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PROJECTED CHANGES OF EXTREME RUNOFF CHARACTERISTICS UNDER CLIMATE CHANGE CONDITIONS – CASE STUDY FOR A CENTRAL/EASTERN EUROPEAN CATCHMENT

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1. INTRODUCTION

Regional climatological conditions play key roles in the different processes of the whole hydrological cycle, especially, in runoff. Therefore, projected regional climate change, e.g., temporal and/or spatial changes of precipitation, are very likely to substantially modify the hydrological processes in the future. These projected changes may result in various natural, environmental and socio-economic hazards (e.g., floods, landslides, droughts, water scarcity, sustainability of food production, etc). In order to decrease the overall exposure to such potential future problems, it is essential to estimate and evaluate future climatic trends on regional and sub-regional scales and prepare detailed assessments of hydrologic responses with special focus on runoff extremes. This study aims to contribute to this general goal with analysis of climate change impacts on runoff extremes (both high and low) over a relatively small catchment area, called Zagyva-Tarna, located in the northern part of Central Hungary (Fig. 1).

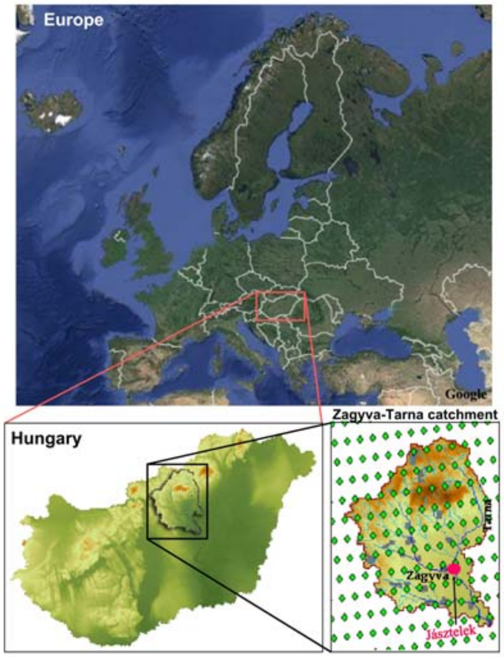

Fig. 1: Topography and geographical location of the basin of study.

The total length of the Zagyva river is 179.4 km; the whole ~5676 km^2 large catchment can be found completely in Hungary. The investigated domain shows complex topography with mountainous and hilly regions as well, as lowlands. Thus, the annual mean precipitation varies from 500 mm to 750 mm, whereas the annual mean temperature is between 7 °C and 10.5 °C. The flood wave propagation is relatively fast due to the steepness (it is located in the region of the Mátra mountain, where the highest point – 1014 m – of Hungary can be found). Meanwhile, small streams often dry out and apart from floods, the water transportation is small. Flood risk in this subregion is higher than the average in the country; several severe flood events occurred in the past 75 years, e.g., in 1940, 1941, 1969, 1974, 1975, 1979, and 2010. Therefore, in order to manage the potential threats associated with floods, it might be necessary to build more water reservoirs in this area (KÖTIKÖVIZIG, 2015). We aim to analyze whether such actions are needed under the future climatic conditions.

2. METHODOLOGY AND THE APPLIED MODELS

In this section we present the main steps of the analysis (Fig. 2), the applied climatological and hydrological models. In the framework of this study, first of all, we implemented the DIstributed WAtershed (DIWA) hydrological model for the Zagyva-Tarna catchment taking into account earlier experiences for the Upper-Tisza basin (Pongrácz et al., 2013). After that, calibration of model DIWA for a 2-year-long period (1999–2001) and validation for a 14-year-long period (1990–2003) were carried out for Jásztelek, using historical meteorological and runoff data.

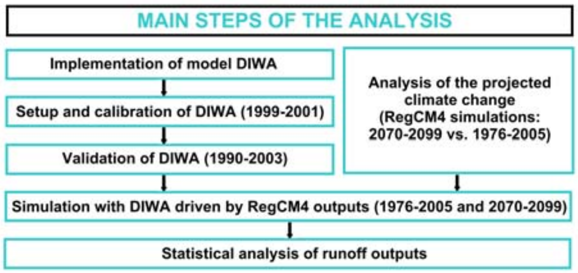

Fig. 2: Main steps of the analysis.

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In the meanwhile, we analyzed the projected climate change for the target area. For this purpose outputs of the RegCM4 regional climate model (RCM; Elguindi et al., 2011) were used. Meteorological data were converted to runoff sequences by running the DIWA hydrological model for past and future time slices (1976–2005, 2021–2050, and 2070–2099). Finally, statistical comparison and evaluation of the characteristics of runoff processes in the observed-past, the modeled-past, and the-modeled future were completed.

For our analysis the physically based DIstributed WAtershed hydrological model is used (Szabó, 2007; Szabó et al., 2010). DIWA takes into account several aspects, which substantially affects hydrological elements, and therefore runoff processes (Fig. 3), too. For example, it considers topography, thus, surface gradient and local drainage direction, as well. The model distinguishes 45 land use types and 3 soil layers (including the uppermost, organic level of the soil, the so-called O-horizon). DIWA uses different LAI for each month, and different solar energy for every 10-day-long time period. It also takes into account the characteristics of the streambed, e.g., streambed gradient and roughness. Furthermore, it involves submodels for interception, snowmelt, infiltration, and unsaturated flow. The hydrological model requires daily meteorological data as input, namely, precipitation, average temperature, and minimum temperature. Potential evaporation is calculated using the method of Varga-Haszonits (1969).

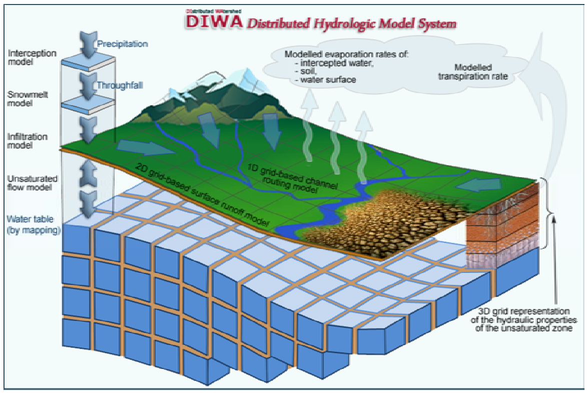

Fig. 3: Schematic description of the physically based, DIstributed WAtershed hydrological model.

Historical meteorological and runoff data are available for 14 years (1990–2003) to analyze trends in the recent past. In order to provide meteorological input data for the hydrological model for the future, outputs of climate simulations are needed. In this study, we used the RegCM4 regional climate model adapted for the Carpathian Region by the Department of Meteorology of the Eötvös Loránd University (Bartholy et al., 2015b) in the framework of Med-CORDEX Initiative (Somot et al., 2012) and RCMGIS project (Szépszó et al., 2015). Physically-based global climate models (GCM) cover the entire globe and are able to describe the Earth’s climate system, however, regional climate models driven by GCM outputs are more appropriate tools for impact studies than GCMs, because (i) their horizontal resolution is much finer and (ii) they simulate extreme events more precisely.

The horizontal resolution of RegCM4 outputs is 10 km, and it covers the 1970–2099 time period with 1 day time step (Pieczka et al., 2015). The necessary initial and boundary conditions were provided by the RegCM4 experiment with 50 km horizontal resolution (Bartholy et al., 2015b), which was driven by the HadGEM global climate model (Collins et al., 2011). The applied HadGEM and RegCM4 simulations use the new, relatively optimistic RCP4.5 scenario (van Vuuren et al., 2011), in which the radiative forcing relative to the preindustrial period is stabilized at 4.5 W/m^2 shortly after 2100. Furthermore, it assumes changes in energy sources (shifts to electricity) and expansion of forest lands. Thus, the peak concentration level of greenhouse gases is estimated at 650 ppm of CO_2 equivalent (Thomson et al., 2011).

Calibration and validation of DIWA distributed hydrological model are completed for the joint watershed after the confluence of the two Hungarian rivers (Zagyva and Tarna), until the cross-section located in Jásztelek, Hungary at 47.5°N 20.0°E (Fig. 1, indicating by the magenta point) using historical meteorological and runoff data based on measurements. For the manual calibration 2-year-long period was selected between 1st October 1999 and 30th September 2001, when both a high flood wave and a longer, low flow subperiod occurred. Fig. 4 illustrates the results of the calibration. No systematic errors can be recognized in the scatter-plot diagram, as values are close to the black, solid line (y = x) representing the perfect match between simulated and measured river discharges. Therefore, we can conclude that DIWA is dynamically adequate for describing real hydrological processes.

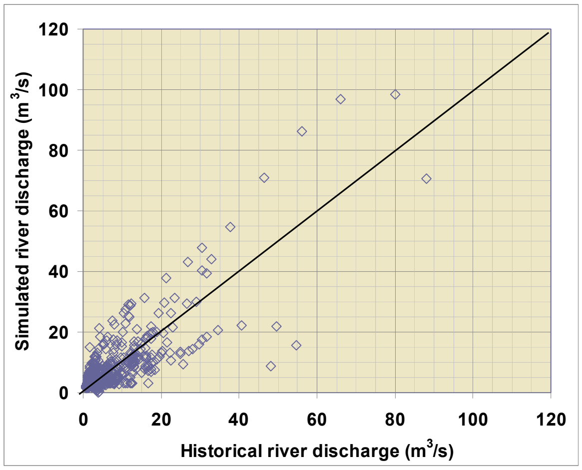

Fig. 4: Scatter-plot diagram of the historical and simulated river discharge, after calibrating the model DIWA for Jásztelek (01.10.1999–30.09.2001).

3. RESULTS

First, a brief summary of the projected regional climate change between 1976–2005 and 2070–2099 is presented based on RegCM4 simulation outputs, then, the main characteristics of extreme hydrological events in the past and the future 30-year-long time periods are evaluated using historical and simulated meteorological data as input for the model DIWA.

3.1 *Projected climate change*

According to the RegCM4 simulations, higher temperature values are likely to occur in the future in the Zagyva-Tarna catchment, as well, as in Hungary. In the target region (i.e., the catchment area) clear warming is projected by at least 2 °C (Table I) for every season by the end of the 21st century compared to the reference period (1976–2005). The largest average increase (> 3 °C) of temperature is projected for summer and fall.

Considering precipitation, spatial distribution is estimated to be similar to the past, however, temporal distribution throughout the year is projected to be rearranged. For the future, drier summers are estimated by about 25% less precipitation, whereas the other seasons are likely to become wetter compared to the reference period.

Table I: Projected seasonal mean temperature and precipitation change in the Zagyva-Tarna catchment on the basis of RegCM4 simulation using RCP4.5 scenario by 2070–2099 relative to the 1976–2005 reference period

Season	Estimated average temperature increase	Estimated average precipitation change
Winter (DJF)	2.4 °C	+26%
Spring (MAM)	2.1 °C	+13%
Summer (JJA)	3.2 °C	–25%
Fall (SON)	3.2 °C	+4%

One of the often used climate indices is the mean length of dry spells (Pongrácz et al., 2014). Mean Dry Spell (MDS; expressed in days) remarkably affects runoff processes, therefore, we calculated the time series of this index using RegCM4 simulation outputs. For summer, increasing trend of MDS is estimated (Fig. 5) although less precipitation days are likely to occur in the future compared to the reference period. MDS is projected to be 10–12 days on average in summer in the last three decades of the 21st century, whereas in the reference period it was only 7–8 days, which implies ~40% relative change within about a century. In the other three seasons, the projected changes are small, i.e., between –20% and +20%, and mostly not significant. Moreover, signs of the projected changes are different within the target catchment area.

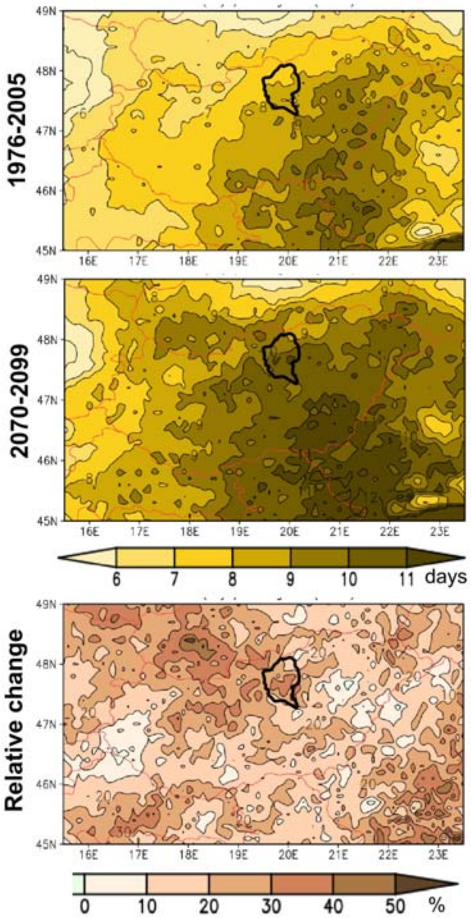

Fig. 5: Simulated mean length of dry spells in summer in 1976–2005, 2070–2099, and the estimated relative change based on RegCM4 simulations. Black contours indicate the Zagyva-Tarna catchment area on the maps.

3.2 *Estimated river discharge values*

In this section relative frequency of river discharge values is analyzed on annual and seasonal scale. For this purpose different thresholds are used to categorize the entire discharge range. 1–2 m^3/s is considered low flow with partial water use restrictions. Average discharge range can be found between 2 m^3/s and 40 m^3/s. Discharge values between 40 m^3/s and 70 m^3/s implies the flood range, which requires flood defense actions. If the river discharge is higher than 70 m^3/s indicating extreme flood, then intense flood defense is necessary.

Our preliminary results indicate quite large differences between the observed-past and modeled-past in every case (Figs. 6, 7, and 8), which is mainly due to the overall overestimation of precipitation (and underestimation in summer) by the RegCM4 simulation (Bartholy et al., 2015b). Thus, bias correction of the raw RegCM4 outputs will be necessary in order to make more precise, more reliable assessments. However, on the basis of the uncorrected simulation results we can still compare the modeled-past to the modeled-future to evaluate the estimated relative changes and provide a rough idea about the likely trends for the future, i.e., the last three decades of the 21st century relative to the reference period in the late 20th century.

On annual scale, relative frequency of low flow range is projected to increase, whereas the average river discharge values are likely to become less frequent by the end of the 21st century (Fig. 6). In case of flood and extreme flood ranges, our preliminary results do not suggest any significant change.

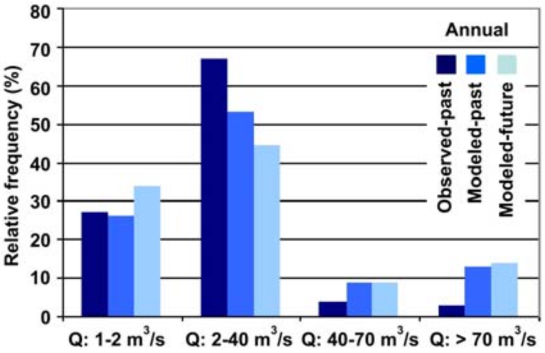

Fig. 6: Relative frequency of annual river discharge values, considering different thresholds.

Similarly to the annual discharge values, the average range is projected to decrease in winter (Fig. 7). The estimated changes in winter for the other three discharge ranges are different from the annual scale changes. The relative frequency of low flow will probably not change, whereas the relative frequency of high river discharge values (> 40 m^3/s, flood and extreme flood range) is likely to increase slightly in the future. This can be explained by the projected regional climate change: for this season, more frequent and more intense precipitation events are projected for Hungary by several different regional climate models (Bartholy et al., 2015a; Pongrácz et al., 2015).

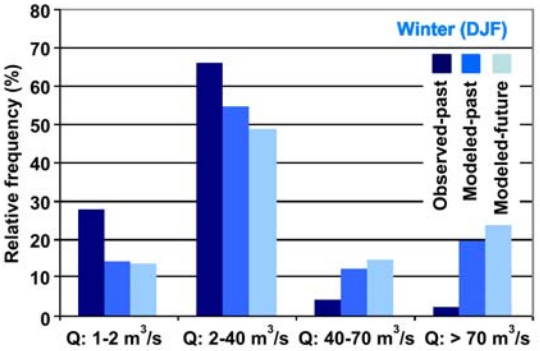

Fig. 7: Relative frequency of river discharge values in winter, considering different thresholds.

As a consequence of the estimated overall drying tendency with less precipitation days and longer dry spells in summer (e.g., Pongrácz et al., 2014; 2015), low flow ranges are likely to become substantially more frequent by the end of the 21st century (Fig. 8) according to the RegCM4 simulations. Hence, the relative frequency of the average river discharge values is projected to decrease. Occurrences of flood and extreme flood ranges are estimated to decrease very slightly (not significant though) because a large amount of water can be easily transported by a partially dried-out riverbed.

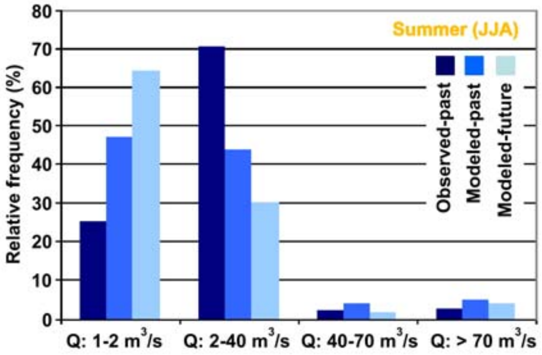

Fig. 8: Relative frequency of river discharge values in summer, considering different thresholds.

3.3 *Estimated runoff characteristics*

In this subsection, statistical analysis based on comparison of runoff data for the observed-past, modeled-past, and modeled-future is evaluated for the catchment of Zagyva-Tarna. Distributions of yearly runoff values are presented in Fig. 9. The low and high extremes can be well separated in the diagram. The above mentioned overestimation of annual runoff values can clearly be recognized, i.e., a shift of the distribution can be identified between the observed-past and modeled-past.

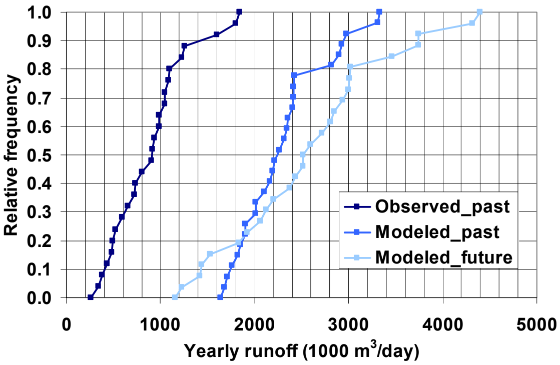

Fig. 9: Distributions of yearly runoff values based on the observed-past, the modeled-past, and the modeled-future meteorological data.

This shift occurs mainly because the DIWA-driving RegCM4 simulation remarkably overestimates precipitation in most part of the entire simulation period, especially in the winter half years (Bartholy et al., 2015b). According to the simulations, more frequent and more intense extreme high and extreme low values are likely to occur in the future compared to the past reference period. These changes can be partly explained by the projected regional climate change. More specifically, on one hand, drier summers are likely to occur with longer dry spells (Pongrácz et al., 2014), hence extreme low river discharges are expected. On the other hand, the other seasons are likely to become wetter with more extreme precipitation events (Bartholy et al., 2015a), and therefore, the occurrence of extreme high river discharges are also estimated to increase.

Figs. 10 and 11 compare the distributions of runoff values for the modeled-past and modeled-future in winter and summer, respectively. Our results do not suggest remarkable changes in the distributions of runoff values for spring and fall, that is why the corresponding diagrams are not shown here.

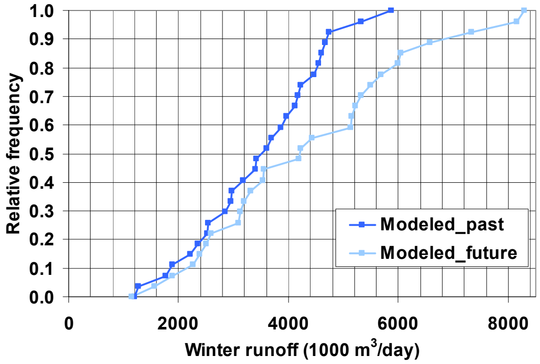

Fig. 10: Distributions of winter runoff values based on the modeled-past (1976–2005) and the modeled-future (2070–2099) meteorological data.

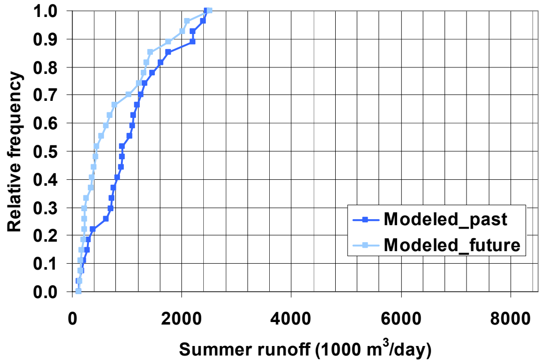

Fig. 11: Distributions of summer runoff values based on the modeled-past (1976–2005) and the modeled-future (2070–2099) meteorological data.

In winter (Fig. 10), higher percentile values, thus more intense extremes are likely to occur in the future time period (2070–2099) compared to the reference period (1976–2005). The suggested increase of maximum runoff values in winter is quite large (> 25%): from about 6,000,000 m^3/day to over 8,000,000 m^3/day.

On the contrary, lower percentile values and generally lower runoff are projected for summer by the end of the 21st century (Fig. 11). These estimated changes can be directly linked to the projected regional climate change, i.e., longer MDS and higher temperature values estimated for summer.

4. CONCLUSION

In this paper projected changes of extreme runoff characteristics were analyzed using the DIWA physically-based, distributed hydrological model and climate simulations of the RegCM4 model. For the past, we compared the results of the observations and the simulations; and it can be concluded, that they differ substantially. However, this discrepancy can be eliminated by applying a percentile-based bias correction to the raw outputs of regional climate model simulations. For this purpose, we plan to use the homogenized, observation-based CarpatClim (Spinoni et al., 2015) dataset.

According to our preliminary results, more extreme (both high and low) runoff events are likely to occur in the Zagyva-Tarna catchment at the late 21st century compared to the late 20th century reference period. Frequency and intensity of extremes are both estimated to increase in the target area located in Hungary, Central/Eastern Europe. Hence, in order to mitigate the potential environmental threats, it is essential to build appropriate adaptation strategies, and then, act according to them.

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