Potential impacts of climate change on hydrology and water resources of the Tâmega River, Portugal

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The Tâmega River watershed is shown as a case study that illustrates the challenges presented by integrated regional assessment of climate change scenarios in a large watershed in northern Portugal. Results are evaluated by comparing simulated hydrologic scenarios derived from both observational climate databases for a recent past period (1950–2015) and EURO-CORDEX model simulations for the future (2021–2100). Future climate change scenarios are based on an ensemble of five climate model chain experiments and on two Representative Concentration Pathways (RCP4.5 and RCP8.5). A reconstruction of flowrates within the entire Tâmega River catchment and for the historical period is accomplished, which is particularly useful when observed data is missing. The projected climate change impacts on annual flowrates show a decrease from 18% to 28% relative to observations (70.9 m^3 s^{-1}).

Very high resolution (~1 km) of daily mean, minimum and maximum temperatures over mainland Portugal (PT.TG.HRES, PT.TN.HRES and PT.TX.HRES) over the baseline period of 1950–2015 were retrieved for the Tâmega River catchment (Fonseca and Santos, 2018). Daily precipitation totals (PT02 database) provided by the Portuguese Weather Service (Instituto Português do Mar e da Atmosfera – IPMA, www.ipma.pt) are accessible for Portugal for a period of 1950–2003. Daily streamflow data, were collected at four hydrometric stations, from the Sistema Nacional de Informação de Recursos Hídricos (SNIRH, www.snirh.pt). Climatic datasets from a five-member ensemble of GCM-RCM chain simulations (Table 1), calculated within the framework of the EURO-CORDEX project, were retrieved for the development of climate change projections. The climatic data were then used as input in the Hydrological Simulation Program FORTRAN (HSPF) model, to assess future daily flowrates at the four available hydrometric station in the Tâmega River. The hydrological model (HSPF) is an integrated part of the environmental analysis system: Better Assessment Science Integrating Point and Non-point Sources (BASINS), which is designed to perform water quantity and quality based studies (Bicknell et al., 2001). The verification of the model performance was undertaken by three statistical metrics: Deviation Runoff (Dv), Nash-Sutcliffe efficiency coefficient (E) (Nash and Sutcliffe, 1970) and the Coefficient of Determination (R^2).

Daily hydrographs for the recent-past period (1950–2015) were analised. They show the information on the observed, calibrated and validated data as well as the reconstruction of the flowrates for the entire period. Daily hydrographs at all hydrometric stations show quite satisfactory agreements between observed and simulated flowrates, as confirmed by the daily values of the statistical criteria (Table 2).

The climate change signals of the annual mean precipitation (RR), mean (TG), minimum (TN) and maximum (TX) air temperatures in the Tâmega River catchment, for the period of 2021–2100 and under both RCP scenarios, were created. In general, both RCPs show precipitation decreases over most of the watershed, mainly under RCP8.5. Annual mean temperatures vary from 10 to 15 ºC, with warmer temperatures at the River mouth (lowest elevation). Future scenarios show an increase of up to 3.5 ºC under RCP8.5. For the future scenarios, strong upward trends are displayed, more pronounced for TN in the northern half of the basin (up to 3 ºC) and for TX in its southern half (up to 3.5 ºC), also accompanied by a noticeable increase along the river streamline. The result scenarios hint at a significant decrease in the mean annual flowrate (–17.5% for RCP4.5 and –27.6% for RCP8.5). Temperature increases between 10 % and 22 % and evaporation between 12 % and 23 %, while annual mean precipitation shows a slight decrease over the years (–7% and –13% for RCP4.5 and RCP8.5, respectively). Additionally, there is a very high correlation between precipitation and flowrate, with R^2 of 97%, 85% and 93% for baseline, RCP4.5 and RCP8.5, respectively. The global perspective shows a decrease in the annual flowrates, though an increase is observed in winter, particularly in January and February, while clear downward trends are simulated for summer and autumn. Similar studies reported increases of winter and early spring runoffs, accompanied by decreases in summer runoff, except for basins were massive snowmelt is synchronized with late spring flowrate peaks (Cunderlik and Simonovic, 2005; Eckhardt and Ulbrich, 2003; Loukas et al., 2002).

In the present study, the spatial-temporal changes of meteorological and hydrological variables and the linkage between surface runoff and precipitation/temperature over the Tâmega River catchment were addressed. The annual precipitation over the Tâmega River catchment exhibit weakly decreasing trends across the entire future period. Temperatures, on the other hand, show consistently warming trends throughout the watershed for the future period, with a mean warming rate of 0.03ºC per year for maximum temperature (TX) and of 0.01ºC per year for minimum temperature (TN), resulting in a mean annual flowrate decreased at all hydrometric stations by about 0.25 $m^3 s^{-1}$ per year. The results achieved here were also reported in similar basin-scale modelling studies of impacts of climate change on hydrology (Krysanova et al., 2017; Skoulikaris and Ganoulis, 2011; Yu and Wang, 2009). The outcomes of this study should to be considered as indicative of the expected future, providing guidelines rather than accurate predictions. Still, future water resources availability in the catchment may be under strong pressure to meet water security in the region under climate change, particularly during the dry season (summer half of the year).

Table 1. Integrated General Circulation Models (GCMs) with Regional Climate Models (RCMs) used to assess climate change impacts on Tâmega River hydrology.

GCMs	RCMs	Institution
CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4-8-17	CLMcom
CNRM-CERFACS-CNRM-CM5	SMHI- RCA4	SMHI
MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17	CLMcom
MPI-M-MPI-ESM-LR	SMHI- RCA4	SMHI
ICHEC-EC-EARTH	DMI-HIRHAM5	DMI

Table 2. Statistical criteria values of the deviation of volumes (Dv), R-squared (R^2) and Nash-Sutcliffe coefficient of efficiency (E) for the calibration and validation of daily flowrate at the four hydrometric stations in Tâmega watershed.

Calibration	Dv (%)	R^2 (%)	E
HydroS1 (1957-1980)	-10.4	82.5	0.83
HydroS2 (1985-2000)	9.7	75.2	0.83
HydroS3 (1955-1970)	-6.8	91.8	0.92
HydroS4 (1988-2000)	-3.1	79.8	0.85
Validation			
HydroS1 (1981-2011)	10.3	71.9	0.71
HydroS2 (2001-2011)	-9.9	88.3	0.85
HydroS3 (1972-1987)	5.6	71.7	0.72
HydroS4 (2001-2014)	-9.4	85.7	0.89

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References

Fonseca A, Santos J. High-Resolution Temperature Datasets in Portugal from a Geostatistical Approach: Variability and Extremes. Journal of Applied Meteorology and Climatology 2018; 57: 627-644.

Bicknell BR, Imhoff JC, Kittle Jr JL, Jobes TH, Donigian Jr AS, Johanson R. Hydrological simulation program-Fortran: HSPF version 12 user’s manual. AQUA TERRA Consultants, Mountain View, California 2001.

Cunderlik JM, Simonovic SP. Hydrological extremes in a southwestern Ontario river basin under future climate conditions/Extrêmes hydrologiques dans un basin versant du sud-ouest de l'Ontario sous conditions climatiques futures. Hydrological Sciences Journal 2005; 50.

Eckhardt K, Ulbrich U. Potential impacts of climate change on groundwater recharge and streamflow in a central European low mountain range. Journal of Hydrology 2003; 284: 244-252.

Krysanova V, Vetter T, Eisner S, Huang S, Pechlivanidis I, Strauch M, et al. Intercomparison of regional-scale hydrological models and climate change impacts projected for 12 large river basins worldwide—a synthesis. Environmental Research Letters 2017; 12: 105002.

Skoulikaris C, Ganoulis J. Assessing climate change impacts at river basin scale by integrating global circulation models with regional hydrological simulations. Eur Water 2011; 34: 53-60.

Yu PS, Wang YC. Impact of climate change on hydrological processes over a basin scale in northern Taiwan. Hydrological Processes: An International Journal 2009; 23: 3556-3568.