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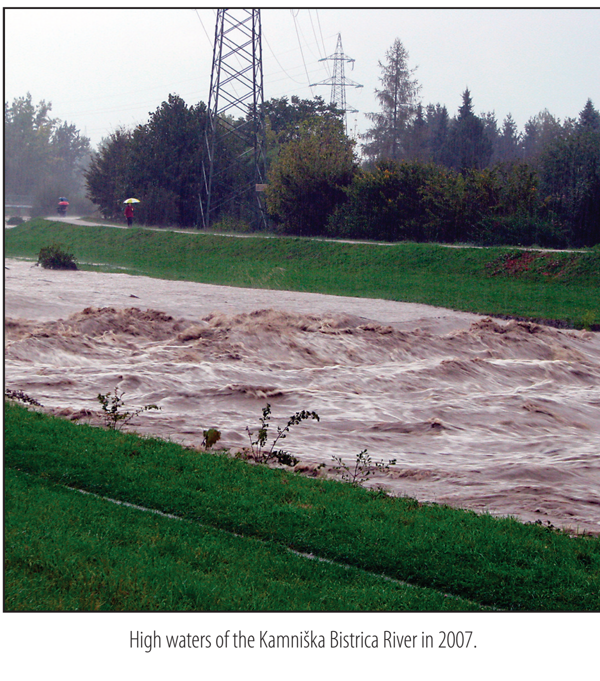
THE INFLUENCE OF CLIMATE CHANGE ON DISCHARGE FLUCTUATIONS IN SLOVENIAN RIVERS

Janij Oblak, Mira Kobold, Mojca Šraj



High waters of the Kamniška Bistrica River in 2007.

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Janij Oblak[1], Mira Kobold[1,2], Mojca Šraj[1]

The influence of climate change on discharge fluctuations in Slovenian rivers

ABSTRACT: In recent decades, an increase in the number of extreme flood events as well as extreme drought events has been observed in Slovenia. This rise the need for a comprehensive analysis of trends in discharge data series. In the study, statistical trends in seasonal and annual mean, maximum, extreme and low discharge values were investigated using the Mann Kendall test. The results show a temporal and spatial variability of trends in discharge. In general, a decreasing trend in water quantities in the rivers was observed. However, results at some gauging stations indicate statistically significant increasing trends, especially for maximum and extreme discharges. Additional analyses show that the discharge trends depend on the location of the gauging station.

KEY WORDS: hydrology, geography, trend analysis, Mann Kendall test, discharges, Slovenia

Vpliv podnebnih sprememb na nihanja pretokov v slovenskih rekah

POVZETEK: V zadnjih desetletjih v Sloveniji opažamo povečanje števila tako ekstremnih poplavnih kot tudi ekstremnih sušnih dogodkov. To kaže na potrebo po kompleksni analizi trendov v serijah podatkov o pretokih. V raziskavi smo s pomočjo testa Mann Kendall analizirali statistične trende sezonskih in letnih povprečnih, največjih, ekstremnih in nizkih vrednosti pretokov. Rezultati kažejo časovno in prostorsko spremenljivost trendov pretokov. V splošnem smo zaznali trend zmanjševanja količin vode v rekah. Rezultati nekaterih vodomernih postaj pa kažejo na statistično značilno naraščajoče trende, zlasti za največje in ekstremne pretoke. Dodatne analize kažejo, da so trendi pretokov odvisni od lokacije vodomerne postaje.

KLJUČNE BESEDE: hidrologija, geografija, analiza trenda, Mann Kendallov test, pretoki, Slovenija

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1 Introduction

A recent study by Blöschl et al. (2019) demonstrated that no uniform pattern in trends of flood discharge series can be found in Europe in the past five decades. They identified three regional patterns of both increasing and decreasing trends in flood discharges in Europe. Floods are becoming increasingly severe in northwestern Europe, while their intensity is decreasing in southern and eastern Europe. Increasing floods in northwestern Europe are the result of increasing autumn and winter precipitation, while the decreasing trend of flood events in southern Europe is the result of decreasing precipitation and increasing evaporation. However, the decreasing snow cover due to global warming is the reason for the decrease in flooding in Eastern Europe. The average increasing trend of floods in Europe is up to 11% and decreasing by up to 23% per decade (Blöschl et al. 2019). Similarly, Mediero et al. (2015) found a mixed pattern of changes in flood frequency and few significant changes in the flood timing at a pan-European scale by using the longest streamflow records. They identified a stronger field-significant decreasing trends in flood magnitude in the Atlantic region comparing the periods 1920–1999 and 1956–1995 as well as in the Continental region comparing the periods 1900–1999 and 1939–1998. An unclear trend pattern was found in terms of annual number of floods above a threshold, apart from a decreasing trend in the Alpine region for all the periods considered. No clear trend patterns were found with respect to the timing of floods, apart from field-significant increasing trends in the continental region and decreasing trends in the Alpine region in the period 1900–1999 (Mediero et al. 2015). In neighbouring Austria, annual maximum floods for the period 1976–2007 showed increasing trends in 17% of the catchments with a general tendency for increasing trends in the north, decreasing trends in the south, increasing trends in winter floods in the west and decreasing trends in the southeast (Hall et al. 2014). The majority of the stations showed no significant change. For the Alpine region of France, Switzerland, Germany, Italy, Austria and Slovenia, an increasing trend in spring floods associated with snowmelt is found during 1961–2005 (Hall et al. 2014).

In Slovenia, due to high climatic diversity, the magnitude and frequency of flood events is expected to increase at some gauging stations and decrease in others (Bezak, Brilly and Šraj 2016; Kovačič 2016; Šraj et al. 2016; Šraj, Menih and Bezak 2016; Hrvatin and Zorn 2017a; Šraj and Bezak 2020). Furthermore, an increase in torrential flooding is expected due to the increase in local convective precipitation (Blöschl et al. 2019). Indeed, Slovenia has faced an increasing number of flood events causing high damage and even fatalities (Zorn and Komac 2011; Komac and Zorn 2020). Analyses show that extreme flood events have occurred more frequently since 1990 than before (Kobold, Dolinar and Frantar 2012). To name a few, the Železniki flood in 2007 claimed six lives (Kobold 2008), in 2010 part of Ljubljana was flooded (Strojan et al. 2010), and in 2012 Drava River flooded due to increased runoff from neighbouring Austria (Klaneček 2013). Furthermore, in 2014, Slovenia experienced a total of 83 days with high hydrological conditions in at least one river catchment (Golob and Polajnar 2016), flooding karst poljes (Frantar and Ulaga 2015), part of the capital was flooded again (Fazarinc 2014), and the Bolska stream with two fatalities and the Mislinja River with one fatality showed their strength again.

On the other hand, temperature changes and uneven temporal and spatial distribution of precipitation (Hrvatin and Zorn 2017b; Ocena tveganja za sušo 2017; Cunja, Kobold and Šraj 2019) are increasingly causing water scarcity and droughts in Slovenia as well (Kajfež-Bogataj and Bergant 2005; Sušnik et al. 2013; Šebenik, Brilly and Šraj 2017; Cunja, Kobold and Šraj 2020; Jelen, Mikoš and Bezak 2020). After 1990, agricultural drought was declared 11 times in Slovenia, 9 of since 2000 (2000, 2001, 2003, 2006, 2007, 2009, 2012, 2013, 2017). In most of these years, the drought reached the level of a natural disaster, which means that the estimated direct damage exceeded 0.3‰ of the planned state budget revenue (Ocena tveganja za sušo 2017).

Given that an increased number of both extreme flood events (Kobold, Dolinar and Frantar 2012) and extreme drought events (Sušnik et al. 2013; Ocena tveganja za sušo 2017) have been observed in Slovenia in recent decades, the need for comprehensive analyses of trends in different types of discharge data series arose. Therefore, the main objectives of the study were to investigate trends in (i) seasonal and annual mean discharge values (Qs), (ii) seasonal and annual maximum mean daily discharge values Qvp, (iii) extreme seasonal and annual flood discharge values defined by the peak-over-threshold method with an average of one (POT 1) and three (POT3) peaks per year and (iv) seasonal and annual low discharge indices describing the 7- and 30-day duration of low flows (Qmin7 and Qmin30).

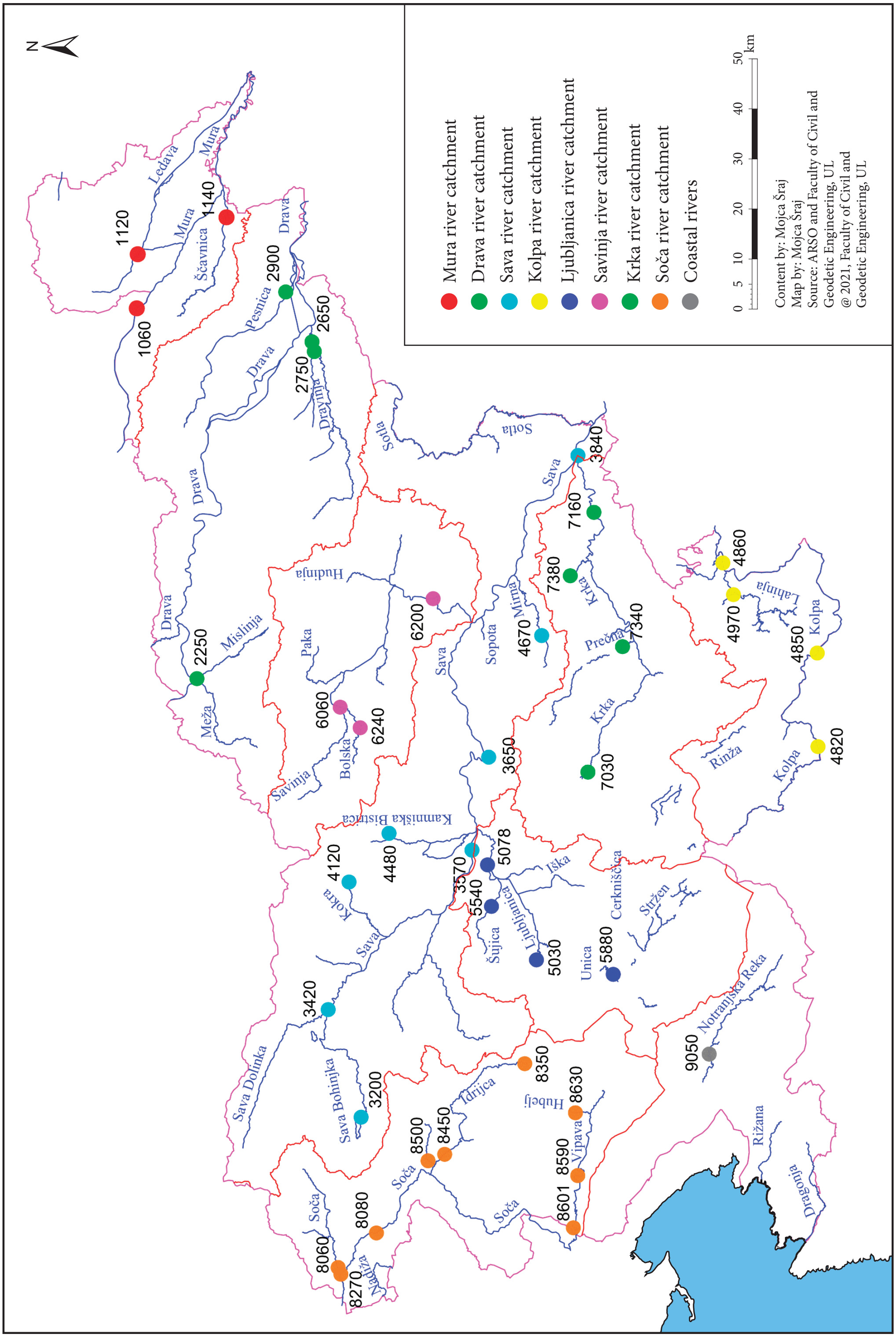
2 Data and methods

Analyses were performed based on daily discharge data series (Arhiv hidroloških podatkov 2017) at 40 gauging stations in Slovenia (Table 1 and Figure 1). The criteria for inclusion of individual gauging station into the study were as follows: (1) at least 52 years of data (1961–2013), (2) no gaps in the data series, (3) uniform

Table 1: List of gauging stations studied with associated catchment area (Arhiv hidroloških podatkov 2017).

Station code	Main catchment	Gauging station	River	Catchment area [km^2]
1060	Mura River	Gornja Radgona	Mura	10,197.2
1140		Pristava	Ščavnica	272.5
1220		Polana	Ledava	208.2
2250	Drava River	Otiški Vrh	Meža	550.9
2650		Videm	Dravinja	763.8
2750		Tržec	Polskava	187.8
2900		Zamušani	Pesnica	477.8
3200	Sava River	Sveti Janez	Sava Bohinjka	94.0
3420		Radovljica	Sava	908.0
3570		Šenjakob	Sava	2,284.8
3650		Litija	Sava	4,821.4
3840		Čatež	Sava	10,185.8
4120		Kokra	Kokra	112.3
4480		Nevlje	Nevljica	82.0
4670		Martinja vas	Mirna	164.6
4820	Kolpa River	Petrina	Kolpa	460.0
4850		Radenci	Kolpa	1,191.0
4860		Metlika	Kolpa	2,002.0
4970		Gradac	Lahinja	221.3
5030		Vrhnika	Ljubljanica	1,135.1
5080		Moste	Ljubljanica	1,762.5
5540		Razori	Šujica	46.9
5880		Hasberg	Unica	Karst
6060	Savinja River	Nazarje	Savinja	457.3
6200		Laško	Savinja	1,663.6
6240		Kraše	Dreta	100.8
7030	Krka River	Podbukovje	Krka	321.4
7160		Podbočje	Krka	2,238.1
7340		Prečna	Prečna	294.2
7380		Škocjan	Radulja	108.0
8060	Soča River	Log Čezsoški	Soča	324.7
8080		Kobarid	Soča	437.0
8270		Žaga	Učja	50.2
8350		Podroteja	Idrijca	112.8
8450		Hotešk	Idrijca	442.8
8500		Bača pri Modreju	Bača	142.3
8590		Dornberk	Vipava	468.5
8600		Miren	Vipava	590.0
8630		Ajdovščina	Hubelj	93.2
9050	Coastal Rivers	Cerkvenikov mlin	Reka	377.9

Figure 1: Location of the considered gauging stations coloured according to the associated river catchment. ►


Mura river catchment
Drava river catchment
Sava river catchment
Kolpa river catchment
Ljubljanica river catchment
Savinja river catchment
Krka river catchment
Soča river catchment
Coastal rivers
0 5 10 20 30 40 50 km
Content by: Mojca Šraj
Map by: Mojca Šraj
Source: ARSO and Faculty of Civil and Geodetic Engineering, UL
@ 2021, Faculty of Civil and Geodetic Engineering, UL

spatial distribution of stations covering different flow regimes, and (4) data from the catchments with the least possible anthropogenic influence or where the influence of human activities, such as deforestation, urbanization, construction of reservoirs, water abstraction is minimal (Kundzewicz et al. 2005). The choice of the end of the time period under consideration is related to the missing data. Slovenian Environment Agency carried out the renovation of Slovenian gauging stations within the BOBER project (Roškar 2015) in 2014–2016 and there was a data outage (semi-annual and more) at most gauging stations during these years.

Statistical trends were investigated using seasonal and annual mean discharge values (Qs), seasonal and annual maximum mean daily discharge values Qvp, extreme seasonal and annual flood discharge values defined by peak-over-threshold method (POT) with an average of one (POT 1) and three (POT3) peaks per year, and seasonal and annual low discharge indices describing the 7- and 30-days duration of low discharges (Qmin7 and Qmin30).

POT samples were defined using Hydrospect software (Radziejewski 2011). More details about the POT method can be found in (Bezak, Brilly and Šraj 2014). In order to detect trends in aforementioned data samples non-parametric Mann Kendall (MK) test was applied (Kendall 1975) (Equations 1-3), which is one of the most commonly used tests for detecting trends in hydro-meteorological data. Its greatest advantage is that it is robust against missing values and ties in the data and does not require normality of the data (e.g., Douglas, Vogel and Kroll 2000; Strupczewski, Singh and Feluch 2001; Šraj et al. 2016). The null hypothesis of the MK test is that there is no trend in the series and the alternative hypothesis is that there is either positive or negative trend in the tested series (Bezak, Brilly and Šraj 2016). The MK test statistic τ is defined as follows (Douglas, Vogel and Kroll 2000):

$$\tau = S/D \quad (1)$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_j) \quad (2)$$

$$D = n(n-1)/2 \quad (3)$$

where *x* is the discharge value at time *i* and *j*, and *n* is the sample length. Kendall package (McLeod 2011) implemented in R software (R Core Team 2013) was used for the trend analyses. The significance levels of 0.05 and 0.1 were applied to identify the statistical significance of the trends in the data series. Additionally, the presence of serial correlation in the data series was investigated in order to avoid incorrectly rejecting the null hypothesis of no trend in the time series (Yue, Pilon and Cavadias 2002; Šraj et al. 2016).

3 Results and discussion

3.1 Trend analysis

The results of the trend analyses for all considered data series are presented in Figure 2. The analysis of the mean discharge values (Qs) shows that the mean annual discharges decreased during the period 1961–2013 at all the considered stations, statistically significant at most of them (25 at the significant level of 0.05 and 6 at the significant level of 0.1). This finding is consistent with the results of Frantar, Kobold and Ulaga (2008), who analysed the trends of mean discharges at the 22 gauging stations in Slovenia using the data for the whole observations period up to and including the year 2005. Obviously, the decreasing trend of mean discharges continues 10 years later. Further analysis by season shows that the decrease in mean discharge in the summer and spring seasons is statistically significant for the majority of the gauging stations considered. In fact, the rivers of the Adriatic catchment have a statistically significant decrease in mean discharge in the summer season and the rivers of the Black Sea catchment in the summer and spring seasons. The mean discharges in winter and autumn mostly do not show statistically significant trends. The decrease in mean discharges is mostly the consequence of the decrease in precipitation and the increase in temperature, which in turn increases evapotranspiration in recent decades (Frantar, Kobold and Ulaga 2008;

Figure 2: Results of trend analyses for the period 1961–2013. ➤


1060
1140
1220
2250
2650
2750
2900
3200
3420
3570
3650
3840
4120
4480
4670
4820
4850
4860
4970
5030
5080
5540
5880
6060
6200
6240
7030
7160
7340
7380
8060
8080
8270
8350
8450
8500
8590
8600
8630
9050
Qs winter
Qs spring
Qs summer
Qs autumn
Qvp winter
Qvp spring
Qvp summer
Qvp autumn
POT3 winter
POT3 spring
POT3 summer
POT3 autumn
POT1 winter
POT1 spring
POT1 summer
POT1 autumn
Qmin7 winter
Qmin7 spring
Qmin7 summer
Qmin7 autumn
Qmin30 winter
Qmin30 spring
Qmin30 summer
Qmin30 autumn
Qs
Qvp
POT3
POT1
Qmin7
Qmin30
Positive trend
Statistically significant positive trend at α=0.1
Statistically significant positive trend at α=0.05
Negative trend
Statistically significant negative trend at α=0.1
Statistically significant negative trend at α=0.05
Trend was not determined

Ocena tveganja za sušo 2017; Maček et al. 2018; Šraj, Mikoš and Bezak 2019). The results are consistent with those published by Stahl et al. (2010), who came to a regionally coherent picture of annual discharge trends with negative trends identified mainly in the headwater catchments of the larger rivers (e.g. Danube River) of Austria and Germany, Czechia and Slovakia, while positive trends were identified for the main streams of the larger rivers.

The annual maximum mean daily discharges (Qvp) do not show such a uniform trend as the mean annual discharges (Figure 2). Two gauging stations, Prečna (7340) and Škocjan (7380) in the Krka River catchment show a statistically significant increasing trend (at the significant level of 0.1) in the annual maximum discharge series. Previous studies have shown also that some gauging stations in Slovenia have statistically significant trends in the annual maximum flood series (Kobold, Dolinar and Frantar 2012; Bezak, Brilly and Šraj 2016; Šraj, Menih and Bezak 2016). For example, Škocjan gauging station (7380) on the Radulja River with a statistically increasing trend in annual maximum discharges is one of the stations, that have been investigated in detail in some other studies investigating the impact of variable climate on floods in Slovenia (Šraj, Menih and Bezak 2016; Šraj and Bezak 2020). A detailed study of the relationship between annual maximum discharges and annual precipitation have demonstrated a good correlation between high annual precipitation and high discharges for Škocjan at the Radulja River (Šraj, Menih and Bezak 2016). On the other hand, 10 gauging stations show statistically significant decreasing trends in annual maximum discharge series (7 at the significant level of 0.05 and 3 at the significant level of 0.1). Stations with a decreasing trend are located in various river catchments; however, most of them in the Soča River catchment. The rivers of the Adriatic Sea catchment mostly demonstrate a statistically significant decreasing trend in the maximum discharges in the spring and summer seasons, while we cannot give unambiguous conclusions for the rivers of the Black Sea catchment. We can only state that we have quite a few stations in the Ljubljanica and Kolpa river catchments with a statistically significant decrease in the annual maximum discharges in summer. We can make a general statement that the results of the trends of the maximum annual discharges (Qvp) indicate regional diversity with a predominantly decreasing trend, which is in agreement with the results of Frantar, Kobold and Ulaga (2008).

The results of the trend analysis of the extreme annual discharge values defined by the peak-over-threshold method (POT) with an average of one (POT 1) and three (POT3) peaks per year also show no uniform trend. However, compared to the trends in the annual maximum discharges, even more gauging stations demonstrate the statistically increasing trend in the extreme discharge series. 8 gauging stations show statistically significant increasing trends in POT3 data series (4 at the significant level of 0.05 and 4 at the significant level of 0.1) and 6 gauging statins in POT1 data series (5 at the significant level of 0.05 and 1 at the significant level of 0.1). Most of them are located in the Ljubljanica and the Krka River catchments (Figure 2). Among 40 stations considered, only station Kraše (6240) at the Dreta River shows a statistically significant decreasing trend for POT3 data series. Seasonal analysis show that the increasing trend of extreme discharges is statistically significant, especially in the autumn followed by spring. Frantar, Kobold and Ulaga (2008), who analysed trends of discharges at the 22 gauging stations in Slovenia using the data for the whole observation period until 2005, reported an increasing trend for the POT1 data series only for the Ščavnica River. However, they reported that the number of gauging stations with an increasing trend increased in case of the POT3 data series. Thus, it seems that the number of extreme flood events has increased in recent years.

Annual low discharges with a duration of 7 days (Qmin7) decrease statistically significantly for the rivers of the Black Sea catchment (Figure 2). The Kolpa, Ljubljanica and Savinja rivers show statistically significant decreasing trend for all analysed gauging stations, while the Mura, Drava, Sava, and Krka rivers show a statistically significant decreasing trend for most of the considered stations. The rivers of the Adriatic Sea catchment show no uniform trends as 5 gauging stations in the Soča River catchment demonstrate statistically significant decreasing trend and 4 stations do not show any statistically significant trend. All together 30 out of 40 gauging stations show a statistically significant decreasing trend (27 at the significant level of 0.05 and 3 at the significant level of 0.1). Qmin7 discharges decrease at most of the stations in the summer, while in the Kolpa, Ljubljanica and Krka catchments also in the autumn season and in the Drava, Sava, Kolpa, Ljubljanica, Krka and Soča catchments also in the spring season. Frantar, Kobold and Ulaga (2008) reported an increasing trend of low discharges in the karstic and eastern areas of Slovenia using the data for the whole observation period up to 2005. However, they argued that the number of gauging stations with an increasing trend is getting smaller, while the number of those with a decreasing trend increase. The results of this study demonstrate that for the period 1961–2013 none of the considered stations has a statistically significant increasing trend in data series of annual low discharges with a duration of 7 days (Qmin7) anymore. In comparison with other European countries, the study by Stahl et al. (2010) showed that low discharges have decreased in most regions, where the lowest mean monthly discharge occurs in summer, but vary for catchments, which have discharge minima in the winter season and secondary low discharge in summer. In most of western and central Europe, the lowest discharge occurs in late summer, between July and September. In the Alps and northern Europe, the annual minima occur in January and February (Stahl et al. 2010).

Very similar results are observed in the trend analysis of annual low discharges with a duration of 30 days (Qmin30). Overall, together 31 out of 40 gauging stations demonstrate statistically significant decreasing trend (28 at the significant level of 0.05 and 2 at the significant level of 0.1) (Figure 2). Additionally, seasonal trend analysis indicates that summer low discharges (Qmin30) show a statistically significant decreasing trend for 36 stations considered.

3.2 Analysis of station location influence

Since precipitation in Slovenia typically decreases in the direction from west to east, we performed additional analyses of the influence of the water gauging station location on the results of the calculated discharge trends. The analysis was performed using annual and seasonal values for all selected data series, namely Qs, Qvp, POT3, POT1, Qmin7 and Qmin30.

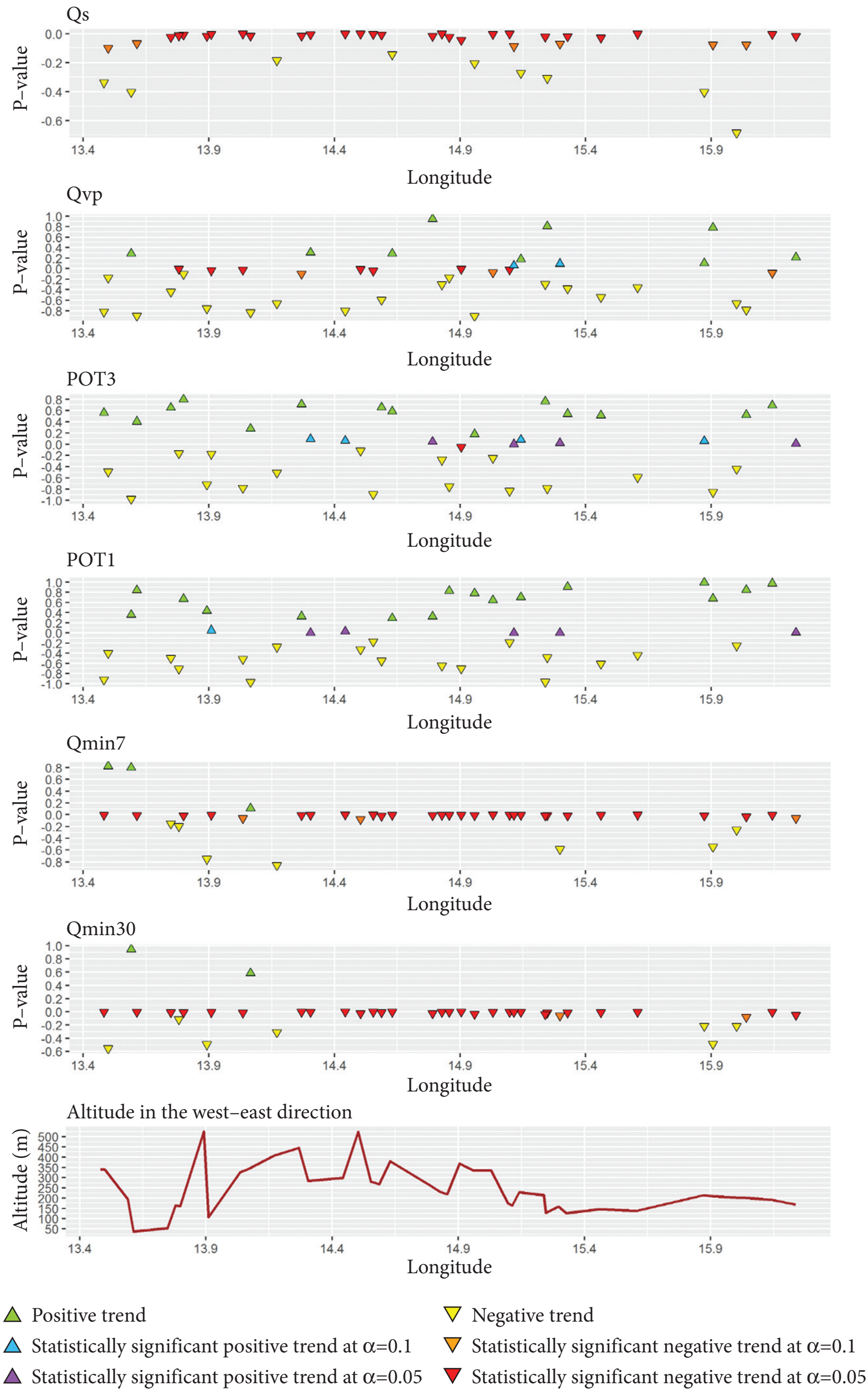
The analysis shows that the mean annual discharges (Qs) are decreasing across the country regardless of the location, most of them statistically significantly (Figure 3). As we noted earlier, the annual maximum mean daily discharges (Qvp) do not show as consistent trends as the mean annual discharges. Statistically significant decreasing trends of Qvp mostly occur in the western and central part of Slovenia, while statistically significant increasing trends mostly occur in the eastern and central part of the country (Figure 3). Furthermore, the extreme annual flood discharge values (POT1 and POT3) do not show statistically significant decreasing trends, with the exception of the POT3 data series at Kraše gauging station at Dreta River. Statistically significant increasing trends of the POT3 data series were found mainly in the east of the country, while in case of POT1 data series statistically significant increasing trends occur regardless of the location. Annual low discharges with a duration of 7 days (Qmin7) and 30 days (Qmin30) have a statistically significant decreasing trend at most of the considered stations regardless of the location (Figure 3).

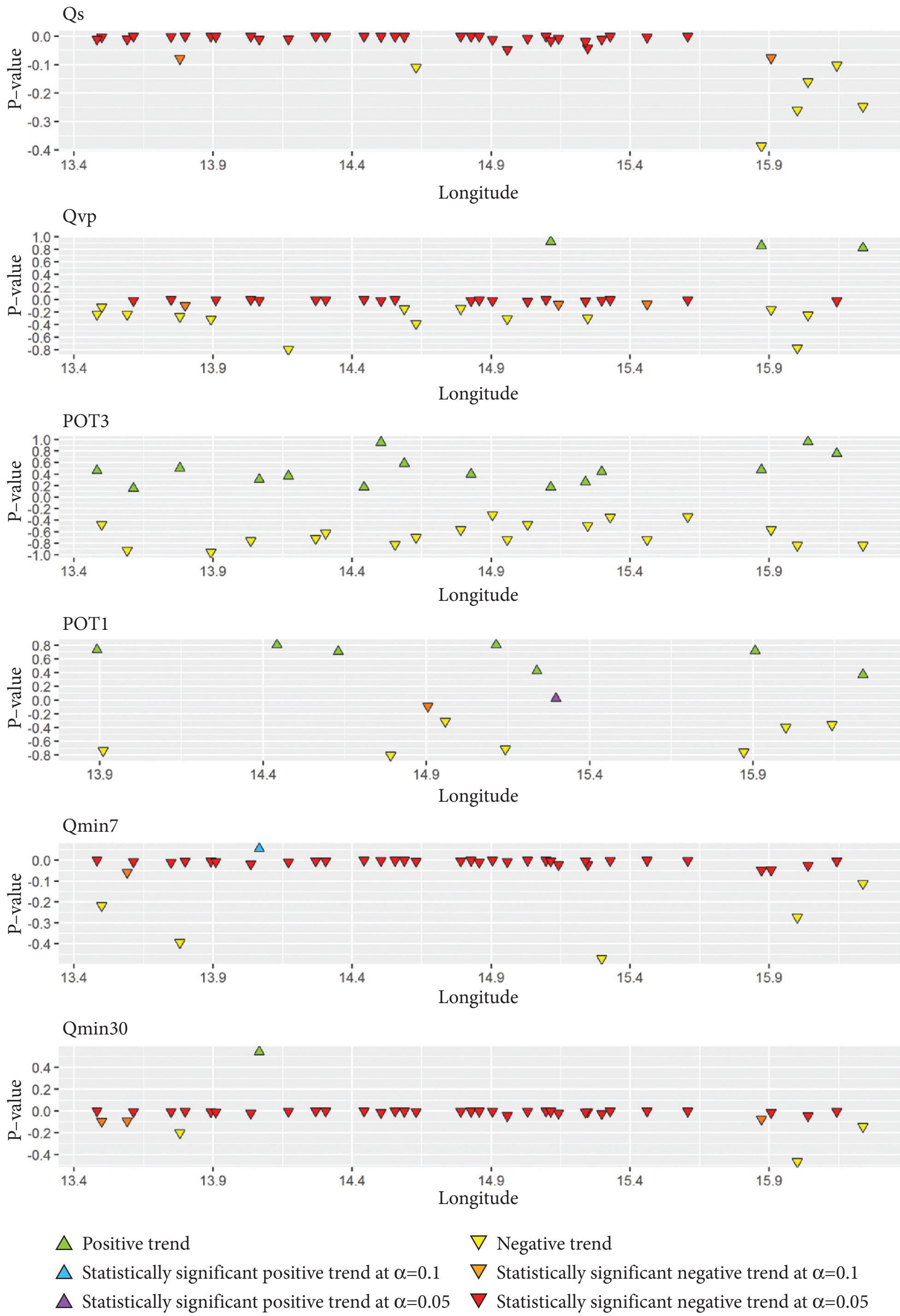
Analysis by season shows that mean summer discharges (Qs) have a statistically significant decreasing trend throughout the country with the exception of the eastern part, where decreasing trends are mostly not statistically significant (Figure 4). In addition, the largest summer discharges (Qvp) in Slovenia are mostly statistically significantly decreasing, with the exception of some stations in the eastern part of the country, where the trends are increasing, but not statistically significant. The same is true for the summer low discharges (Qmin7 and Qmin30), which mostly show statistically significant decreasing trends across the country regardless of the location (Figure 4).

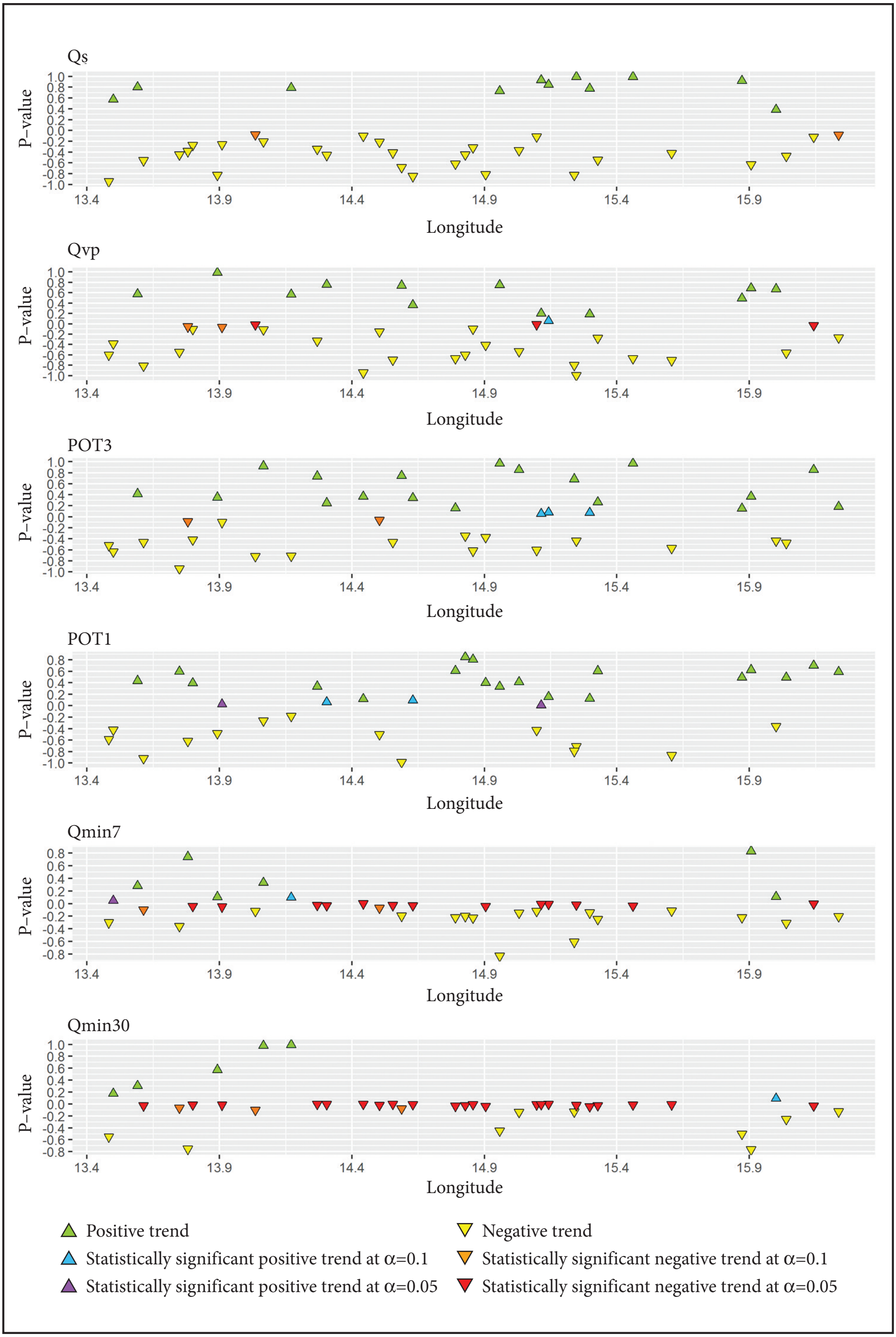
Mean autumn discharges (Qs) are mostly decreasing; however, the trend is statistically significant for two stations. Location does not appear to affect these results (Figure 5). The same can be concluded for the largest autumn discharges (Qvp). Stations with statistically significant decreasing trends are found in the eastern, western and central parts of the country. On the other hand, the extreme autumn flood discharges are mostly increasing, especially the POT1 data series. Stations with the statistically significant increasing trend in the POT1 and POT3 values are mainly located in the central part of Slovenia. Autumn low discharges (Qmin7 and Qmin30) mostly show decreasing trends (Figure 5). However, they are not as pronounced as for the summer low discharges, especially in the eastern and western part of Slovenia.

Statistically significant decreasing trends in mean winter discharges (Qs) are characteristic mainly for the eastern part of the country. The same is true for the largest winter discharges (Qvp). The extreme winter discharges show decreasing and increasing trends. Stations with statistically significant increasing trends

Figure 3: Trends in annual values of discharge data series for the period 1961–2013, plotted in west-east direction. ➤ p. 164
Figure 4: Trends in summer values of discharge data series for the period 1961–2013, plotted in west-east direction. ➤ p. 165
Figure 5: Trends in autumn values of discharge data series for the period 1961–2013, plotted in west-east direction. ➤ p. 166


Qs
P–value
Longitude
Qvp
P–value
Longitude
POT3
P–value
Longitude
POT1
P–value
Longitude
Qmin7
P–value
Longitude
Qmin30
P–value
Longitude
Altitude in the west–east direction
Altitude (m)
Longitude
13.4
13.9
14.4
14.9
15.4
15.9
Positive trend
Statistically significant positive trend at α=0.1
Statistically significant positive trend at α=0.05
Negative trend
Statistically significant negative trend at α=0.1
Statistically significant negative trend at α=0.05


Qs
P–value
Longitude
Qvp
POT3
POT1
Qmin7
Qmin30
Positive trend
Negative trend
Statistically significant positive trend at α=0.1
Statistically significant negative trend at α=0.1
Statistically significant positive trend at α=0.05
Statistically significant negative trend at α=0.05


Qs
P–value
Longitude
Qvp
P–value
Longitude
POT3
P–value
Longitude
POT1
P–value
Longitude
Qmin7
P–value
Longitude
Qmin30
P–value
Longitude
Positive trend
Negative trend
Statistically significant positive trend at α=0.1
Statistically significant negative trend at α=0.1
Statistically significant positive trend at α=0.05
Statistically significant negative trend at α=0.05

in POT3 values are located in the eastern and central parts of the country, while stations with statistically significant increasing trends in POT1 values are located in the western part of the country. Furthermore, three stations showing statistically significant decreasing trends in POT1 data series are located in the central part of the country. Winter low discharges (Qmin7 and Qmin30) show mostly decreasing trends, which are less pronounced in the western part of the country.

The results for the spring discharge data series are very similar to the summer results, but less pronounced. Mean spring discharges (Qs) are decreasing throughout the country. Most of them are statistically significant, except in the western part where the trend is not statistically significant. Furthermore, the largest spring discharges (Qvp) have mostly statistically significant decreasing trend, except for some stations in the eastern part of the country, where the trends are increasing, but not statistically significant. Extreme spring discharge values (POT1 and POT3) do not show consistent trends as they increase at some stations and decrease at others. Statistically significant decreasing trends in extreme discharges were found at some stations in the western and central parts of the country, whereas statistically significant increasing trends were found in the eastern and central parts of the country. Location does not appear to have the influence on trends of the spring low discharges.

4 Conclusion

The results of the study show that climate variability during the considered period (1961–2013) influences the temporal and spatial variability of discharges and associated floods and droughts in Slovenia. In general, a decrease in water quantities in the rivers was observed. Similar conclusions were drawn also by Frantar, Kobold and Ulaga (2008) using the data for the whole observation period until 2005. Thus, it seems that similar trends continue also a decade later.

Mean annual discharges are decreasing at all stations considered, statistically significant at most of them. Furthermore, the rivers of the Adriatic catchment demonstrate a statistically significant decrease in mean discharges in the summer season and the rivers of the Black Sea catchment in the summer and spring seasons. On the other hand, the maximum mean daily discharges do not show such uniform trends as the mean discharges as some gauging stations exhibit statistically significant trends in annual maximum discharge series. However, despite the fact that the results of the trends of the maximum annual discharges indicate regional differences, a predominantly decreasing trend was observed. The rivers of the Adriatic Sea catchment mostly demonstrate a statistically significant decreasing trend in the maximum discharges in the spring and summer seasons, while the rivers of the Black Sea catchment do not show uniform trends. The extreme annual discharge values also do not show a uniform trend; however, even more gauging stations show a statistically increasing trend compared to the trends in maximum discharges. Most of them are located in the Ljubljanica and the Krka River catchments. Furthermore, the results of the trend analysis of low discharges demonstrate statistically significant decrease for the rivers of the Black Sea catchment, while for the rivers of the Adriatic Sea catchment some stations do not show statistically significant changes. Low discharges decrease in summer at most stations, while in some catchments they also decrease in autumn and spring.

The results show that the discharge trends depend to some extent on the location of the gauging station. This was to be expected due to the great climatic and landscape diversity in Slovenia. The findings of the study related to the trends of different types of discharge data series should be taken into account in practice, e.g. for effective water management, flood protection, granting permits for water abstraction, designing of irrigation systems.

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