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EFFECT OF CLIMATE CHANGE ON THE HYDROLOGICAL CHARACTER OF RIVER MAROS, HUNGARY-ROMANIA

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Abstract

It is highly probable that the precipitation and temperature changes induced by global warming projected for the 21st century will affect the regime of Carpathian Basin rivers, e.g. that of River Maros. As the river is an exceptionally important natural resource both in Hungary and Romania it is necessary to outline future processes and tendencies concerning its high and low water hydrology in order to carry out sustainable cross-border river management. The analyses were based on regional climate models (ALADIN and REMO) using the SRES A1B scenario. The modelled data had a daily temporal resolution and a 25 km spatial resolution, therefore beside catchment scale annual changes it was also possible to assess seasonal and spatial patterns for the modelled intervals (2021-2050 and 2071-2010). Those periods of the year are studied in more detail which have a significant role in the regime of the river. The study emphasizes a decrease in winter snow reserves and an earlier start of the melting period, which suggest decreasing spring flood levels, but also a temporally more extensive flood season. Changes in early summer precipitation are ambiguous, and therefore no or only slight changes in runoff can be expected for this period. Nevertheless, it seems highly probable that during the summer and especially the early autumn period a steadily intensifying water shortage can be expected. The regime of the river is also greatly affected by human structures (dams and reservoirs) which make future, more detailed modelling a challenge.

Keywords: River Maros, catchment hydrology, climate change, RCMs

INTRODUCTION

River Maros has always been an important natural resource on the Southern Great Plains of the Carpathian Basin. The amount of water it drains annually equals to the total water consumption of Hungary. Although only part of this water is utilised, the river is by far the most significant water resource for irrigation and industrial activity in the region. Besides, it also feeds a thriving riparian ecosystem and has a unique geomorphological character. The availability and quality of its resources are endangered by several factors. From among these the short and long term effects of human interventions and that of climate change have to be emphasized. The future of River Maros and adjacent territories is determined basically by the amount of water drained by the river.

Previous research has demonstrated that the Late Pleistocene and Holocene evolution of the river has primarily been affected by climatic variations (Kiss et al., 2013). The fluvial system is still very active and it is highly sensitive to external forcing factors (Kiss and Sipos, 2007), from which recent climate change is getting to be more and more pronounced. In the near future climate change will supposedly alter the duration and pattern of both flood and low water discharges and the intensity of channel development. Large number of investigations have demonstrated that the actual changes of the temperature and precipitation will have significant effects on all factors of the environment, and can also alter the rate of geomorphologic, and especially fluvial processes (Dikau and Schrott, 1999).

The possible causes of climate change concerning river hydrology and fluvial activity has been addressed by several studies recently. These apply for the simulations climate models to predict future deviations in temperature and precipitation. For concluding general trends on large catchments global climate models (GCM) are applied by several studies (e.g. Boyer et al., 2010; Chung and Jung, 2010; Zeng et al., 2012), however, differences in the topography and hydrology of subcatchments would call for the downscaling of global models (Dobler et al., 2012), or the application of regional climate models (RCM) at best (Veijalainen et al., 2010). Studies agree, however that the application of several models and emission scenarios can increase the reliability of results (Kay et al., 2006; Smith et al., 2013). However, moderate analyses usually apply the A1B SRES scenario for calculations.

One of the most important problems addressed by hydrologists is the expectable change in flood frequency and flood height. In this respect variations in snow/precipitation ratio and seasonal rainfall distribution are key parameters (Boyer et al., 2010; Bell et al., 2012). As a consequence of these flood hazard can increase even if total annual runoff is expected to decrease (Kay et al., 2006; Zeng et al., 2012). Furthermore, in several cases the elongation of the flood season, can result a lower predictability concerning flood timing in the future (Dobler et al., 2012).

On the other end water shortage may pose serious problems for water managers (Lorenzo-Lacruz et al., 2010; Koutroulis et al., 2013). Beside well known consequences, such as future limitations in water use and related agricultural, economic and social conflicts, even accelerated geomorphological change can be expected at certain catchments (Smith et al., 2013). Concerning low stage periods predictability of river hydrology is highly limited by human interventions (e.g. water retention, irrigation), which is a problem on most of engineered rivers (Kiss and Blanka, 2012). Among these circumstances adaptation will be a key issue.

In this study a conceptual framework was set up for the trends in catchment scale hydrological changes concerning River Maros. The major questions were: (1) What changes can be expected in temperature and precipitation on the watershed of the river in the 21st century? How these changes can affect the regime of the river and the total annual volume of water drained? The tendencies of future changes were explored by using regional climate models. The study aims to provide base for future hydrological modelling and runoff calculations.

STUDY AREA

The catchment of River Maros is located in the southeastern part of the Carpathian Basin. 92% of its total area (30 000 km2) belongs to Romania, the remaining 8% to Hungary (*Fig.1*). River Maros and its tributaries are mostly fed by precipitation and overland flow. Due to the geology of the catchment (overwhelmingly volcanic and crystalline rocks) and the high proportion of very steep slopes floods rise relatively quickly, and last for only a short time. Two major floods may develop annually on the river. The first is due to snowmelt in early spring, the second is caused by early summer rainfall usually in June (*Fig. 2*). Following the April-June floods the rest of the year is characterized by low stages, which last for approximately 10 months from June till March, with a minimum water delivery at October (Boga and Nováky 1986).

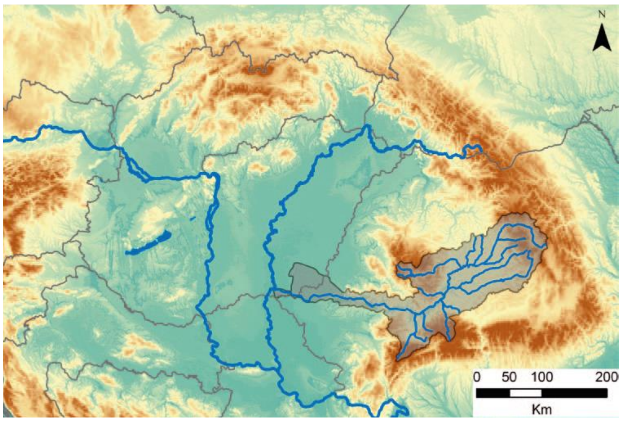

Fig. 1 The location of the Maros catchment within the Carpathian Basin

The mean annual discharge of the river is 160 m^3/s. Peak and minimum discharges are around 2000-2500 m^3/s and 30-50 m^3/s, respectively.

The area is dominated by westerly winds, though from time to time the effect Eastern-European and Mediterranean air masses are also significant (Csoma 1975). The annual mean temperature on the catchment is between 4–11 °C, though there is a great territorial variation, determined primarily by the topography. As a general rule the value of the mean annual temperature is increasing continuously in an east-west direction. In the Giurgeu Mountains the mean annual temperature in the 20th c. has been 4–6 °C, in the Transylvanian Basin 8–9 °C, west of the Arad–Oradea line it has been just above 10 °C, while southwest of the Nadlac–Szeged line it has been above 11 °C (Csoma, 1975; Andó, 2002). 70–80% of the water drained by the river is originating from precipitation (Andó, 1993, 2002). Still, there is no close relation between floods and the temporal distribution of precipitation (Andó, 2002), as the greatest floods are initiated by the melting of snow, accumulating in the winter period. The spatial distribution of precipitation shows a great variation (*Fig. 3*). At the source of the river annual values are around 600 mm, going downstream this amount can double on the western slopes of the Gurghiu Mountains,but reaching the closed Transylvanina basin it falls back to 600 mm again. It increases again in the region of the Sebeş and Retezat Mountains. West of Lipova precipitation decreases continuously (Csoma, 1975).

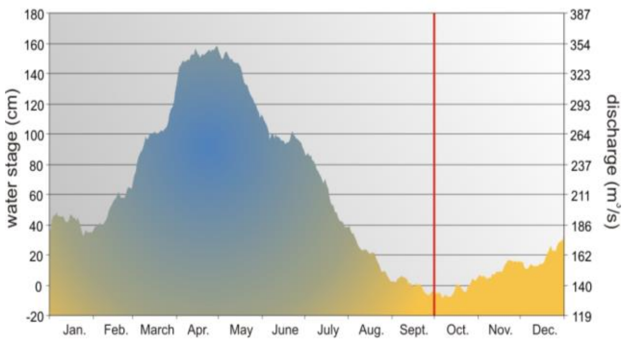

Fig. 2 An average hydrological year based on 50 year mean values (1950-2000)

Climate model simulations for the 21st century predict a continuous, but uneven temperature rise, with the most intense increase occurring in the summer months in the Carpathian Basin. The change in total annual precipitation in the models is not significant; however, the temporal distribution is expected to become more uneven: decreasing summer and increasing winter precipitation (Bartholy et al., 2008, Szabó et al., 2011; Csorba et al., 2012). Climate simulations do also emphasize that extreme weather events may occur more frequently in the next century. This will be especially true for drought periods which will be longer and more severe than before (Szépszó et al., 2008).

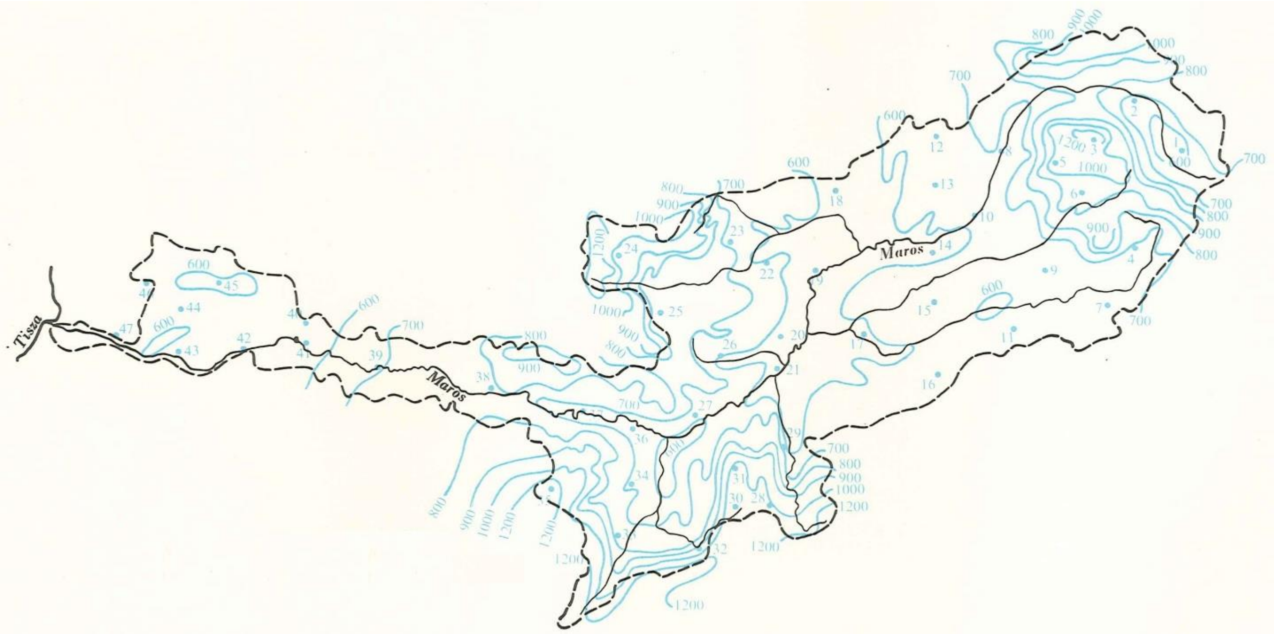

Fig. 3 Yearly mean precipitation (1901-1940) on the Maros catchment (Csoma, 1975)

METHODS

Climatic changes concerning the entire Earth are best predicted by global numerical models. These incorporate the most important processes and relationships acting in and between the major elements of the Earth system (atmosphere, oceans, continents, ice sheets, biosphere, society). The horizontal resolution of global models, however, is only around 100 km, which does not provide adequate information for performing smaller scale, regional analyses (Szépszó and Zsebeházi, 2011).

For the investigation of smaller areas, such as the drainage basin of a river, regional climate models can be applied. The resolution of these is much better than that of global models, since input data are more detailed and smaller scale relationships can be considered. As a consequence, atmospheric processes and surface changes can be predicted more precisely for a given area (van der Linden and Mitchell, 2009; Szabo et al., 2011). Large, Earth scale models, however determine the possible end values of the regional forecast (Giorgi and Bates, 1989; Giorgi 1990). The projection of climate processes to the future includes several uncertainties. These are caused by the natural oscillation of the climatic system, the complicated relationships between environmental elements, the limitations concerning the resolution of input data and the hardly predictable social-economic processes (Cubasch et al., 2001; Hawkins and Sutton, 2009). From among the factors above mankind can affect mostly social-economic processes, and most of all, these factors can significantly determine the rate of climate change.

Several regional climate models comprise the territory of the Carpathian Basin, these are the ALADIN, the REMO, the PRECS and the RegCM (Szépszó et al., 2008). For the purposes of estimating future climatic processes on the Maros catchment, the change of climatic parameters was calculated on the basis of the ALADIN (www.cnrm.meteo.fr/aladin) and the REMO (www.remo-rcm.de) models, since these are based on the SRES A1B scenario.

These models assume a moderate increase in the emission of greenhouse gases and an average degree of global warming. Concerning population numbers the A1B scenario assumes an increase till the middle of the century and a decrease later, besides, it foresees a fast economic growth, the quick spread of new and more efficient technologies and a balance between the use of fossil and renewable energy sources (Nakicenovic and Swart, 2000; IPCC 2007).

The horizontal resolution of the applied model data is 0.22° (approximately 25 km). The climate projections were generated by the Numerical Modelling and Climate Dynamics Division of the Hungarian Meteorological Service. For making comparisons, temperature and precipitation data were investigated. Expected changes were examined for those periods of the year which are the most important in terms of floods and low water periods.

The models provide daily temperature and precipitation data for the 2021–2050 and the 2071–2100 periods. Results are given as the difference from the daily average values of the 1961–1990 reference period in mm for precipitation and in °C for temperature. From the daily data series average values were calculated for the two future periods (2021-2050 and 2071-2100) for those months which are important in terms of the hydrology of River Maros. Values were calculated for the grid points, interpolation between points was made by using kriging.

At present our aim was to demonstrate the tendency of changes, but later on the basis of these data further models can be generated in terms of runoff and water balance.

RESULTS

Compared to the reference values both models predict an average 1.3–1.4 °C temperature increase for the 2021–2050 period in the winter months (*Fig. 4*). However, in a longer perspective the models forecast somehow different values. According to the REMO the rise of mean temperature can be as much as 3.9 °C for 2071–2100, which is a substantial increase. The ALADIN predicts a little lower increase, being around 2.1 °C *(Fig. 4*, *Table 1)*. However, even if we take the more optimistic version a significant warming can be expected on the entire catchment. If we take a look at *Fig. 4*, in the first modelling period temperature rise seems to be uniform on the catchment. However, later the Eastern Carpathian tributaries and the lowland section of the river can be more affected. Concerning the entire catchment, average precipitation values calculated by the two models are very different. According to the ALADIN, practically no change can be expected, while the REMO predicts a 22 mm increase for 2021–2050 and 34 mm for 2071–2100 (*Fig. 5*, *Table 2*). Average values though hide some regional differences. Both models agree that there can be a notable increase in precipitation on the eastern mountainous part of the catchment (Giurgeu Mountains), while only a slight increase (REMO) or even a substantial decrease (ALADIN) can be expected in the west (*Fig. 5*). Based on the above, it seems well supported that due to general warming the average snow reserve will decrease on most of the sub-catchments. Although, at higher altitudes in the Eastern Carpathians the snow/precipitation ratio might be higher as a matter of precipitation increase. The severity of flooding on these sub-catchments will mostly be determined by the intensity of snowmelt.

Table 1 Average temperature change (°C) on the Maros catchment

	REMO		ALADIN	
	2021-2050	2071-2100	2021-2050	2071-2100
December-February	1.4	3.9	1.3	2.1
May-June	1.1	2.4	1.5	3.1
July-August	1.4	5.0	3.0	5.5
September-October	2.2	4.8	2.5	4.6
Annual	1.4	3.8	2.02	3.55

March and April temperature has a significant effect on the start and intensity of snow melt and therefore the development of floods. Based on the models, a general temperature increase can be expected (*Fig.*

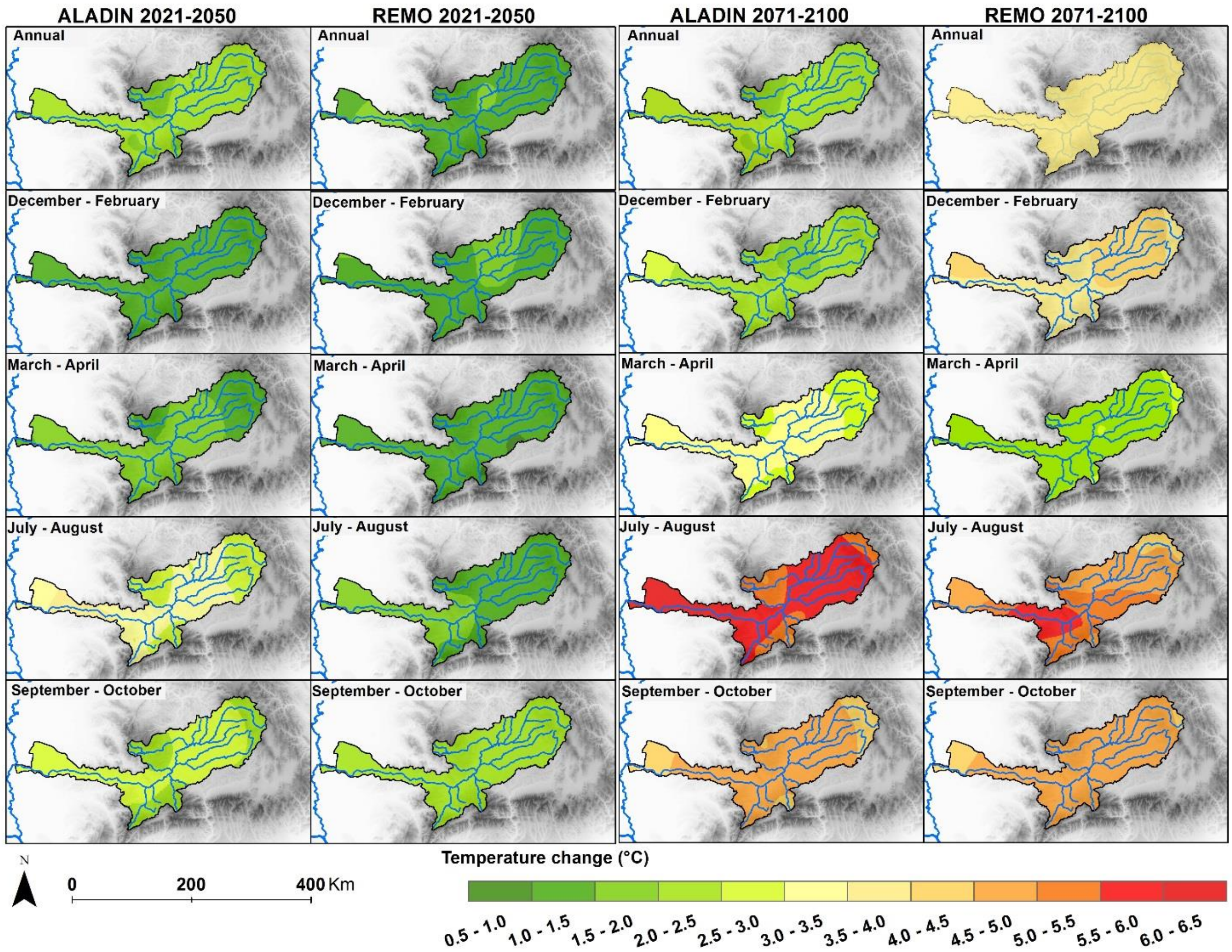

Fig. 4 Model predictions of temperature change compared to the reference period

4, *Table 1*). For the first period (2021–2050) an average 1.1–1.5 °C growth is suggested. By the second period (2071–2010) this value can be as much as 2.4 °C (REMO) or 3.1 °C (ALADIN). Warming up can be more intensive in the Transylvanian Basin and on the lowlands, however the Eastern catchment can also face an approximately 1.0 °C later a 2.0 °C temperature increase in the spring period during the 21st century (*Fig. 4*, *Table 1*). These changes suggest that in an average year early spring snowmelt can be faster in the upland catchment. This does not necessarily mean greater floods, because we have seen the total snow reserve can be slightly lower. Nevertheless, the period of flood development will extend, and in years of higher winter precipitation the chance of the development of extreme floods can increase.

Based on previous observations, the second potential flood of the year can occur as a consequence of May and June rainfalls (Andó, 2002). Model predictions are ambiguous in this respect (*Fig. 5*, *Table 2*).

According to average data calculated for the entire catchment, REMO forecasts an insignificant change in early summer rainfall for the 2021–2050 period, and a substantial 50 mm decrease for 2071–2100. On the other hand ALADIN predicts an approximately 30 mm increase for the first period and just a minor increase for the second (*Fig. 5*, *Table 2*). The pattern of change is also different. According to the ALADIN model, the most significant increase can be expected in the middle of the catchment. On the contrary REMO heralds the most significant decrease also to this area (*Fig. 5*). Therefore, the direction of change in this case is highly uncertain. Consequently, it is hard to tell whether the significance of early summer rain-fed floods will increase or decrease. If we take the average of the two models rather insignificant changes can be expected.

Table 2 Average precipitation change (mm) on the Maros catchment

	REMO		ALADIN	
	2021-2050	2071-2100	2021-2050	2071-2100
December-February	22.38	34	0.12	-5.5
May-June	-3.5	-50.1	32.6	35.4
July-August	-0.3	-55.3	-21.5	-55.6
September-October	2.2	8.3	-2.8	-17.4
Annual	2	-53	44	-20

As it was mentioned earlier, the low water period starts in July (Boga and Nováky, 1986). From August discharges can be as low as 50 m^3/s. The

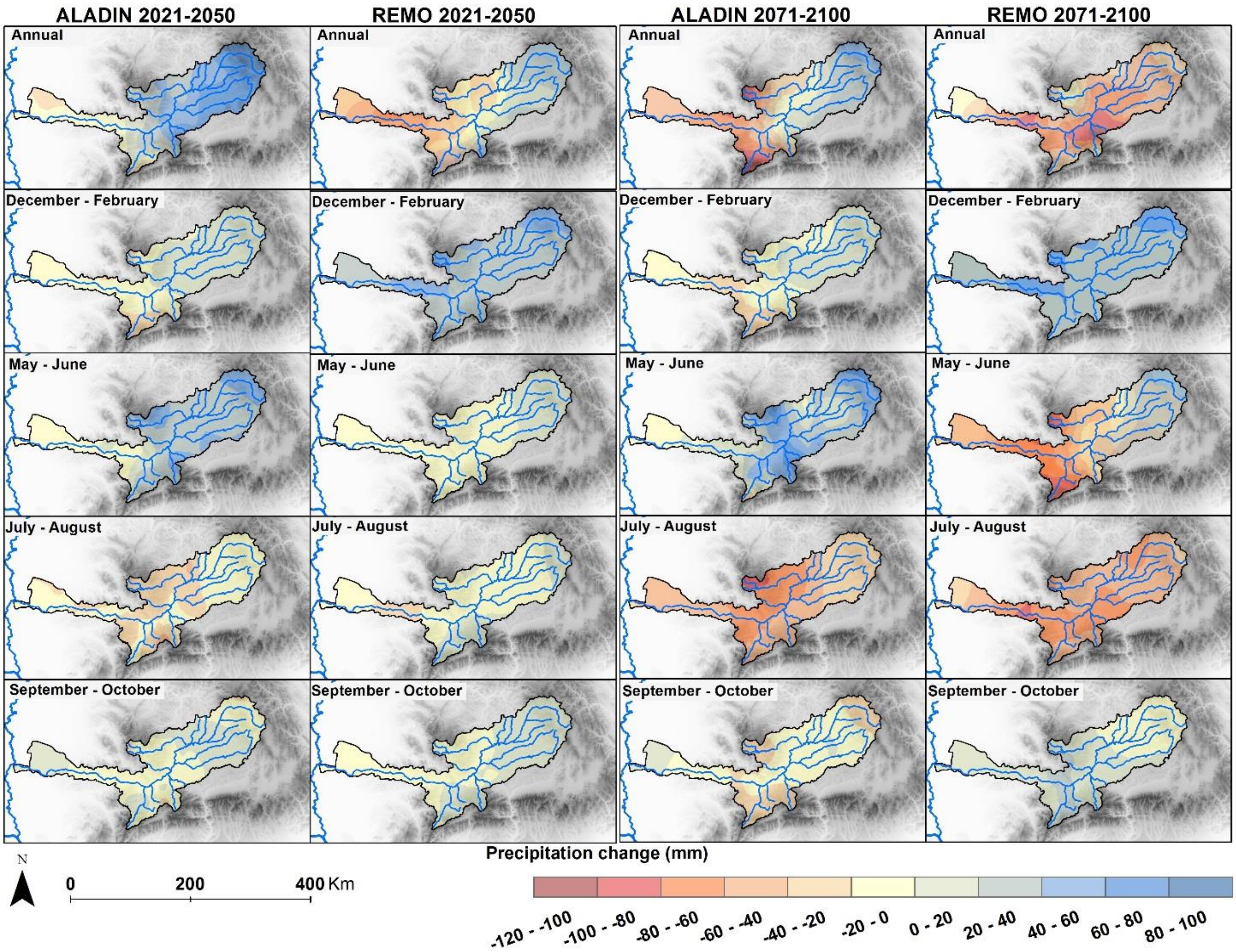

Fig. 5 Model predictions of precipitation change compared to the reference period

volume of water arriving to the lowland sections is greatly determined by the intensity of evaporation on the catchment. Of course, human interventions, such as water storage, can also be of great significance. In this respect July–August temperatures are very important. Both models forecast an increase, being between 1.4 °C (REMO) and 3.0 °C (ALADIN), for the first modelling period (2021–2050). Concerning the second period (2071–2100) the increase can be even more significant, reaching 5.0 °C (REMO) or 5.5 °C (ALADIN) (*Fig. 4, Table 1).* The expected temperature growth is fairly uniform on the catchment, however, according to ALADIN, warming will mostly affect the Gurghiu Mountains and the lowland areas, while REMO predicts the most intensive increase on the middle part of the catchment. Therefore, the spatial pattern for warming cannot be unambiguously determined. In the meantime, there is a high chance for the decrease of summer precipitation. Regarding the average values for the entire catchment the ALADIN model forecasts a 20 mm decrease for 2021–2050, while according to the REMO, catchment averages may not change. However, both models agree that by 2071–2100 precipitation loss can be around 55 mm (*Table 2*), affecting mostly the middle part of the drainage basin. The decrease can be less intensive in the western slopes of the Hargitha, Giurgeu and Gurghiu Mountains (*Fig. 5*). Concerning the summer period, therefore, increasing evaporation and decreasing precipitation can be forecasted. This can lead to a significant reduction in average discharges, which may result an increasing water shortage during the low water period starting from July–August.

Based on previous observations (Konecsny and Bálint, 2007), usually the September–October period brings the lowest discharges on River Maros (sometimes only 30–40 m^3/s). If catchment scale average temperature change is considered the two models are in good agreement. For 2021–2050 both models forecast a temperature increase, being around 2–3 °C, while between 2071–2100 average warming can be as much as 4–5 °C (*Fig. 4*, *Table 1*). Concerning the spatial distribution of temperatures, warming might affect less the slopes of the Apuseni Mountains and the Gurghiu Mountains, but in the Transylvanian Basin and the Tarnava Tableland temperature rise can be dramatic (*Fig. 4*). Precipitation change is less obvious on the basis of the models, and catchment scale averages seem to stay more or less the same as the 1961–1990 reference values (*Table 2*). The calculated few mm changes are insignificant and they are within the error of the prediction.

The high correspondence of the two models suggests that there is going to be a significant warming in the early autumn period. In the meantime average precipitation values will hardly change, which can finally result a more intensive water loss through evaporation. This can lead to the development of long drought periods along River Maros.

DISCUSSION

Although we have seen that in certain cases the two models do not reinforce each other, there are some clearly recognisable tendencies in terms of future climate. Warming will be general both in spatial and temporal terms. However, lower lying closed areas, such as the Transylvanian Basin, can be more severely affected. It seems also clear that temperature rise will be the most significant in the summer–autumn period, though the REMO model forecasts significantly warmer winters as well. In the meantime, changes in precipitation are harder to predict. What seems obvious though is that the late summer period will face a significant precipitation decrease on the basis of average values. Changes in other seasons are less unambiguous (*Table 3*).

Table 3 Precipitation change (%) compared to the reference period on the mountain section of the catchment

	REMO		ALADIN	
	2021-2050	2071-2100	2021-2050	2071-2100
December-February	21%	31%	0%	-8%
May-June	-2%	-26%	16%	17%
July-August	0%	-32%	-12%	-32%
September-October	2%	8%	-3%	-17%
Annual	0%	-7%	6%	-3%

If annual mean values are considered, a significant 1.4 °C (REMO) and 2.0 °C (ALADIN) temperature increase can be predicted already for 2021–2050. Moreover, by 2071–2100 overall warming can be 3.6 °C (ALADIN) and 3.8 °C (REMO) compared to the values of the 1961–1990 reference period. Interestingly, annual precipitation values show a slight increase for 2021–2050 in case of the ALADIN model, but for the 2071–2100 period both models forecast a significant, 20–50 mm decrease. Taking into consideration that the average precipitation is between 600–1000 mm on the catchment, this means a 5–10% reduction in annual runoff. The decrease can be even more significant if increasing evaporation is accounted, but further modelling is necessary to explore these relationships.

Concerning the hydrological regime of the river we can expect a more uniform runoff during the winter, however, early spring snow melt can be more intensive. In the meantime early summer floods might be less significant (*Table 3*). Therefore, the frequency and average magnitude of floods will slightly decrease, however, if conditions are suitable (high winter precipitation and fast snowmelt) extreme floods can of course occur. Although several climate-related studies emphasize the relevance of high-precipitation extremes (Szépszó et al., 2008), these will be characteristic mostly on the western half of the Carpathian Basin (Horányi et al., 2009). Consequently, from a climatic aspect the hazards and conflicts related to floods and flood protection will not increase significantly along the Maros/Mureş in the near future. On the other hand, results show that summer and autumn low water extremes may be more frequent, and severe water shortage may occur along the lower section of the river from time to time (*Table 3*). Moreover, as we have seen, total annual runoff will certainly decrease in the long run. According to Konecsny (2010), there are already periods with significant water deficit, meaning that the discharge is lower than the statistically determined average low water value. Thus, the main problems and conflicts related to the changing regime of the river will be related primarily to low water events.

CONCLUSIONS

Calculations concerning the future climate of the Maros/Mureş catchment were outlined, and the tendency of expectable changes was assessed in this study concerning the hydrological regime of the river.

Due to increasing temperatures at winter the average snow reserve can decrease on several sub-catchments. Nevertheless, at higher altitudes greater reserves may develop, since models herald a slight increase in winter precipitation. Spring snowmelt can be faster in the upland catchment, thus in years when winter precipitation is high the probability of extreme floods can increase. In general, however, the magnitude of floods is expected to decrease. Based on the models, considerable changes in the volume of early summer rainfed floods are not expected. For the summer and early autumn period dramatically increasing temperature and decreasing precipitation can be forecasted. This can lead to a significant reduction in average discharges. On a catchment scale mean annual temperature is expected to increase by 1.4-2.0 °C and 3.6-3.8 °C in average by 2021–2050 and 2071–2100, respectively. Mean annual precipitation presumably will only slightly change by the first modelling period, however, for 2071–2100 the models forecast a significant, 20–50 mm decrease. Considering the above a 5–10% reduction can be expected in annual runoff, and the severity of droughts will certainly increase.

Consequently, the main problems and conflicts of the future will be related primarily to low water events. Industrial, agricultural, ecological and recreational demands need to be harmonised as each of these will grow during the increasingly hot and dry summer period. All these problems call for a unified water management strategy with a sustainable share of resources between the upstream and lowland sections of the river and also between the two neighbouring countries.

Acknowledgements

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References

Andó, M. 1993. The geography of the Mures River. *Acta Geographica Szegediensis* 31, 1–9.

Andó, M. 2002. A Tisza vízrendszer hidrogeográfiája. SZTE Természeti Földrajzi Tanszék, Szeged.

Bartholy, J., Pongrácz, R., Gelybó, Gy., Szabó P. 2008. Analysis of expected climate change in the Carpathian Basin using the PRUDENCE results. *Időjárás Quarterly Journal of the Hungarian Meteorological Service* 112, 249–264.

Bell, V.A., Kay, A.L., Cole, S.J., Jones, R.G., Moore, R.J., Reynard, N.S. 2012. How might climate change affect river flows across the Thames Basin? An area-wide analysis using the UKCP09 Regional Climate Model ensemble. *Journal of Hydrology* 442–443, 89–104. DOI: 10.1016/j.jhydrol.2012.04.001

Boga, L., Nováky, B. 1986. Magyarország vizeinek műszaki-hidrológiai jellemzése: Maros. Vízgazdálkodási Intézet, Budapest.

Boyer, C., Chaumont, D., Chartier, I., Roy, A.G. 2010. Impact of climate change on the hydrology of St. Lawrence tributaries. *Journal of Hydrology* 384, 65–83. DOI: 10.1016/j.jhydrol.2010.01.011

Chang, H., Jung, I.W. 2010. Spatial and temporal changes in runoff caused by climate change in a complex large river basin in Oregon. *Journal of Hydrology* 388 (3–4), 186–207. DOI : 10.1016/j.jhydrol.2010.04.040

Cubasch, U., Meehl, G., Boer, G., Stouffer, R. , Dix, M., Noda, A., Senior, C., Raper, S., Yap, K. 2001. Projections of Future Climate Change. In. Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. (eds.). Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 525–582.

Csoma, J. 1975. A Maros hidrográfiája. In. Vízrajzi Atlasz Sorozat 19 Maros.VITUKI, Budapest. 7–12.

Csorba, P., Blanka, V., Vass, R., Nagy, R.,Mezősi, G. 2012. Hazai tájak működésének veszélyeztetettsége új klímaváltozási előrejelzés alapján. *Földrajzi Közlemények* 136(3), 237–253.

Dikau, R., Schrott, L. 1999. The temporal stability and activity of landslides in Europe with respect to climatic change (TESLEC): main objectives and results.*Geomorphology* 30, 1–12. DOI: 10.1016/S0169-555X(99)00040-9

Dobler, C., Bürger, G., Stötter, J. 2012. Assessment of climate change impacts on flood hazard potential in the Alpine Lech watershed. *Journal of Hydrology* 460–461, 29–39. DOI : 10.1016/j.jhydrol.2012.06.027

Giorgi, F. 1990. Simulation of regional climate using a limited area model nested in a general circulation model. *Journal of Climatology* 3, 941–963. DOI : 10.1175/1520-0442(1990)003<0941:SORCUA>2.0.CO;2

Giorgi, F., Bates, G., 1989. The Climatological Skill of a Regional Model over Complex Terrain. *Monthly Weather Review* 117, 2325–2347. DOI :10.1175/1520-0493(1989)117<2325:TCSOAR>2.0.CO;2

Hawkins, E., Sutton, R., 2009. The potential to narrow uncertainty in regional climate predictions. *Bulletin of American Meteorological Society* 90, 1095–1107. DOI : 10.1175/2009BAMS2607.1

Horányi, A., Csima, G., Szabó, P., Szépszó, G. 2009. Regionális klímamodellezés az Országos Meteorológiai Szolgálatnál. MTA előadás 2009.09.15. (http://www.met.hu/doc/tevekenyseg/klimamodellezes/MTA-2009.09.15.pdf)

IPCC 2007. Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the IPCC. Edited by S. Solomon, D. Qin, M. Manning,Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller. Intergovernmental Panel on Climate Change, Cambridge University Press, New York, p. 996 (http://www.ipcc.ch)

Kay, A.L., Jones, R.G., Reynard, N.S. 2006. RCM rainfall for UK flood frequency estimation. II. Climate change results. *Journal of Hydrology* 318, 163–172. DOI: 10.1016/j.jhydrol.2005.06.013

Kiss, T., Blanka V. 2012. River channel response to climate- and human-induced hydrological changes: case study on the meandering Hernád River, Hungary. *Geomorphology* 175–176, 115–125. DOI: 10.1016/j.geomorph.2012.07.003

Kiss, T, Sipos, Gy. 2007. Braid-scale geometry changes in a sand-bedded river: Significance of low stages. *Geomorphology* 84, 209–221. DOI: 10.1016/j.geomorph.2006.01.041

Kiss, T, Sümeghy, B., Sipos, Gy. 2013. Late Quaternary paleodrainage reconstruction of the Maros River alluvial fan. *Geomorphology* 204, 49–60. DOI: 10.1016/j.geomorph.2013.07.028

Konecsny, K. 2010: A kisvizek főbb statisztikai jellemzői a Maros folyó alsó szakaszán. *Hidrológiai Közlöny* 90(1), 45–55.

Konecsny, K., Bálint, G. 2010. Low water related hydrological hazards along the lower Mureş/Maros river. In Riscuri şi catastrofe, Universitatea „Babeş-Bolyai". Facultatea de Geografie. Laboratorul de riscuri şi hazarde. Casa Cărţii de Ştiinţă. Cluj-Napoca 8/6 van der Linden P., Mitchell J.F.B. (eds.) 2009. ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exeter, UK. (http://ensembles-eu.metoffice.com/docs/Ensembles_final_report_Nov09.pdf)

Koutroulis, A.G., Tsanis, I.K., Daliakopoulos, I.N., Jacob, D. 2013. Impact of climate change on water resources status: A case study for Crete Island, Greece. *Journal of Hydrology* 479, 146–158. DOI: 10.1016/j.jhydrol.2012.11.055

Lorenzo-Lacruz, J., López-Moreno, J.I., Beguería, S., García-Ruiz, J.M., Cuadrat, J.M. 2010. The impact of droughts and water management on various hydrological systems in the headwaters of the Tagus River (central Spain). *Journal of Hydrology* 386 (1–4), 13–26.

Nakicenovic, N., Swart, R. 2000: Emissions Scenarios. A Special Report of IPCC Working Group III. Cambridge University Press, Cambridge, UK. 570p.

Smith, V.B., David, C.H., Cardenas, M.B., Yang Z.L. 2013. Climate, river network, and vegetation cover relationships across a climate gradient and their potential for predicting effects of decadal-scale climate change. *Journal of Hydrology* 488, 101–109. DOI: 10.1016/j.jhydrol.2013.02.050

Szabó, P., Horányi, A., Kruzselyi, I., Szepszó, G. 2011. Az Országos Meteorológiai Szolgálat regionális klímamodellezési tevékenysége: ALADIN-Climate és REMO. 36. Meteorológiai Tudományos Napok beszámolókötete. Budapest, 87–101.

Szepszó, G., Zsebeházi, G. 2011. Az ENSEMBLES projekt regionális modelleredményeinek alkalmazhatósága Magyarország éghajlatának jellemzésére. 36. Meteorológiai Tudományos Napok beszámolókötete. Budapest, 59–75.

Szepszó, G., Bartholy, J., Csima, G., Horányi, A., Hunyady, A., Pieczka, I., Pongrácz, R., Torma, Cs. 2008. Validation of different regional climate models over the Carpathian Basin. EMS8/ECAC7 Abstracts 5, EMS2008–A–00645.

Veijalainen, N., Lotsari, E., Alho, P., Vehviläinen, B., Käyhkö, J. 2010. National scale assessment of climate change impacts on flooding in Finland. *Journal of Hydrology* 391 (3–4), 323–350. DOI: 10.1016/j.jhydrol.2010.07.035

Zeng, X., Kundzewicz, Z. W., Zhou, J., Su, B. 2012. Discharge projection in the Yangtze River basin under different emission scenarios based on the artificial neural networks. *Journal of Hydrology* 282, 113–121. DOI: 10.1016/j.quaint.2011.06.009