Climatic perspectives

Viktória Blanka, Gábor Mezősi, György Sipos, Boudewijn van Leeuwen, Petru Urdea, Alexandru Onaca

The future evolution of the Maros/Mureş is determined basically by the amount of water drained and the volume of sediment transported by the river. It has been shown earlier how dynamically the river was changing in the past 20 000 years when it was wandering around on its alluvial fan. Its evolution was primarily determined by the long and short term variation of climate (temperature and precipitation). Meanwhile, we have also seen that the fluvial system is still very active and it is sensitive to external impacts. From among these forcing factors climate change, getting more and more obvious, and human interventions do have a key role. In the near future these issues will greatly determine both flood and low water discharges and the intensity of channel development.

When addressing the future of the Maros/Mureş the major questions were: How will climate change on the catchment during the 21st century? Can these variations influence 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. Nevertheless, the calculation of direct changes related to river evolution and runoff is going to be the task of the near future.

Nowadays the warming of the global climate system is becoming increasingly obvious. A 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 the geomorphologic processes (Dikau and Schrott 1999). In the past decades climate extremities have become more and more pronounced also in the Carpathian Basin. The models predict a continuous, but uneven temperature rise, with the most intense increase occurring in the summer months. 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).

Before investigating possible changes, let's see the present and near past features of the climate on the Maros/Mureş catchment. In general we can say that the area is dominated by westerly airflows, 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, though the source area of the Arieş is the coldest. 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. 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).

Methods

The most up-to date and accepted method to describe and quantify the processes related to climate change, is the application of climate models. 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 countries or a drainage basin of a river, the so called 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, Szabó et al. 2011). Large, Earth scale processes are incorporated to the regional models on the basis of a chosen global model, the data of which will later also 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. As the exact direction of social and economic development cannot be precisely foreseen, the Intergovernmental Panel of Climate Change (IPCC) elaborated more, exactly six, scenarios for future change. These scenarios presume different degree green house gas emissions (carbon dioxide, methane, etc.) on the basis of several factors, but primarily considering the changes in human population and energy consumption. Forecasted emission data then determine fundamentally the output values of the different models. Scenarios can be described as optimistic, pessimistic or intermediate (Fig. 1).

Fig. 1. – page 112

For the purposes of estimating future climatic processes on the Maros/Mureş catchment, two regional models were applied (ALADIN and REMO). Both models work with the A1B scenario, which assumes a moderate increase in the emission of greenhouse gases and an average degree of global warming (Fig. 1). 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. 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.

Several climate models comprise the territory of the Carpathian Basin, these are the ALADIN, the REMO, the PRECS and the RegCM (Szépszó et al. 2008). When analysing the Maros/Mureş catchment, the change of climatic parameters was calculated on the basis of the French ALADIN (www.cnrm.meteo.fr/aladin) and the German REMO (www.remo-rcm.de) models, since these models are based on the A1B scenario, which is an intermediate type of social-economic models on the future. 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 (IPCC 2007).

The horizontal resolution of the applied model data is approximately 25 km. The models were ran by the Numerical Modelling and Climate Dynamics Division of the Hungarian Meteorological Survey. 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. From the daily data series average values were calculated for those months which are important in terms of the hydrology of the Maros/Mureş. Values were calculated for the grid points, interpolation between points was made by using kriging.

Results

Warmer winters with slightly more precipitation

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. 2). 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. 2). 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. 2, 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. 3). Average values though hide some regional differences. Both models agree that there can be a notable increase in precipitation in the area of the Giurgeu Mountains, while only a slight increase (REMO) or even a substantial decrease (ALADIN) can be expected in the west (Fig. 3).

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. Nevertheless, at higher altitudes in the Eastern Carpathians the snow reserves might be higher than earlier as a matter of precipitation increase. It remains a question however, how torrent these floods can be in the future, as this is mostly determined by the intensity of snow melt.

Fig. 2. – page 114
Fig. 3. – page 115

Warmer springs, uncertain change in early summer precipitation

March and April temperature is very important from the aspect of snow melt and therefore the development of floods. Based on the models, a general temperature increase can be expected (Fig. 4). 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).

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, in years of higher winter precipitation the chance of the development of extreme floods can increase.

Fig. 4. – page 116

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). According to average data calculated for the entire catchment, the REMO forecasts an insignificant change 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). The pattern of change is also different. According to the ALADIN model, the most significant increase can be expected in the middle of the drainage basin. On the contrary the 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 almost impossible to tell whether the significance of early summer rain-fed floods will increase or decrease. If we take the average of the two models then rather insignificant changes can be expected.

Fig. 5. – page 117

Hot and dry summers

As it was mentioned earlier, the low water period starts sometime in July (Boga and Nováky 1986). From August discharges can be as low as 50 m^3/s. The volume of water arriving to the lowland sections is primarily determined by the intensity of evaporation and the amount of precipitation supply 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. 6). The expected temperature growth is fairly uniform on the catchment, however, according to the ALADIN, warming will mostly affect the Gurghiu Mountains and the lowland areas, while the REMO predicts the most intensive increase on the middle part of the catchment (Fig. 6). Therefore, the spatial pattern for warming cannot be unambiguously determined.

In the meantime, there is a high chance for the decrease of summer precipitation as well. 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 (Fig. 7). However, both models agree that by 2071–2100 precipitation loss can be around 55 mm, affecting mostly the middle part of the catchment. The decrease can be less intensive in the western slopes of the Hargitha, Giurgeu and Gurghiu Mountains (Fig. 7).

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.

Fig. 6. – page 119
Fig. 7. – page 120

Warmer autumns with hardly changing precipitation

Based on previous observations (Konecsny and Bálint 2007), usually the September–October period brings the lowest discharges on the Maros/Mureş (sometimes only 30–40 m^3/s). If catchment scale average temperature change is considered the two models are in good agreement (Fig. 8). 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. 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 Târnava Tableland temperature rise can be dramatic (Fig. 8).

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 (Fig. 9). 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 the Maros/Mureş.

Fig. 8. – page 121
Fig. 9. – page 122

Hydrological perspectives

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.

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 (Fig. 10). 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 (Fig. 11). 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.

Fig. 10. – page 123
Fig. 11. – page 124

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. 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/Mureș 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. 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

In this section we presented calculations concerning the future climate of the Maros/Mureş catchment. We also outlined the tendency of expectable changes concerning the hydrological regime of the river. The most important conclusions are the following:

- 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 rain-fed 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.

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