Assessing uncertainty in the hydroclimatic modelling chain by using hydroinformatics platforms with varying complexity

Milan Stojković[*], Dragana Obradović[*], Nikola Milivojević[*]

[*] Institute for the development of water resources "Jaroslav Černi", Department of hydrology and applied informatics, Beograd, Serbia

milan.stojkovic@jcerni.co.rs, dragana.obradovic989@gmail.com, nikola.milivojevic@gmail.com

***Abstract*— Uncertainty in hydrological modeling has played a significant role in assessing the impacts of climate change on water resources. The considerable uncertainty in the predicted streamflows is more likely lies in climatic modelling depending on the chosen Global Climate Models (GCMs) and Regional Climate Models (RCMs), choice of the bias correction method, the assumed initial and boundary conditions, the chosen greenhouse gas emission scenarios and scenarios of future socio-economic development. Also, there are uncertainties related to the hydrological modeling scheme caused by input hydrological data, hydrological model structures and parameterization of hydrological model. In this research, the uncertainties the projected streamflows due to climate change are addressed by the direct variance method since this technique is capable for assessing different sources of uncertainties nested into the hydroclimatic modelling chain. In the case of climatic modelling four RCMs are used to derive inputs for hydrological models at river basin spatial scale under different greenhouse gasses emission scenarios. Namely, the RCP 4.5 and 8.5 pathways are used for this purpose. For hydrological modelling, the Precipitation-Runoff Modeling System (PRSM) and the 3DNet Catch hydrological model are applied. The research is carried out for the Lim River basin, while the simulations covered the 2011-2040 time frame with respect to the bassline time period 1961-1990.**

I. Introduction

A notion "uncertainty" is considered as a lack of reliable input data and incomplete knowledge regarding climatic and hydrological systems due to their natural complexity and variability [5]. The reducing individual uncertainties in climate simulations and the subsequent hydrological simulations represent major challenges since the impact modeling chain propagates modeling errors directly in streamflows.

However, it seems that uncertainties in hydrological projections cannot be significantly reduced at present [7], although it is possible that some uncertainty can be reduced in future by modelling improvements [4]. At this moment, evaluating and quantifying uncertainties in hydrological response due to climate change are imposed as an adequate solution to target specific areas where uncertainty is large but potentially reducible [4]. Hence, the information regarding individual contribution of uncertainty within hydroclimatic modelling is an important issue, which can facilitate decision-making process in certain river basin.

The assessment uncertainty in hydrological projections under climate change is commonly achieved by addressing uncertainties in the impact modeling chain. The modelling chain consists of different elements such as the selection of Global Climate Models (GCM) and Regional Climate Models (RCMs), the selection of downscaling models and the selection of hydrological model [6]. The considerable uncertainty in the predicted streamflows is more likely lies in climatic modelling depending on the selection of GCMs and RCMs, choice of the bias correction method, the assumed initial and boundary conditions, the chosen greenhouse gas emission scenarios and scenarios of future socio-economic development [5]. Also, there are uncertainties related to the hydrological modeling scheme caused by lack of reliable information needed for hydrological calibration, hydrological model structures and parameterization of hydrological model.

This implies that ignoring one of the uncertainty sources may cause great risk in domain of water resource planning and management [7, 10, 3, 2]. Also, uncertainty sources have not yet been clearly evaluated in most previous studies due to different regional characteristics of the river basins. For this reason, this study aims (1) to establish a framework for assessing uncertainty in the modelling chain for a future time frame in the Lim River Basin in Serbia, (2) to quantify the most dominant sources of uncertainties (i.e. emission scenarios, regional climate models, hydrological models), especially the contribution from hydrological models since it has not been addressed, and (3) to determine future hydrological changes for the considered river basin.

For this purpose, four regional climate models, two greenhouse gas emission scenarios and the two hydrological modes are used. In terms of hydrological modelling, the Precipitation-Runoff Modeling System (PRSM) [1] and the 3DNet Catch hydrological model [9] are be applied. The aforementioned hydrological models have distributed parameters with a physical connotation, which aims at evaluating the hydrological response of various combinations of climate and land use data. Any difference in the results from the three models will be predominantly due to inherent differences in the model structure, rather than input data.

II. HYDROCLIMATIC MODELING CHAIN

The study is performed for the Lim River basin upstream of the Prijepolje hydrological station that covers area of 3160 km^2. The Lim River represents the biggest tributary to the Drina River. Immediately downstream of the town of Prijepolje is the location of the storage lake used by the "Potpeć" hydropower plant.

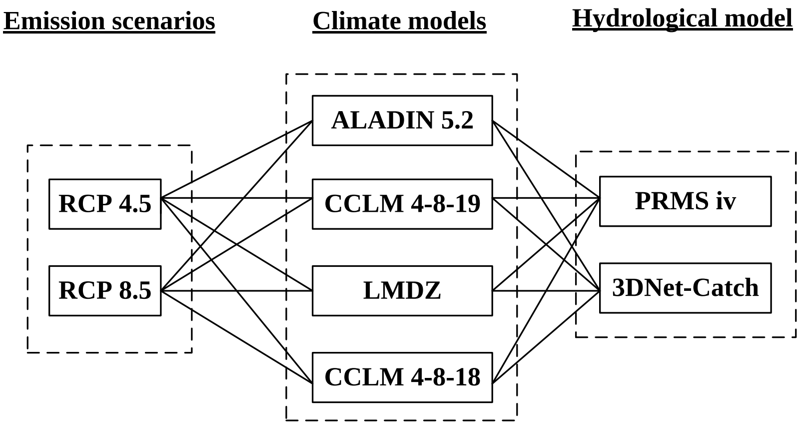

Figure 1. Framework of the impact modelling chain.

As can be seen from Figure 1, the impact modeling chain is composed of two emission scenarios, two hydrological models and four climate models. The aim of climate modelling in the impact modelling chain is to create plausible climate change scenarios for most important climate driver for the Lim River basin. Then, the climatic projections are used as the input for hydrologic simulations so as to estimate hydroclimatic ensembles for the aforementioned river basin.

For the purpose of climate modelling, the climate sets from four RCMs are used, namely, ALADIN 5.2, CCLM 4-8-19, LMDZ, CCLM 4-8-18 which have horizontal spatial resolution of 0.44°[11]. The climatic data sets are simulated in the baseline years 1961– 1990 and in the future time frame 2011–2040 under two emission scenarios of representative concentration pathways (RCP) of RCP 4.5 and RCP 8.5.

To prepare the climatic data sets for hydrological simulations a statistical bias correction is used. Namely, daily precipitation and temperature is match with the records at climatic stations within the Lim River basin for the baseline period. In this manner, the corrective functions are formed and applied to the outputs of climate modelling separately for each climatic station for the future time frame.

The assessment of the impact of climate changes upon water resources is based upon the application of a hydrologic models by the use of derivates from climate modeling. Particularly, daily precipitation as well as minimum and maximum daily temperature obtained from GCMs are used as the input signals for hydrologic simulations. Subsequently, the input climate parameters for the hydrologic models are projected on the river basin spatial scale by application of multiply RCMs.

For hydrological modelling, two hydroinformatics platforms are employed. Particularly, the Precipitation-Runoff Modeling System (PRSM) [1] and the 3DNet Catch [9] with inputs from climate modelling are apply for the Lim River Basin.

The former hydrological model is integrated into the Object Modeling System, whereas the FORTRAN modules have been ported on the Java programming language in order to facilitate their easier integration, scalability, portability and use with other models and model components. The latter one is developed on a GIS-oriented platform called 3DNet associated with hydrologic modules. The hydrological model is implemented in C++ which warrants fast computations and enables simulations with minimum data requirements. One should note that both hydrological models are a deterministic with distributed parameters with a physical connotation, which aims at evaluating the hydrological response of various combinations of climate and land use data.

III. EVALUATING AND QUANTIFYING UNCERTAINTIES

The hydroclimate modeling chain for projecting the possible changes in daily flows consists of three types of elements: emission scenarios, climate modelling and hydrological modelling. Considering this, 8 data sets are formed for the baseline period and 16 impact modeling chain combinations are determined for the projected period 2011-2040 under RCP 4.5 and RCP 8.5 emission scenarios.

To assess the contribution from separate elements of uncertainties in the hydroclimatic modelling chain, the direct variance method is used since it can assess the contribution of a separate modeling chain element by varying the samples of this element and calculating the variance according to the ensemble of the projected changes in a particular hydrological variable [7].

For each data sets the flow duration curve Q_d are assessed during the baseline period 1961-1990 and the future time frame 2011-2040. Then, it is calculated the climate change signal Y_d [8]:

$$Y_d = Q_d^{bas} - Q_d^{fut} \qquad (1)$$

where Q_d^{bas} and Q_d^{fut} represent the flow duration curve for the baseline period and the future time frame.

The climate change signal of the daily streamflows Y_d is illustrated as $Y_d^{i,j,k}$ where subscriptions represents i, j and k represent the indices for emission scenarios, hydrological models and climate models, respectively.

The variances of Y_d considering multiply sources of uncertainties are estimated in the following way [7]:

$$VAR_{emision\ scenarios} = \frac{1}{I-1}\sum_{i=1}^{2}(\bar{Y}^{i,0,0} - \bar{Y}^{0,0,0})^2 \qquad (2)$$

$$VAR_{hydrologal\ model} = \frac{1}{J-1}\sum_{i=1}^{2}(\bar{Y}^{0,j,0} - \bar{Y}^{0,0,0})^2 \qquad (3)$$

$$VAR_{climate\ model} = \frac{1}{K-1}\sum_{i=1}^{2}(\bar{Y}^{0,0,k} - \bar{Y}^{0,0,0})^2 \qquad (4)$$

where $\bar{Y}^{i,0,0}$, $\bar{Y}^{0,j,0}$, $\bar{Y}^{0,0,k}$ and $\bar{Y}^{0,0,0}$ are the mean values of the samples of the climate change signal Y_d for emission scenarios, hydrological models, climate models and the total ensembles, respectively.

Having been determined the variances from previous equations, contribution ratios of uncertainty sources considered can be estimated as follows [7]:

$$f_{emision\ scenarios} = \frac{VAR_{emision\ scenarios}}{Total\ varinace} \quad (5)$$

$$f_{hydrologal\ model} = \frac{VAR_{emision\ scenarios}}{Total\ varinace} \quad (6)$$

$$f_{climate\ model} = \frac{VAR_{emision\ scenarios}}{Total\ varinace} \quad (7)$$

where $f_{emision\ scenarios}$, $f_{hydrologal\ model}$ and $f_{climate\ model}$ are the corresponding uncertainty contribution ratios for emission scenarios, hydrological models, climate models, respectively. The contribution ratios are between 0 and 1 refer as to a contribution of 0% and 100% to the total uncertainty, respectively.

IV. Results

The research is carried out for the Lim River basin, while the simulations covered the 2011-2040 time frame with respect to the bassline time period 1961-1990. For the purpose of climate modelling, four reginal climate models within global climate models are used under RCP4.5 and RCP 8.5 climate scenario.

to +11.3% and from -8.3% to +11% for RCP4.5 and RCP 8.5, respectively.

Changes in intra-annual distribution of precipitation and increase in temperature lead to a change in hydrologic projections in two forms:

(1) Changes in intra-annual streamflow distribution,

(2) Changes in multi-annual streamflow pattern.

During the future period 2011-2040 can be expected the changes in flows at annual level within a range from -16% to +15.8% relate to the base period. The relative changes in the median of daily flows for the future time frame (2011-2040) with respect to observed period (1961-1990) are given in Table 1, together for both hydrological models based on climate data derived from four climate models.

One should note that the changes in flow pattern are more pronounced during seasons, with an emphasis on the winter and summer seasons when can be expected an increase and decrease of flows, respectively.

The results from hydrological modelling (the duration curves of simulated daily flows) by using PRMS and Catch model are given at Figure 2 and Figure 3 for the baseline period 1961-1990 and for the future time frame 2011-2040, respectively.

Based on duration curves of daily flows for the baseline and future period it is estimated the climate change signal.

TABLE I. THE RELATIVE CHANGES IN THE MEDIAN OF DAILY FLOWS FOR THE FUTURE TIME FRAME (2011-2040) WITH RESPECT TO OBSERVED PERIOD (1961-1990).

Emission scenario	RCP4.5	RCP4.5	RCP4.5	RCP4.5	RCP8.5	RCP8.5	RCP8.5	RCP8.5
RCM	CM5	CM	IPSL-CM5A-MR	MPI-ESM-LR	CM5	CM	IPSL-CM5A-MR	MPI-ESM-LR
PRMS	-9.0%	8.6%	-7.8%	10.1%	-11.4%	9.1%	-6.8%	-13.4%
Catch	-6.1%	10.8%	-6.3%	15.8%	-5.3%	14.1%	-6.7%	-16.0%

RCMs suggest a temperature increase within the Lim River basin for all seasons during the 2011-2040 period. The increase in the median of annual temperature is in the range from 1.7^{0}C to 2.5^{0}C and from 1.8^{0}C to 3.2^{0}C for RCP4.5 and RCP 8.5, respectively. The change precipitation in the future is relatively small at annual level and more pronounce at seasonal time scale. The changes in the median annual precipitation is in the range from -11%

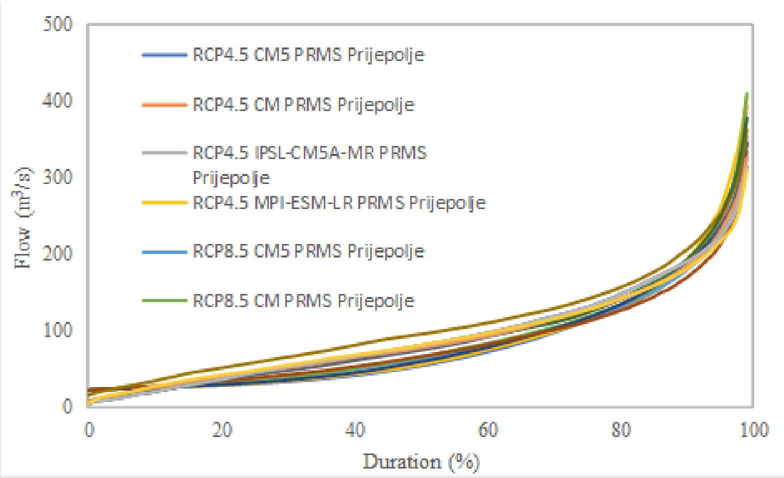

Figure 2. Duration curves of daily flows for the Prijepolje hydrological station over the baseline period (1961-1990).

Such signal is used to assess the contribution from separate elements of uncertainties in the hydroclimatic modelling chain by the direct variance method. The predominant uncertainty source among the three modeling chain elements is climate models with 78% of the total uncertainty. Hydrological models are the second most important uncertainty source since it explains 12% of the total uncertainty. Emission scenarios contribute with 10% of the total uncertainty as the least important uncertainty source after climate and hydrological models.

V. Conclusion

We have investigated the hydrological response due to climate change based on the four different RCMs, two hydrological models and two emission scenarios. The Lime River basin is chosen to test the proposed framework for assessing the uncertainty from different sources. The considerable uncertainty in the predicted streamflows is in climatic modelling depending on the selection RCMs. Hence, the projected streamflows should be taken with caution in the water management plans and studies.

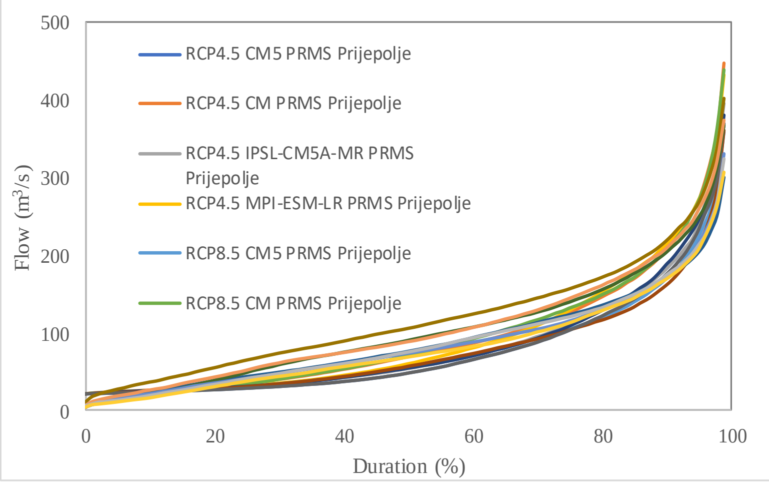

Figure 3. Duration curves of daily flows for the Prijepolje hydrological station over the future period (2011-2040).

Despite the large uncertainties in projecting hydrological variables, most modeling ensemble members show an increase in winter streamflows, and a decrease in summer streamflows. One should note that the results possess a few limitations since they are based on ensembles of small number of members. In the future research we will address additional sources of uncertainty. Our results are not directly transferable to the river basins with different morphological, hydrological and climate characteristics, but the presented framework can be applied to other regions.

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REFERENCES

[1] Markstrom SL. 2015. PRMS-IV, the precipitation-runoff modeling system, version 4. U.S. Geological Survey Techniques and Methods, book 6, chap. B7

[2] Mockler, EM et al. 2016. Assessing the relative importance of parameter and forcing uncertainty and their interactions in conceptual hydrological model simulations. *Advances in Water Resources*. 97: 299-313

[3] Wilby RL, Harris I. 2006. A framework for assessing uncertainties in climate change impacts: Low flow scenarios for the River Themes, UK. *Water Resource Research*. 42, W02419.

[4] Kay AL, Davies HN, Bell VA, Jones RG. 2009. Comparison of uncertainty sources for climate change impacts: flood frequency in England. *Climatic Change*. 92:41–63.

[5] Kundzewicza Z.W., Krysanovad V., Benestadb R.E., Hovb O, Piniewskic M. Ottod I.M. 2018. Uncertainty in climate change impacts on water resources. *Environmental Science and Policy* 79: 1–8

[6] Mandal S., Simonovic S. 2017. Quantification of uncertainty in the assessment of future streamflow under changing climate conditions. *Hydrological Processes*. 31:2076–2094.

[7] Yuan F et al. 2017. Assessing the relative importance of parameter and forcing uncertainty and their interactions in conceptual hydrological model simulations. *Journal of Hydrology* 554 (2017) 434–450

[8] Bosshard T at al. 2013. Quantifying uncertainty sources in an ensemble of hydrological climate-impact projections. *Water Resources Research*, 49: 1523–1536

[9] Stanić M, Todorović A, Vasilić Ž, Plavšić J. 2017. Extreme flood reconstruction by using the 3DNet platform for hydrological modelling. *Journal of Hydroinformatics*. DOI: 10.2166/hydro.2017.050

[10] Lee MH, Bae DHB, 2016. Uncertainty assessment of future high and low flow projections according to climate downscaling and hydrological models. *Procedia Engineering* 154: 617-623.

[11] World Bank, 2017, Support to Water Resources Management in the Drina River Basin http://www.wb-drinaproject.com/index.php/en/