Tema broja / Topic:

IZ POVIJESTI OKOLIŠA RIJEKE DRAVE

FROM THE DRAVA RIVER'S ENVIRONMENTAL HISTORY

CLIMATE CHANGE IN THE EASTERN ALPS AND THE FLOOD PATTERN OF THE DRAVA RIVER

KLIMATSKE PROMJENE U ISTOČNIM ALPAMA I POPLAVNI OBRASCI RIJEKE DRAVE

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Sažetak

Značajan porast temperature (iznad svjetskog prosjeka od 0,2°C po desetljeću) predviđa se za alpski dio dravskog područja s većom vjerojatnosti od samih promjena u količini i godišnjem režimu padalina. Mjesečni oborinski podaci pokazuju sve veće vrijednosti na sjeveroistoku i karakteristične padajuće trendove u južnom dijelu bazena, s rastućom opasnošću od suše. Jednostavna korelacija između dugoročnih oborina (dnevne, tjedne i mjesečne vrijednosti) i pražnjenja Drave ne može se pronaći u meteorološkim povijesnim podacima. Moguće je objašnjenje da generacija otjecanja također ovisi o obliku padalina, zasićenju tla vodom i vegetacijskom pokrovu. Budući da su ovi čimbenici povezani s klimatskim promjenama, istražuje se jesu li godišnji obrasci poplava na rijeci Dravi pobliže ovisni o topljenju snijega ili o trajanju i količini kiše. Za razliku od dubine snijega i dana sa snježnim pokrovom, zasićenje tla u ljeto pokazuje povećanje gornjeg sliva. Dok se veliko proljetno topljenje snijega postupno pomiče k sve ranijim datumima, visoke razine vode u rano proljeće ne dosežu razine poplave. Istražuje se kako raspodjela oborina na gornjem toku Drave i gornjoj Muri utječe na poplave na donjem porječju Drave.

Ključne riječi: klimatske promjene, oborine, poplave, Drava, Mura
Keywords: climate change, precipitation, floods, Drava, Mura

INTRODUCTION

The flood-generating runoff on the Drava mostly derives from tributaries in the mountainous section of the drainage basin located on the territory of Austria (Wachter 2006). Because of the dissected Alpine topography, the distributions of precipitation and runoff coefficient are highly variable and the direct influence of topography (the so-called orographic effect – Lauscher 1976) is difficult to predict. A recently deceased renowned Hungarian hydrogeographer, György Lovász, analysed meteorological data for 85 stations in the upland Drava and Mura catchments (mostly in Austria) in his monograph on the Drava and Mura rivers (Lovász 1972). He described vertical temperature distribution in winter and summer and estimated the extent of orographic control on precipitation distribution. Even with global warming, the revealed fundamental regularities in the distribution of precipitation are still valid today.

The Alps were among the first regions of Europe where climate change was detected (Rudloff 1967) and the largest number of observations indicate change in climatic parameters throughout the 20th (Goler et al. 2000) and 21st centuries. The long-term trends of climate change, however, are difficult to predict as there are large year-to-year oscillations in climatic elements (temperature, precipitation, depth and particularly the duration of snow cover – Smiatek et al. 2009). Several authors (including Auer et al. 2001) claim that temperature rise can be much better predicted for the future than changes in the amount and annual regime of precipitation. In Austria mean summer temperatures have increased by almost 2°C and winter temperatures by ca. 1°C since the 1970s (Schöner et al. 2011) and a further growth of 1°C until 2050 is foreseen.

The observed signs of climate change induced a series of hydrological studies in the Drava basin. Šraj et al. (2007) published a hydrological monograph on the entire Mura drainage basin. They analysed precipitation distribution from data for 99 meteorological stations (83 stations in Austria, 2 in Slovenia, 3 in Croatia and 11 in Hungary). While temperature was rising throughout the basin, monthly precipitation data available for all stations for the period 1971–2000 and for 57 station for 1961–2005 show starkly contrasting trends: increasing values in the northeast and a remarkable drop in the southern part of the basin. Merz et al. (2006) and Merz and Blöschl (2009) analysed a total of 64,461 rainfall events in 459 catchments of Austria and found antecedent soil moisture as the most decisive factor controlling runoff.

In the southern valleys and basins winter temperature and precipitation values tend to drop, but occasionally show high extremes. Although the rate of change is slow, in the Alpine regions of the Drava catchment higher and higher precipitation amounts are recorded decade by decade. Eitzinger et al. (2016) found annual precipitation between 2002–2014 to be higher than the long term (1981-2010) average in several Austrian study sites. Seasonal distribution is generally favourable with most precipitation falling in the growing season (April-September), but a shift towards the winter half-year (October-March) is also discernible (Strauss et al. 2013). In 29 % of dry years between 2002 and 2014, precipitation totals were both below winter and summer averages (Eitzinger et al 2016). More fundamental changes in precipitation and evapotranspiration are predicted for the second half of the 21st century (BMLFUW 2010).

Although land use and soil properties certainly influence infiltration/evapotranspiration/runoff ratios locally (see e.g. Chifflard et al. 2004), they are likely to average out over larger catchments. The analyses of variations between subcatchments have disclosed the impact of different topographic parameters on river regime (Eder et al. 2001).

Runoff generation in upper Drava catchment is strongly affected by snow and glacier melt (Eder et al. 2001). In the southern alpine region storm tracks from the Mediterranean fundamentally influence soil moisture variability. In the lower part of the southern alpine region, however, rainfall is significantly lower and snow processes are less influential (Merz and Blöschl 2009).

Historical floods on the Drava have been studied by Petrić and Obadić (2007). Along the lower section of the Drava River, the coincidence of floods on the Danube and its tributaries were analysed (see e,g, Prohaska and Ilić 2010). Floods of the lower Drava are caused by its high discharges, backwater effect of the Danube River, ice jams on either of these rivers or (very rarely) coinciding maximum discharges of both rivers (Bonacci et al. 2010; Tadić et al. 2016). Recently, Tadić et al. (2016) found that backwater influences of the Danube control flood occurrence at Osijek, Croatia, particularly over the last 40 years when Drava River discharges and water levels have dropped and the discharges and water levels of the Danube River have increased.

Modelling approaches through the downscaling of regional climate models, such as the CLM (relying on the Global Climate Model of the Max Planck Institute), based on the A1B scenario judged most probable in previous IPCC reports, have been applied to the Drava-Mura Basin (Kromp-Kolb and Schwarzl 2009; Smiatek et al. 2009; Schöner et al. 2011). The prediction period was for the period of 2021–2050 with 1976–2007 used as reference. The outcome of the calculation is in accordance with the prediction for the lower Drava Basin and the Carpathian Basin (KVVM 2008, MFGI NAK 2013): as regards mean air temperature, a rise of ca 1°C is foreseen. Milder winters are in sight involving less snow and earlier snowmelt. Warming, however, is expected to be more pronounced in the summer half year. Hydrologists warn that 1-2°C change in temperature and increased (up to ±30 %) year-to-year variability in annual precipitation may lead to 60 % modification in runoff (Nováky and Bálint 2013).

The above changes will probably fundamentally influence hydrological conditions in the Drava-Mura catchment. Among the direct impacts of climate change in the Alpine regions higher flood risk is usually mentioned (Niederer 2013).

METHODS

To overview the impact of climate change both long and short-term trends in meteorological parameters should be analysed. The longest data series almost cover the entire 20th century for most of the countries of the Drava basin. Decadal changes in river discharge can be best detected from a simple comparison of monthly precipitation and snowmelt data between the first and second half of the 20th century. Since direct human impact (hydroelectric developments) has heavily transformed water regime, time series of daily discharge along the middle section of the Drava River are less suitable for such a comparison. Upstream the cascades of hydroelectric plants, however, discharges are only moderately influenced by anthropic effects. Therefore, the time series from the meteorological stations and river gauges at Amlach (near Lienz, East Tirol) and Oberdrauburg, Carinthia, respectively, had been selected for an analysis of the Drava water regime and from Bruck an der Mur for the Mura water regime (Fig. 1). On-site correlations between total precipitation and water discharge are calculated.

Temperature and precipitation records at selected hydrographical foci of the Drava (Lienz, at confluence with the Isel, and Villach, Carinthia, at confluence with the Gail) are compared in tabulated form (Table 1). Similarly, for the Mura Bruck an der Mur, Styria, (confluence with the Mürz) and Leibnitz, Styria, (downstream the confluence with the Kainach) long-term climatic time series are shown (Table 1). Data for the first half of the 20th century (1901–1950) are compared to the values for 1971– 2000. The database derives from the Hydrographic Year-books of the Zentralanstalt für Meteorologie und Geodynamik (ZAMG), processed by Lovász (1972) for the period 1901–1950.

Fig. 1 *Topography of the Drava drainage basin with the locations of meteorological stations and river gauges used in the paper*

The upper catchment of the Drava is represented by the Lienz-Tristach meteorological station and the nearby Amlach, East Tirol, river gauge. If maximum monthly precipitation values are plotted, the periods where heavy rainfalls are responsible for high water levels can be identified. The chart clearly shows how many flood events directly derive from local runoff, while the rest result from rainfalls upstream. To take soil moisture conditions into account, daily precipitation time series were also involved into the analysis. The periods with prolonged rainfalls (at least six rainy days within a ten-day interval) are assumed to lead to soil saturation and thus to promote flood generation. Similarly, the indication of the duration of snow cover and snowmelt allows the identification of rain-on-snow events.

The frequency and seasonal occurrence of floods are studied on the discharge time series of Oberdrauburg, Carinthia, on the upper Drava from 1951 to 2014 (source of data: ZAMG). The frequency of floods is estimated from the seasonal distribution of events where the long-term mean river discharge (131 m^3 s-1) was threefold exceeded at the Oberdrauburg gauge. Although flood hazard is more closely related to river levels than river discharges, changes in precipitation amounts are more directly reflected river discharges. Therefore, the discharge values are plotted.

To illustrate the relationship between the monthly distribution of precipitation and river discharge in the Mura catchment, observations at Bruck an der Mur are used (source of data: ZAMG) and compared to the discharge curve at Petanjci, Slovenia, on the lower Mura section.

Different kinds of correlations between precipitation and discharge are expected along the lower sections of rivers. Since at Osijek, Croatia, the river gauge of which town is often used to characterize the lower Drava, the backwater effect of the Danube is strong (Tadić et al. 2016), the time series of the river gauge at Botovo, Koprivnica-Križevci county, (available for the period 1926–2012) is chosen to represent the river regime of the lower Drava section. Unfortunately, opportunities to examine the correlations with regional rainfall are limited as the main meteorological station at Varaždin (selected to represent the Croatian section of the Drava River, 43 km upstream) only supplies precipitation data since 2000. Therefore, a comparison between monthly precipitation and monthly maximum discharges are only made for the 21st century data series.

RESULTS AND DISCUSSION

A simple comparison of climate data for the selected sites from the early and late 20th century confirms climate change trends – opposite in the mountains of the upper catchment and the basins of the middle catchment (Table 1).

Table 1 *Comparison of climatic parameters in selected catchments between 1901–1950 and 1971–2000 time series (data from Lovász 1972 and ZAMG 2016). Bold numbers indicate remarkable change*

station	mean monthly temperature (°C)		change (°C)	average monthly precipitation (mm)		change (mm)
	1901–1950	1971– 2000		1901–1950	1971– 2000	
Lienz, year	7.5	7.0	-0.5	837	915	+78
January	-4.0	-5.2	**-1.2**	35	42	+7
February	-1.6	-1.9	-0.3	46	35	-11
March	3.3	3.1	-0.2	43	59	**+17**
April	8.1	7.6	-0.5	55	66	+11
May	12.8	12.7	-0.1	73	85	+12
June	16.1	15.9	-0.2	94	99	+5
July	17.6	17.9	+0.3	123	119	-4
August	16.8	17.2	+0.4	105	100	-5
September	13.3	13.0	-0.3	79	88	+9
October	8.1	7.3	-0.8	75	96	**+21**
November	1.7	0.6	**-1.1**	64	76	+12

station	mean monthly temperature (°C)		change (°C)	average monthly precipitation (mm)		change (mm)
	1901–1950	**1971– 2000**		**1901–1950**	**1971– 2000**	
December	-2.8	-4.2	**-1.4**	44	50	+6
Villach, year	8.0	8.6	+0.6	1189	1230	+41
January	-4.1	-2.2	**+1.9**	55	61	+6
February	-1.5	-0.2	**+1.3**	55	65	**+10**
March	3.8	4.1	+0.3	73	72	-1
April	8.5	8.3	-0.2	98	103	+5
May	13.5	13.2	-0.2	102	107	+5
June	16.7	16.7	0	129	133	+4
July	18.4	18.6	+0.2	127	129	+2
August	17.6	18.0	+0.4	121	129	+8
September	13.8	14.6	**+0.8**	122	126	+4
October	8.4	9.4	**+1.0**	118	107	**-11**
November	2.5	3.7	**+1.2**	111	119	+8
December	-1.9	-0.7	**+1.2**	78	79	+1
Bruck/Mur, year	7.9	8.1	+0.2	788	887	+99
January	-3.0	-2.3	**+0.7**	36	36	0
February	-0.7	0	**+0.7**	35	41	+6
March	3.8	3.8	0	35	53	**+18**
April	8.0	7.7	-0.3	55	60	+5
May	12.9	12.8	-0.1	81	91	+10
June	15.9	15.9	0	103	121	**+18**
July	17.6	17.8	+0.2	109	126	**+17**
August	16.9	17.5	**+0.6**	97	110	**+13**
September	13.4	13.7	+0.3	76	79	+3
October	8.3	8.5	+0.2	62	61	-1
November	2.8	2.7	-0.1	53	63	+10
December	-1.3	-1.2	+0.1	46	46	0
Leibnitz, year	8.9	9.2	+0.3	943	915	-28
January	-2.9	-2.1	**+0.8**	43	38	-5
February	-0.7	-0.1	**+0.6**	41	40	-1
March	4.5	4.5	0	48	49	+1
April	9.5	9.4	-0.1	73	62	-11
May	14.4	14.3	-0.1	91	93	+2
June	17.6	17.6	0	115	118	+3
July	19.4	19.4	0	106	119	**+13**
August	18.4	18.6	+0.2	112	109	-3
September	14.7	14.9	+0.2	95	85	**-10**
October	9.3	9.6	+0.3	90	78	**-12**
November	3.6	3.9	+0.3	70	72	+2
December	-0.6	-0.2	+0.4	59	52	-7

In closed mountain basins winters have become colder (Table 1, Lienz). Spring and autumn rainfalls resulted in almost 10 % growth in annual precipition, pointing to increasing Mediterranean cyclonic activity. In contrast, in the Illyric (submediterranean) basins and valleys (represented by Villach – Table 1) the whole winter half-year have become remarkably warmer, but the climate turned to only moderately wetter. A slight warming can be detected in the valleys of Atlantic influence (Table 1, Bruck an der Mur) with higher spring and summer precipitation (intensifying oceanic influence). Winter temperatures have risen close to the boundary of the Pannonian zone (Table 1, Leibnitz), but no change was observed in summer. With the exception of July, an aridification trend can be observed.

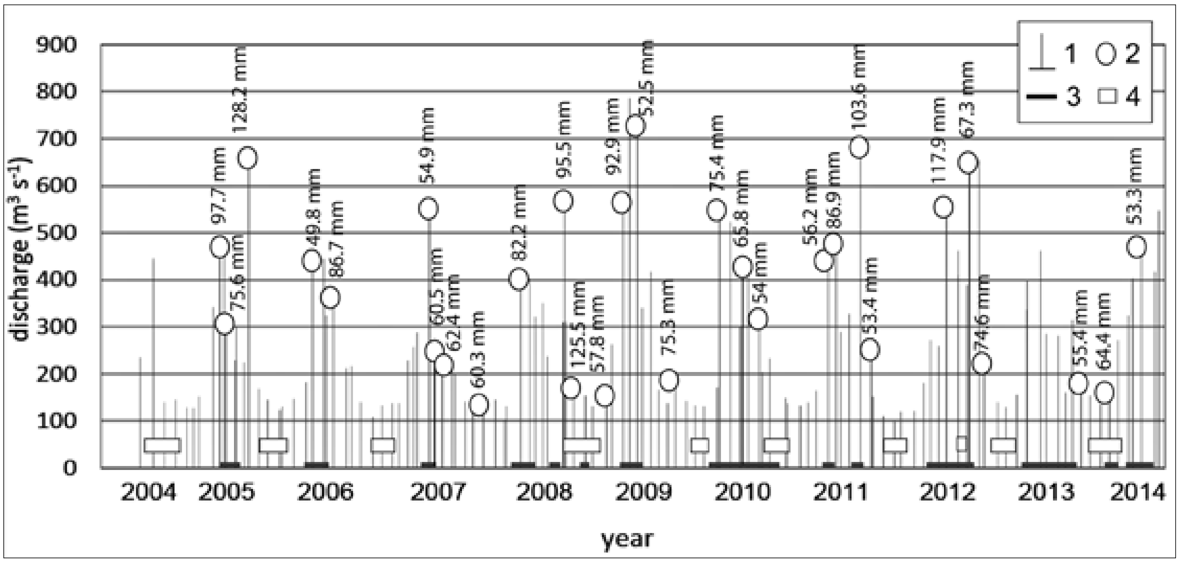

Fig. 2 *Monthly precipitation amounts measured at the Lienz-Tristach meteorological station plotted against Drava monthly discharges at Amlach, 2004–2014 (data source: ZAMG Hydrographic Year-books). 1, monthly precipitation (mm); 2, cumulative rainfall coinciding with high discharge; 3, periods of soil saturation; 4, periods of snow cover*

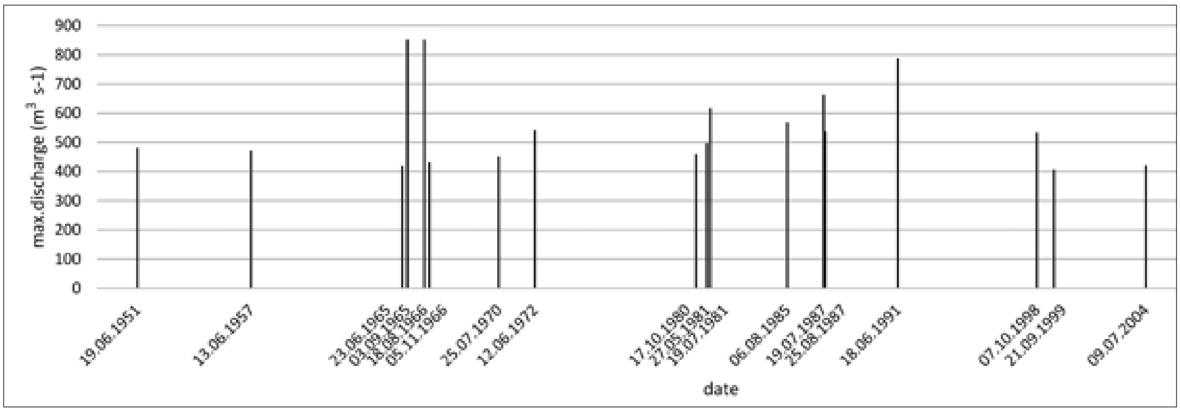

Fig. 3 *Maximum flood discharges on the Drava River at the Oberdrauburg gauge, 1950-2008 (data source: ZAMG)*

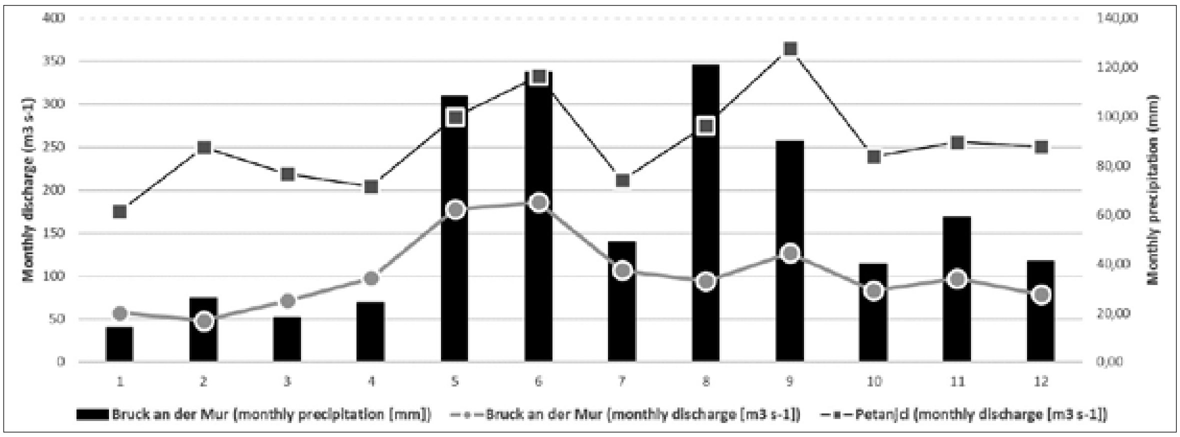

Fig. 4 *Long-term trends in annual precipitation and Drava river discharge at Oberdrauburg, 1901–2000 (data source: ZAMG)*

The impact of the growth in autumn rainfall amounts observed for Lienz (Table 1, Fig. 2) is detectable in the increasing frequency of September and October floods on the Drava at Oberdrauburg (Fig. 3). Although some authors claim that the early summer flood stages of the Drava and its tributaries tend to fall and, at the same time, in autumn water levels are becoming somewhat higher (Prettenthaler et al. 2007), the predominance of early summer (June-July) floods is typical throughout the studied period.

The correlation coefficient between the precipitation and Drava discharge time series at Oberdrauburg for the period 1926-2000 is surprisingly low: only 0.27 (Fig. 4)! In Fig. 2 only few of the high discharges are matched with high rainfall amounts (indicated by circles). Since 2008 the overlaps between soil saturation and snow cover are becoming more and more common, indicating favourable conditions for the rain-on-snow phenomenon, which often generates rapid snowmelt and flooding.

As opposed to the general observation that extreme weather situations are becoming more common during climate change (e.g. Goler at al. 2016), at the Botovo gauge, which represents the lower Drava basin (Fig. 5), the standard deviations of both monthyl precipitation and monthly maximum discharge

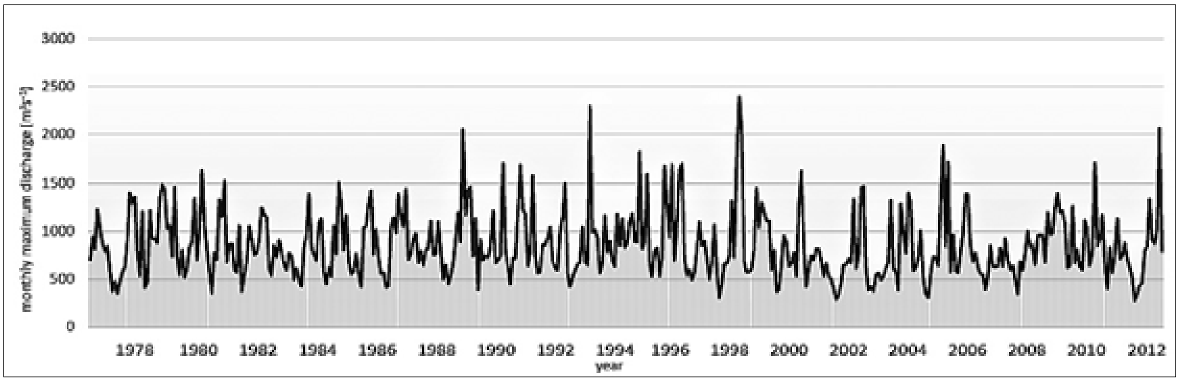

Fig. 5 *Monthly precipitation at Varaždin and monthly maximum discharges of the Drava River at Botovo (data source: Meteorological and Hydrological Service of Croatia, DHMZ)*

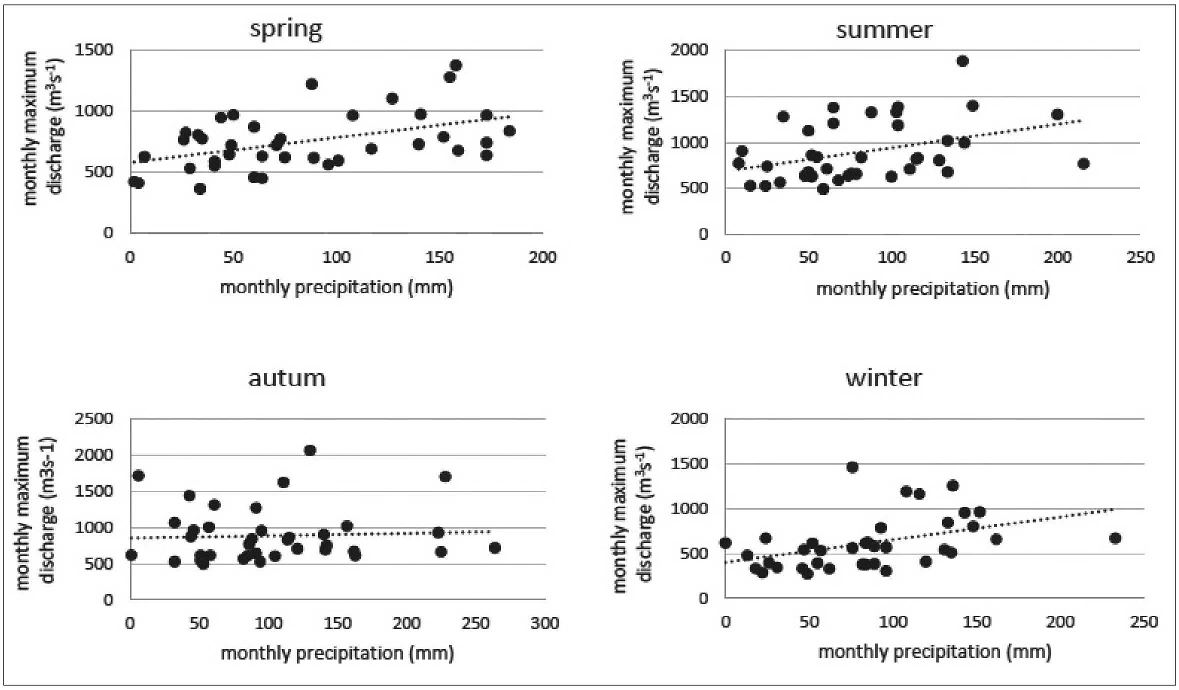

Fig. 6 *Seasonal variation in the relationship between monthly precipitation (at Varaždin) and monthly maximum discharge of the Drava (at Botovo), 2000–2012 (data source: DHMZ)*

time series tend to decline since 1980, an interval with the least flood events. Naturally, precipitation in the Varaždin area has no fundamental contribution to the Drava discharge at Botovo, but broken down to seasons (Fig. 6), it becomes clear that spring and summer rainfalls are often responsible for high discharges on the lower Drava, while autumn rainfalls are less influential.

CONCLUSIONS

Climate change will probably involve the following changes identified for the territory of Austria (Formayer at al. 2001):

- a marked rise in annual mean temperature, less pronounced in maximum monthly temparature in mountain environment;
- considerable growth in the number of sunshine hours in winter;
- higher precipitation amounts in mountains, lower in the lowland;
- snow depth increases in the upland section and decreases in the lowland;
- the duration of snow cover reduced in the lowland (established with high uncertainty);
- the number of sunshine hours has grown in the mountains and in winter;
- relative air humidity has markedly decreased;
- cloud cover increased in summer, but in winter only increased at higher elevations, reduced in the valleys.

While in some closed basins (like the Isel catchment) the orographic effect is weak and annual precipitation at higher elevations is much below average, in topographically open catchments, Mediterranean air is able to flow in through the gaps of mountain ranges and this explains why autumn floods are becoming more and more common in the upper Drava valley. This points to the expansion of Mediterranean influence upstream the upper Drava and its tributaries. In recent decades floods on the upper Drava are more often occur due to major autumn rainfall events generated by Mediterranean cyclone incursions than spring and early summer floods due to air currents of Atlantic origin.

An opposite trend is apparent for the lower Drava catchment, where flood occurrence is more controlled by spring and summer rainfall events.

In the past decade precipitation amounts only increased in some basins of the mountainous section and the duration of snow cover has somewhat reduced. However, longer periods of soil saturation led to prolonged high-water stages, particularly in summer and autumn.

Both rainy periods are observed in the upper Mura catchment, too, with increasing annual amounts and their influences are also detectable in the river regime of the lower Mura and even of the lower Drava.

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SUMMARY

A remarkable temperature rise (above the world average of 0.2°C per decade) is predicted for the Alpine section of the Drava catchment with higher likelihood than changes in the amount and annual regime of precipitation. Monthly precipitation data show increasing values in the northeast and characteristic dropping trends in southern part of the basin, with growing drought hazard. A simple correlation between long-term precipitation (daily, weekly and monthly values) and Drava discharge cannot be found from meteorological records. A possible explanation is that runoff generation also depends on the form of precipitation, water saturation of soils and vegetation cover. Since these factors are all related to climate change, the paper investigates whether the annual pattern of floods on the Drava River depends more closely on snowmelt or on the duration and amount of rainfall. As opposed to snow depth and days with snow cover, soil saturation in summer shows an increase in the upper catchment. While large-scale spring melt is gradually shifting to earlier dates, early spring high water levels do not reach flood levels. It is investigated how the distribution of precipitation along the upper Drava and upper Mura control flood response in the lower Drava catchment.

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