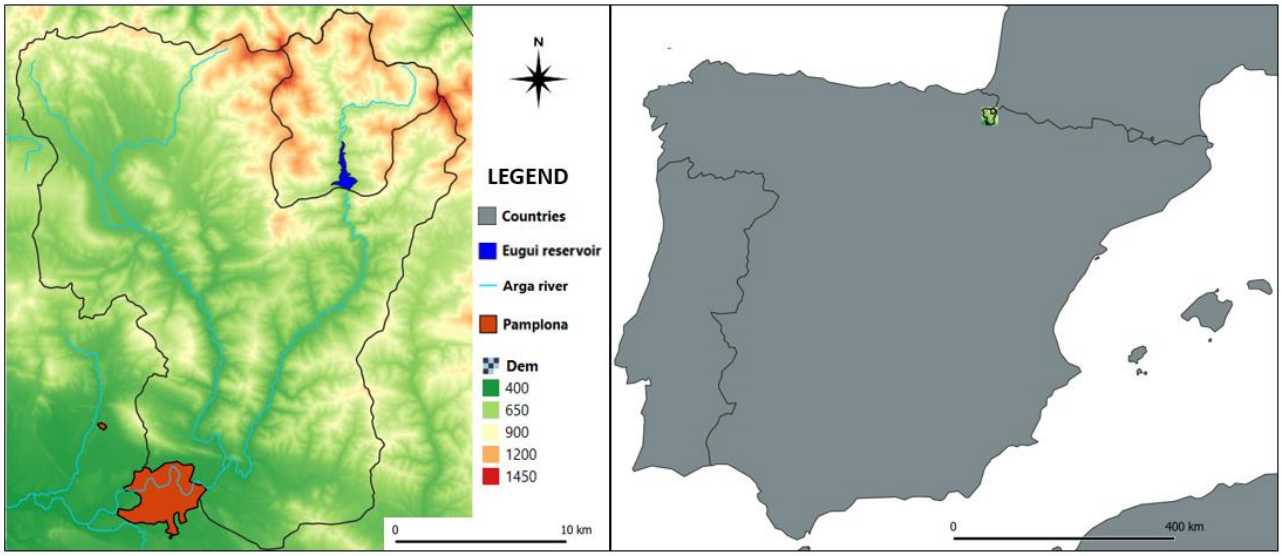

Fig. 1. a) River Arga catchment upstream to the city of Pamplona in Northern Spain and Eugui reservoir in its river catchment. b) Location of the River Arga catchment in Spain.

Rainfall, temperature and streamflow data in the period with observations (13 years) were used for the calibration of the hydrological model (see next section). Climate projections of rainfall and temperature are supplied by 12 climate models (Garijo and Mediero, 2019) in two emission scenario (RCP 4.5 and RCP 8.5) and three time windows (2011-2040, 2041-2070, and 2071-2100).

2. Methodology

The methodology is divided into six parts: i) estimates of expected inflow hydrographs in the Eugui Reservoir in the future; ii) assessment of the impact of climate change on expected initial reservoir water levels at the beginning of flood events in the future; iii) stochastic procedure to combine the probabilities of inflow hydrographs and initial reservoir water levels in the future, simulating flood routing in the Eugui Reservoir;

iv) assessment of the uncertainty sources in the procedure; v) two-dimensional (2D) hydrodynamic modelling of fluvial floods generated by the River Arga in Pamplona; and vi) assessment of flood damages in Pamplona.

Expected changes in flood quantiles for the River Arga in Pamplona were obtained in Lompi et al. (2021), using climate projections as input data of the RIBS event-based and fully-distributed hydrological model (Garrote and Bras 1995a). Daily reservoir water levels expected in the future are obtained combining the HBV continuous hydrological model, to simulate future daily inflow discharges in the Eugui Dam, with a reservoir operation model, to obtain daily outflow discharges and reservoir water levels. The HBV model (Bergstrom 1992) and the reservoir operation model are calibrated with 13 years of observations. The minimum number of simulations required to reach a given threshold (Th) in the model error is obtained. Th is measured with two objective functions: (i) Reff for HBV, that measures the model efficiency (Th>0.85, as a perfect calibration corresponds to a Reff value equal to one), and (ii) Root Mean Squared Error (RMSE) for the reservoir operation model (Th<1.5 m, as a perfect calibration corresponds to an RMSE value equal to zero).

The stochastic procedure generates 10.000 random initial reservoir water levels and inflow hydrographs with a 15-minute time step for each scenario. Flood routing in the reservoir is simulated using the Volumetric Evaluation Method (VEM), obtaining 10.000 maxima reservoir water levels and outflow discharges. Delta changes of maximum outflow discharge quantiles are considered as the ratio between the outflow peak discharges in the future and in the control period for a given return period. Delta changes greater than one will point to an increase in expected outflow discharges in the future. Uncertainty in estimates of rainfall delta changes, inflow hydrographs supplied by the RIBS model, and reservoir water levels, associated to HBV model biases, are considered. The uncertainty chain assessment provides the median values of the future outflow discharges with its confidence interval represented by six percentiles (5th-95th, 10th-90th, and 32th-68th).

The median values of expected maxima outflow discharges released by the dam in the future are summed to the expected natural contribution of the part of the River Arga catchment located downstream the dam, which is obtained with the RIBS model, for all the scenarios. Moreover, flood waves that travel from the dam to the city of Pamplona are routed with the Muskingum model. Water depths in the Pamplona Metropolitan Area are simulated with the 2D IBER hydrodynamic model (Bladé et al., 2014), that uses the inflow hydrographs by the Ulzama and Arga rivers upstream Pamplona. Finally, direct flood losses in buildings in Pamplona are estimated by using the SaferPlaces Platform (Mediero et al., 2022).

3. Results and discussion

The results show an increase in the expected maxima outflow discharges released by the dam in the future due to the lamination of more increase inflow event in the future. Particularly, delta changes of maxima reservoir water levels are greater than one for all the return periods in the RCP 8.5, considering the ensemble of all the climate models, pointing to a decrease in the hydrological dam safety. Therefore, the results highlight an increase of the hydraulic risk in the future in the RCP 8.5, especially at the end of the century. These results are mainly driven by an increase in the overtopping probabilities for such a scenario, where seven of the 12 climate models have an overtopping return period below 1000 years.

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