WATER MANAGEMENT ON TOPLICA RIVER IN CHANGING CLIMATE

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UDK: 556:551.583
DOI:10.14415/konferencijaGFS2017.075

Summary: *It is expected that the future climate changes will affect the water balance components in the river catchments, verily causing changes in water regime. This will also have implications on water supply, irrigation systems, renewable energy sources, industrial production as well as whole ecosystems, therefore it is crucial to quantify those changes. IPCC CO_2 emission scenarios and used climate models forms different possible future meteorological conditions on Toplica river catchment. Hydrological projections are obtained by forcing the HBV model with the precipitation and temperature data of an atmosphere-ocean coupled regional climate model RCM-SEEVCCC, run with two global climate models, ECHAM5 and its previous version SINTEX-G, under the A1B IPCC/SRES scenario. In addition to these simulations, hydrological simulations run by bias corrected results of the ECHAM5/RCM-SEEVCCC for A2 scenario and CMCC-CM/NMMB model for the new IPCC scenario RCP8.5 are done as well. The impact of different scenarios and their implications on Toplica river water management are presented in this paper.*

Keywords: *climate change, water management, Toplica*

1. INTRODUCTION

Water management planners are facing considerable uncertainties on future demand and availability of water. Climate change and its potential hydrological effects are increasingly contributing to this uncertainty. The increasing trend in temperature over the past decades is likely to continue during the 21st century [1]. With this warming, precipitation characteristics are also expected to change [2]; more precipitation is expected to fall in the form of extreme events. This will lead to a more vigorous hydrological cycle, with changes in precipitation and evapotranspiration rates regionally variable. These changes will in turn affect water availability and runoff and thus may affect the rivers discharge regime. The potential effects on discharge extremes that determine the design of water management regulations and structures are of particular concern, since changes in extremes may be larger than changes in average figures.

For an adequate management of the water resources it is important to understand the pattern how temperature and precipitation will change and how the basin will respond. Different climate scenarios, applied in climate projections, are represented with different

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storylines that embody our potential future practices. They make varying assumptions regarding future global population growth, technological development, globalization, and societal values. Better understanding how the water balance fluxes will change in the future is possible if we force the same hydrological model with precipitation and temperature data obtained with different combination of the global and regional climate models and different emission scenarios.
Hydrological projections for Toplica river basin were simulated with the lumped IHMS/HBV model with daily time step. The river discharge is obtained from HBV simulations with the results of an atmosphere-ocean coupled regional climate model RCM-SEEVCCC, run with two global climate models, ECHAM5 and its previous version SINTEX-G, under the A1B IPCC/SRES scenario [3]. In addition to these simulations, hydrological simulations run by bias corrected results of the ECHAM5/RCM-SEEVCCC for A2 scenario and CMCC-CM/NMMB model for the new IPCC scenario RCP8.5 are done as well. Defined scenarios are used to force climate models that enable assessment of possible changes of climate conditions depending on the chosen scenario. In regard to GHG concentration, A1B is characterized as “medium” and A2 as “strong” scenario, while the RCP8.5 scenario exceeds both of them.
The objective of this paper is to investigate how two “strong” emission scenarios and used models will define possible climate change impact on water regime and water resources on Toplica River. It is expected that the changes in the climate data will affect the water balance components in the catchment, verily causing changes in water regime and have implications on water supply, irrigation systems, renewable energy sources, industrial production as well as whole ecosystems, so it is important to quantify these changes.

2. METHODS

CASE STUDY AND DATA Toplica River originates under the highest peaks of Kopaonik Mountain. Untouched nature, numerous hot springs with different temperatures and mineral compositions, preserve its water quality. Seasonal runoff variation is one of the main reason why the accumulation Selova is built there. The accumulation will provide better water supply of the surrounding settlements, flood protection and make water available for irrigation and hydropower production.
The catchment of Toplica River covers the area of 2231 km^2. The mean areal elevation of the catchment is 720 m a.s.l. Cultivated crops dominate the areas under 800 m a.s.l. while the forests are predominant on more elevated areas. Data from the two meteorological stations Niš (202 m a.s.l.) and Kuršumlija (382 m a.s.l.), in period from January 1985 to January 2010, are used in the study. The discharge data from hydrological station Doljevac are available for the same period. The water regime of the rivers in the southern part of Serbia is mostly driven by the snow accumulation and snowmelt. Big seasonal differences are present between winter/spring and summer/autumn mean monthly discharge values. The mean annual runoff is more than 20 % of mean annual precipitation. Average discharge at hydrological station Doljevac is 8.36 m^3/s that corresponds to 118 mm/year of runoff. The average yearly maximum discharge is 92.2 m^3/s.
CLIMATE MODELS Global climate models are the best tools to make future climate projections according to emission scenarios. Due to their coarse spatial resolution, they

can hardly be used in impact-oriented studies, therefore a downscaling procedure is necessary. A commonly used downscaling approach is a high-resolution limited-area model nested in the global model. This approach allows many detailed physical parameterizations in regional climate models (RCM) to simulate local weather and climate events. In this study two regional climate models, RCM-SEEVCCC and NMMB, are used for dynamical downscaling of global data obtained with ECHAM5 and CMCC-CM global climate models.

RCM-SEEVCCC is fully coupled atmospheric-ocean regional climate model. Its atmospheric part is version of NCEP's Eta model (Figure 1). Ocean part of the model is Princeton ocean Model (POM). The coupling between the atmospheric and oceanic part is done explicitly, in a way that models exchange heat and momentum fluxes and sea surface temperature (SST) on every atmospheric physics time step [4][5].

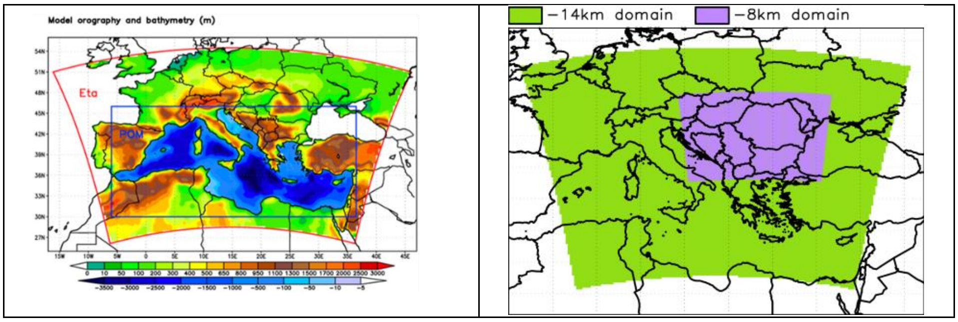


Figure 1: Model domains: RCM-SEEVCCC model (left) and NMMB model (right)

The unified Non-hydrostatic Multi-scale Model (NMMB) developed at NCEP [6] can be run both as a global and as a regional model. In addition, there is a possibility to run model in a global setup with several on-line nested regional domains, which can be stationary or moving depending on user choice.

Combinations of global and regional models, as well as applied emission scenarios are given in Table 1, together with time periods and resolution of the climate projections. Prior the application of the data in hydrological simulations, outputs from regional climate models are bias corrected.

Table 1: Climate models, emission scenarios, time periods and resolution applied for climate projections

Regional climate model	Simulation code	Global clim. model	Emission scenarios	Time periods	Resolution of the model
RCM-SEEVCCC	RCM-SEE-A2	ECHAM5	A2	1971-2100	25 km
NMMB	NMMB-RCP8.5	CMCC-CM	RCP8.5	1971-2100	8 km

HYDROLOGIC MODEL Hydrological model IHMS-HBV [7] is conceptual rainfall-runoff model, composed of smaller number of modules for the transformation of the rainfall to runoff. The model is widely used for the assessment of climate change impact on the water regime in many countries [8][9]. The model functions as a set of modules that perform interpolation of meteorological data, calculate snow accumulation and snowmelt, calculate the actual evapotranspiration, account the soil moisture, determine the volume of runoff and transform it to the discharge hydrograph. Temporally, IHMS-HBV is continuous hydrologic model; spatially, semi-distributed model. The model is horizontally distributed into subbasins, vertically to subzones with vegetation types and position of lakes.

The input data to the model are observed daily values of precipitation, average daily air temperature and mean monthly values of potential evapotranspiration. The air temperature is used for the calculation of the snow accumulation and snowmelt. The values of potential evapotranspiration are averaged monthly values that are transformed into daily values depending of the soil moisture. The basin characteristics are presented with total area, hypsometric curve and the distribution of the vegetation types. The model is adapted to specific catchments through a process of calibration and it estimates a range of water balance states in addition to the final output from the model, the river runoff.

The model for Toplica River is designed as simple single basin model with outlet at Doljevac. Input data for the area-elevation distribution are obtained from ASTER Global Digital Elevation Model [10], while the land cover data are used from the Global Land Cover 2000 Project [11]. Daily input data are provided for two meteorological station: Kuršumlija and Niš. The calibration was undertaken to satisfy best possible Nash-Sutcliffe efficiency value also with the effort to achieve a minimum volume bias in both the calibration period and the total observation period, in order to promote a stable model water balance over the full simulation period (Table 2).

Table 2: Calibration and verification results

Calibration period 1996-2009 Verification period 1985-1995	calibration		verification	
	Nash-Sutcliffe efficiency criterion	accumulated difference (mm)	Nash-Sutcliffe efficiency criterion	accumulated difference (mm)
Toplica River	0.74	-1.03	0.68	-182

IHMS/HBV model simulates the discharge for the same periods as climate models in Table 1. At the beginning of the every period one year is used for the spin-up of the model.

3. RESULTS AND DISSCUSION

CLIMATE PROJECTIONS

The projections obtained with NMMB model according to RCP8.5 emission scenario, indicate that annual temperature will increase from 2˚C to 6˚C till the end of the century, compared to period from 1971 to 2000; for the RCM-SEEVCCC model and A2 scenario the change is likely to be from 0.5˚C to 4˚C.

The increase of annual precipitation is expected for the period 2011-2041 for both models and scenarios. The maximum increase of 18% is expected for A2 scenario and RCM-SEEVCCC model, while the minimum increase of 6% is expected according to the simulations with NMMB model. It can be also expected decrease of precipitation up to -12% later during the century. The RCM-SEEVCCC model shows moderate decrease compared to NMMB model (Figure 2).

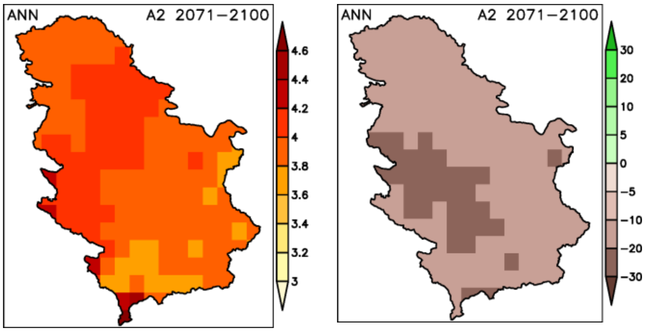


Figure 2: Maps of annual temperature (˚C, left) and precipitation change (%, right) for the period 2071–2100 with respect to 1971–2000 for RCM-SEEVCCC model projections with ECHAM5 A2

Seasonally, projections with RCM-SEEVCCC model give the highest temperature increase in summer season, up to 5°C till the end of the century. According to the NMMB model the increase in temperature, up to 7 degrees, could be expected during winter season (Figure 3).

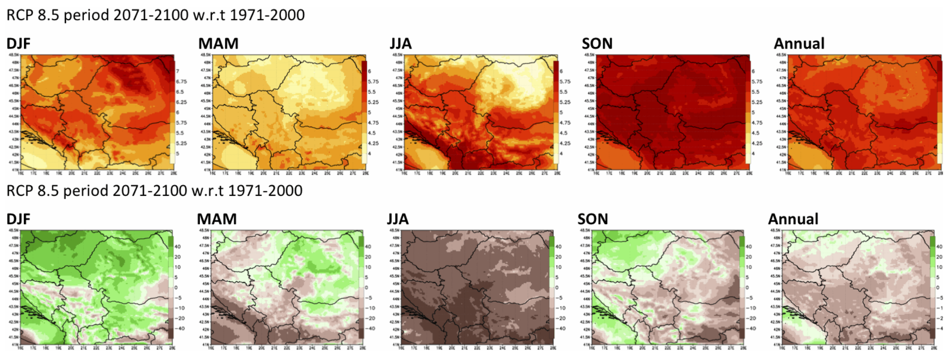


Figure 3: Maps of seasonal temperature (˚C, upper) and precipitation change (%, lower) for the period 2071–2100 with respect to 1971–2000; NMMB-RCP8.5

There is no clear agreement between models and scenarios regarding precipitation change in near future. The precipitation change depends on chosen model, climate scenario and location. Two extreme seasons could be expected till the end of the century: summer as extremely dry with precipitation decrease up to -20% and -40%, and winter as wetter season with the precipitation increase up to 20% and 40%, according to RCM-SEEVCCC and NMMB model respectively [11].

HYDROLOGIC PROJECTIONS FOR TOPLICA RIVER

The hydrologic projections indicate the positive change in runoff for period from 2012-2041 for both RCM-SEE-A2 and NMMB-RCP8.5 compared to reference period from 1971-2000. The changes are +66% and +15%, respectively. For period from 2041-2071, NMMB-RCP8.5 project negative flow change for -9%, while the RCM-SEE-A2 still projects positive change of +23%. The discharge, according to the projections for the distant future, will have negative change for -18% for RCM-SEE-A2, and -38% for NMMB-RCP8.5. The RCM-SEEVCC with ECHAM5 and SINTEX-G as global models and under A1B scenario is also projecting negative discharge for -10% in average for period from 2071-2100 (Figure 4).

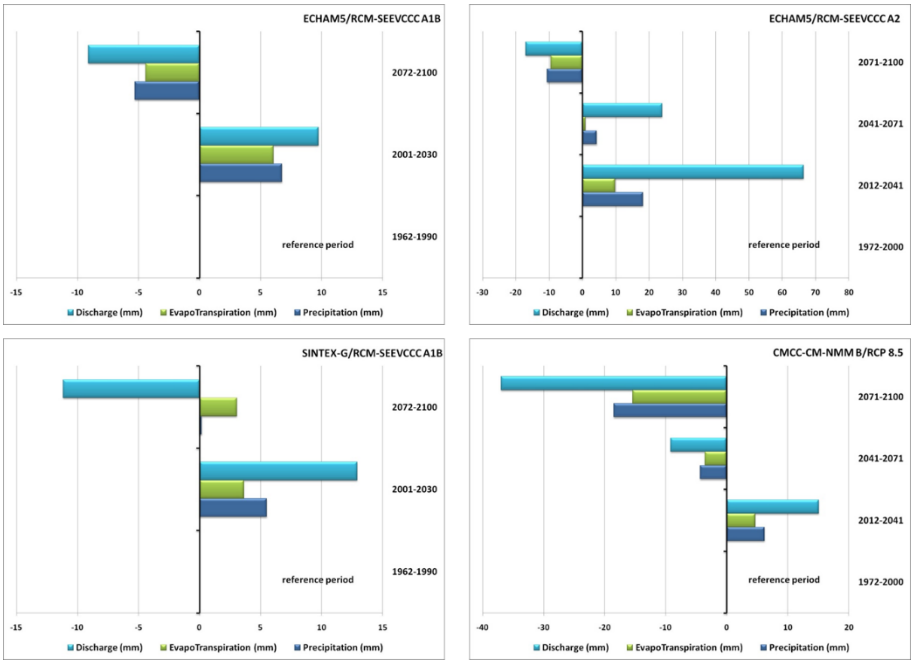


Figure 4: Water balance change (%) for different combinations of global and regional models and emission scenarios for Toplica River; compared to reference period

If we want understand how the precipitation distribution will change in time, we should analyse climate indices for the meteorological stations used in hydrologic model of the analysed river basin. For station Kuršumlija, the annual maximum number of five consecutive wet days will not change significantly in the future, but the amount of the rain for those 5 days will moderate increase from 72 to 90 mm of rain in period from 2011-2040. It will vary from 80 to 100 mm in period from 2041-2070 and then stay on 85 mm.

Also there is notable change in the sum of the daily precipitation amounts exceeding 95th percentile. That sum is 136 mm of rainfall for present period, but will likely increase up to 195 in the next 30 years. In the period from 2041-2070 it will vary from 158 to 200 mm, and from 133 to 177 mm in last 30 years of this century (Figure 5).
At the end of the century, for all combinations of the model and scenarios, the Rx5day indices will be in range from 78 to 93 mm of rain for five consecutive days. The R95p index is the greatest for RCM-SEE-A2, 177.93 mm, and the lowest, 133.62 mm of rainfall, for NMMB-RCP8.5 (Figure 5).

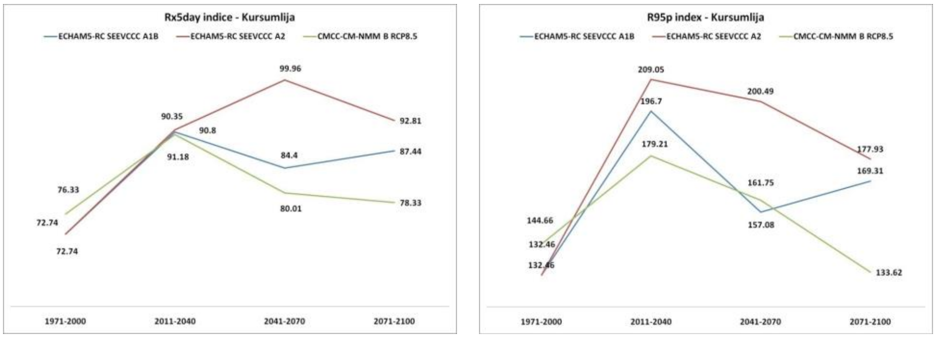


Figure 5: Rx5day indices and R95p index for RCM-SEE-A2 and NMMB-RCP8.5 for all climate periods

In the near-future period, both RCM-SEE-A2 and NMMB-RCP8.5 indicate the increase of the mean seasonal discharge. For the period from 2041-2071, the mean seasonal flow will increase for all seasons except for summer, and in last future period both agrees that autumn and summer will have decrease in seasonal discharge (Figure 6).

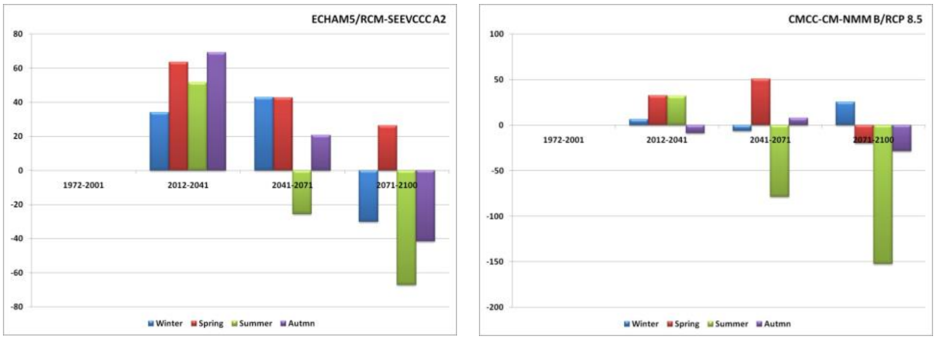
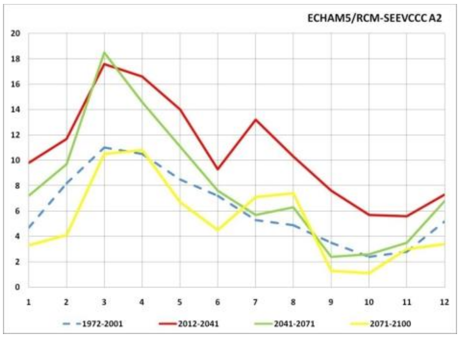


Figure 6: The change of the mean seasonal flow for RCM-SEE-A2 and NMMB-RCP8.5 (%) compared to referent period

Interannual distribution of the mean monthly discharge can be seen on Figure 7.



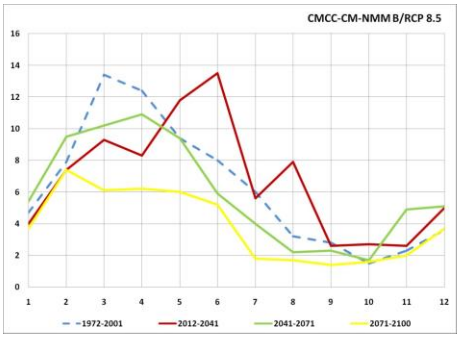


Figure 7: Mean monthly discharge for RCM-SEE-A2 and NMMB-RCP8.5 (m^3/s) for all climate periods

4. CONCLUSIONS AND RECOMMENDATIONS

IMPACT ON WATER MANAGEMENT In the future, accumulation Selova will be important source of drinking water, water for industry and irrigation and will face the climate change impact. If we recognize those changes, there will be enough time to adapt and mitigate.

Water supply: The flow distribution on Toplica River mainly depend on the snow accumulation and snowmelt on the basin. The snow is bringing fresh water during spring to the accumulation and change in snowcover can have strong implications on water supply. According to all climate scenarios and model combinations, it is expected that most of the precipitation during winter at the end of the century will fall as rainfall due to the increase of the temperature during winter.

Flood defence: Sudden snowmelt caused by south wind or sudden rainfall amounts on the snow cover can produce flash floods and bring huge amounts of water to the accumulation in the early spring. In the future, according to the climate projection, we can expect that those events become more frequent.

Hydropower energy: In the past, feasibility studies have relied on historical rainfall and river flow data for the assessment of hydroelectric potential at a proposed site. However, climate change means that these can no longer be relied on to indicate future potential. Changes in the quantity and timing of river runoff, together with increased reservoir evaporation will have a number of effects on the production of hydroelectric power. If we want to quantify the potential change in hydro energy production in the future periods, we need to analyse the annual monthly mean discharge distribution. Analysing the most pessimistic scenarios, we can say that they agreed on the spring discharge increase in period from 2011 till 2070, increase in summer discharge till 2041 and after that significant decrease till the end of the century. There is an unclear signal what will happen with the autumn’s discharge values.

Irrigation: The accumulation is very important for the irrigation of the fields and orchards. The Toplica County has big potentials in orcharding and cattle production, and that will be enabled with good irrigation management. The water quality is also very important. It can be disturbed with the intensive soil erosion and water pollution.

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УПРАВЉАЊЕ ВОДАМА РЕКЕ ТОПЛИЦА У УСЛОВИМА МОГУЋЕ ПРОМЕНЕ КЛИМЕ

Резиме: *Очекује се да ће климатске промене имати утицаја на компоненте водног биланса речног слива а које ће се огледати кроз промену режима течења. Промене је потребно квантификовати због њиховог утицаја на водоснадбевање, наводњавање, коришћење хидроенергије као и на екосистем слива у целини. Различити IPCC сценарији емисије* CO_2 *и климатски модели формирају различите могуће метеоролошке услове на сливу реке Топлица. Хидролошке пројекције су* *симулиране HBV моделом са падавинама и температурама добијеним из RCM-SEEVCCC/ ECHAM5 и RCM-SEEVCCC/SINTEX-G климатских модела по A1B IPCC/SRES сценарију као и ECHAM5/RCM-SEEVCCC модела и A2 сценарија. Анализиран је и утицај новог IPCC RCP8.5 сценарија коришћењем CMCC-CM/NMMB климатских модела. У раду су приказани утицаји које би ови климатски сценарији имали на управљање водама овог слива у будућности.*

Кључне речи: *климатске промене, слив, Топлица*