CLIMATE AND HYDROLOGICAL CHANGES IN SLOVENIA'S PODRAVJE REGION BETWEEN 1961 AND 2018

PODNEBNE IN HIDRLOŠKE SPREMEMBE V SLOVENSKEM PODRAVJU MED LETOMA 1961 IN 2018

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Primljeno / Received: 10. 6. 2020.
Prihvaćeno / Accepted: 1. 12. 2020.
Izvorni znanstveni rad
Original scientific paper
UDK / UDC:
551.58(497.4)"1961/2018"
556(497.4)"1961/2018"

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ABSTRACT

This article examines different annual trends in the climate and hydrological changes in the Slovenian part of the Drava Basin (Sln. Podravje) between 1961 and 2018. Climate change is primarily reflected in the rising average annual temperatures and a significantly shorter duration of snow cover. In terms of hydrological changes, a decrease in the average annual minimum and mean annual discharge can be observed, whereas the average maximum and absolute discharge is increasing in places. In addition to the water volume, changes can also be observed in the rivers' discharge regimes, which may indicate a smaller probability of spring floods, but conversely a higher probability of fall floods.

Key words: climatology, hydrology, climate changes, hydrological changes, discharge regimes, floods, Drava Basin, Slovenia

Ključne besede: klimatologija, hidrologija, podnebne spremembe, hidrološke spremembe, pretočni režimi, poplave, Podravje, Slovenija

1 INTRODUCTION[1]

The Drava River is a right tributary of the Danube. It runs through Italy, Austria, Slovenia, and Croatia, and also forms the border between Croatia and Hungary. It is 720 km long, with its basin cov-

1 Acknowledgments: This study was conducted as part of »The Geography of Slovenia« (P6-0101) research program financed by the Slovenian Research Agency and as part of the international research project »Appropriate Ecological Measures against Flood Hazards in the Hilly Regions of Hungary and Slovenia« (N6-0070) co-financed by the Slovenian Research Agency and the Hungarian National Research, Development, and Innovation Office.

ering 40,095 km^2.[2] The Drava has its source at an elevation of approximately 1,200 m and flows into the Danube at 80 m above sea level. It enters Slovenia at Dravograd at an elevation of 340 m and flows through Slovenia for 142 km (to Središče ob Dravi), dropping in elevation by 148 m. The Drava Basin in Slovenia (Sln. *Podravje*) covers one sixth of the national territory (3,264 km^2). The lengths of all watercourses in the basin is 6,829 km and the density of the channel network is 2 km/km^2.[3]

Water level fluctuations of the Drava largely depend on snowmelt. The river usually has its maximum discharge in June and its minimum in February. It obtains as many as nine-tenths of its water in the mountainous region extending down to Maribor. Its major tributaries are the Isel, Moll, Lieser, Gail, Gurk, and Lavant in Austria, the Meža, (Muta) Bistrica, Dravinja, and Pesnica in Slovenia, and the Mura, Bednja, and Karašica in Croatia. From its confluence with the Mura to its mouth, it is a distinctly lowland river, forming numerous meanders and channels. Before it was trained, its high water caused frequent floods.[4] River training in Austrian Carinthia began in 1882. Flood risk was significantly reduced especially after a chain of hydroelectric plants was constructed,[5] but it has never been fully eliminated.[6] In some places, signs draw attention to past floods, such as the one on November 3rd, 1851, for which the water levels were recorded and marked on the Radlje Plain, at the Fala Cliff, in Maribor's Old Town, and in Ptuj.[7]

Due to its high water volume and gradient, the Drava produces great water power, which is used by several Austrian, Slovenian, and Croatian hydroelectric plants. Run-of-the-river power plants predominate, with reservoirs commonly placed in front of them.[8]

The construction of these power plants and especially their reservoirs have significantly changed the landscape. Today, training and damming determine the volume and speed of discharge, water retention time, water mixing, and shaping of the riverbed.[9]

However, river discharge is connected not only with human-induced changes, but also climate change, which is primarily visible in watercourses with fewer human-induced alterations. Recent years have seen the publication of several articles examining changes in the discharge trends of rivers in western and northern Slovenia in connection with climate change. An increase in the average annual temperature, a decrease in the total annual precipitation, and a drop in the mean annual discharge have been established for the western prealpine hills[10] and the alpine region,[11] as well as the Mediterranean flysch low hills.[12]

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3 Zorn, M. 2018: The economic role of the Drava River in Slovenia: From navigation to hydropower. Podravina, 17 (33).

4 Petrić, H., Obadić, I. 2007: Drava River flooding in Varaždin and Koprivnica parts of Podravina (Drava River Region - between Croatia and Hungary) in the period 17th–19th century. Podravina, 6 (12).

5 Berchtold-Ogris, M. 2001: Porečje Drave. In: Die Drau is eine Frau/Drava je svoja frava. Celovec, Drava.

6 E.g.: Klaneček, M. 2013: Poplave 5. novembra 2012 v porečju Drave. Ujma, 27, pp. 52–61; Kobold, M., Polajnar, J., Pogačnik, N., Petan, S., Sušnik, M., Lalić, B., Šupek, M., Strojan, I., Jeromel, M. 2013: Poplave v oktobru in povodenj v novembru 2012. In: 24. Mišičev vodarski dan. Maribor, Vodnogospodarski biro.

7 Kolbezen, M. 1991: Velike poplave in povodnji na Slovenskem 1. Ujma, 5.

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12 Kovačič, G. 2016: Trendi pretokov rek jadranskega povodja v Sloveniji brez Posočja. Geografski vestnik, 88 (2); Kovačič, G., Kolega, N., Brečko Grubar, V. 2016: Vpliv podnebnih sprememb na količine vode in poplave morja v slovenski Istri. Geografski vestnik, 88 (1).

This article examines selected annual trends in climate and hydrological variables (Table 1) in the Slovenian part of the Drava Basin (Figure 1) between 1961 and 2018. This area is composed of alpine hills (west of Maribor) and Pannonian plains and low hills (east of Maribor).[13]

2 METHODS

To determine the trend of change in selected climate and hydrological variables (Table 1) between 1961 and 2018, the Mann-Kendall test and Theil-Sen estimator (also known as Sen's slope estimator) were used at selected temperature, precipitation, and gauging stations (Tables 2 and 3, Figure 1). The Mann-Kendall test is a nonparametric test used to detect monotonic trends. It is not sensitive to outliers in the data and is based on the test statistics. A positive test statistic implies an increasing trend and a negative test statistic indicates a decreasing trend. Sen's slope estimator is the most frequent nonparametric test used for detecting linear time trends.[14] It is more accurate for asymmetric data distribution than linear regression and for normal data distribution it yields results that are completely comparable to least squares.[15]

The free online software MAKESENS 1.0 (Mann-Kendall test for trend and Sen's slope estimates)[16] was used to calculate the Mann-Kendall test and Sen's slope estimator values.

In addition to the Mann-Kendall test and Sen's slope values, the tables with climate and hydrological variables also show the confidence levels, the (initial) 1961 trend value, (final) 2018 trend value, and absolute and relative trend differences.

In statistics, the confidence level is the probability of the confidence interval calculated containing the true value of an estimated parameter. In this case, a higher confidence level indicates a higher probability that the increasing or decreasing trend of a selected variable detected actually exists.

The initial 1961 trend value represents the value of a selected variable in 1961 read from the trend line, and the final 2018 trend value is the value of a selected variable in 2018 read from the trend line.

The absolute trend difference is the difference between the final and initial trend values and the relative trend difference is the difference between the final and initial trend values expressed in percentage.

The trend value per year can be calculated using the following equation:

trend value per year x = Sen's slope* (trend year x – initial trend year) + initial trend value.

Table 1: Climate and hydrological variables examined.

Climate variables	Average annual temperature
	Annual precipitation
	Days with precipitation over 0.1 mm
	Days with snow cover
Hydrological variables	Average minimum discharge
	Average mean discharge
	Average maximum discharge

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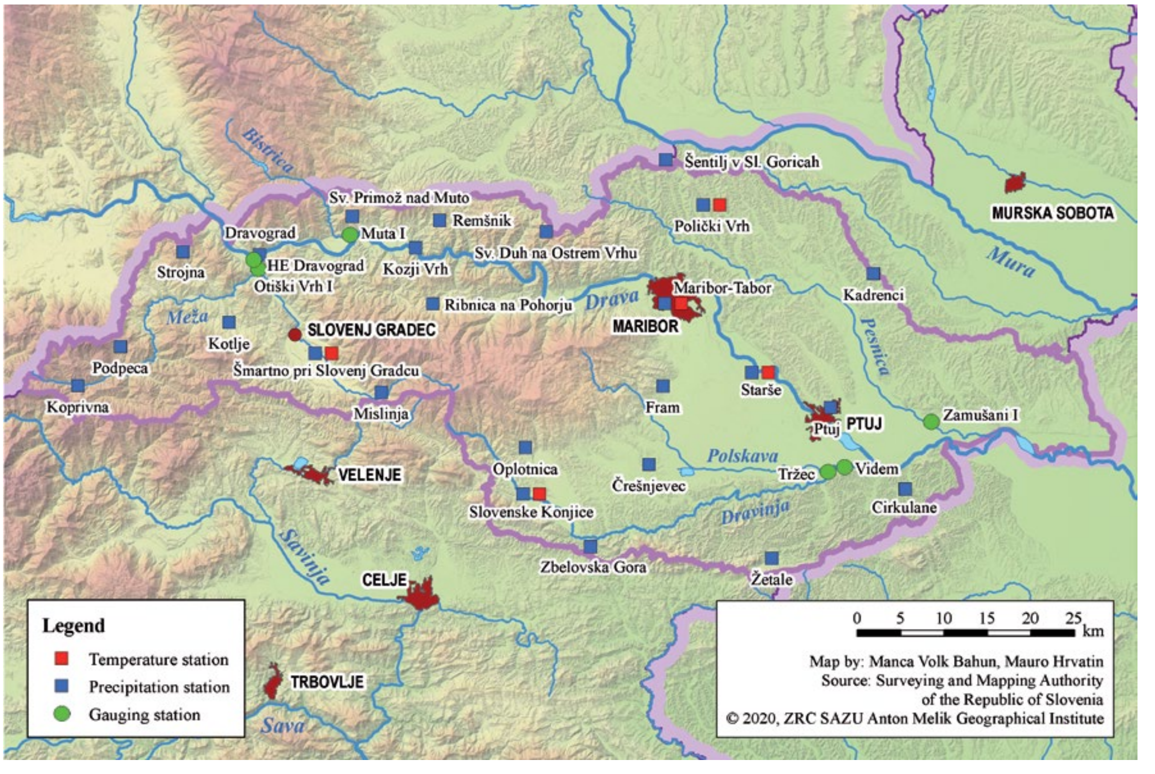

Figure 1: Locations of temperature, precipitation, and gauging stations in the Podravje Region included in the analysis.

3 DATA

3.1 Climate variables

Climate data was obtained from the Slovenian Environment Agency (Arhiv meteoroloških … 2019). The analysis included five temperature and twenty-five precipitation stations in the Slovenian part of the Drava Basin (Table 2, Figure 1) that had measured data over several decades.

Table 2: Weather stations with the time series analyzed.

	Weather station	Municipality	Elevation (m)	Time series	No. of annual measurements
Temperature station	Maribor - Tabor	Maribor	275	1961–2018	56
	Polički Vrh	Pesnica	280	1961–2018	52
	Slovenske Konjice	Slovenske Konjice	330	1961–2018	56
	Starše	Starše	238	1961–2018	56
	Šmartno pri Slovenj Gradcu	Slovenj Gradec	444	1961–2018	58
Precipitation station	Cirkulane	Cirkulane	241	1961–2018	56
	Črešnjevec	Slovenska Bistrica	310	1961–2018	57
	Dravograd	Dravograd	384	1961–2018	57
	Fram	Rače-Fram	320	1961–2016	56
	Kadrenci	Cerkvenjak	302	1961–2018	58
	Koprivna	Črna na Koroškem	840	1961–2017	57
	Kotlje	Ravne na Koroškem	450	1961–2014	54

	Weather station	Municipality	Elevation (m)	Time series	No. of annual measurements
	Kozji Vrh	Podvelka	340	1961–2018	55
	Maribor - Tabor	Maribor	275	1963–2018	56
	Mislinja	Mislinja	589	1961–2018	58
	Oplotnica	Oplotnica	477	1961–2014	52
	Podpeca	Črna na Koroškem	955	1961–2018	57
	Polički Vrh	Pesnica	280	1968–2018	50
	Ptuj	Ptuj	235	1961–2018	58
	Remšnik	Radlje ob Dravi	660	1961–2014	48
	Ribnica na Pohorju	Ribnica na Pohorju	600	1961–2018	56
	Slovenske Konjice	Slovenske Konjice	330	1961–2018	56
	Starše	Starše	238	1961–2017	57
	Strojna	Ravne na Koroškem	940	1961–2018	57
	Sv. Duh na Ostrem vrhu	Selnica ob Dravi	870	1961–2012	45
	Sv. Primož nad Muto (Podlipje)	Muta	760	1961–2018	58
	Šentilj v Slovenskih goricah	Šentilj	306	1961–2018	56
	Šmartno pri Slovenj Gradcu	Slovenj Gradec	444	1961–2018	58
	Zbelovska Gora	Slovenske Konjice	275	1962–2018	55
	Žetale	Žetale	342	1961–2018	55

3.2 Hydrological variables

Hydrological data was obtained from the Slovenian Environment Agency (Arhiv hidroloških … 2019). The analysis included six stations from the Slovenian part of the Drava Basin (Table 3, Figure 1) that had measurement data spanning several decades.

The (Muta) Bistrica River discharge changed completely after 1987, when the Soboth reservoir was built on it on the Austrian side. From that reservoir water runs through a high-pressure pipeline to the Koralpe hydroelectric plant at Lavamünd, where it flows into the Drava. The following minimum biological discharge has been specified through a bilateral agreement with Austria for the Feistritz River (Sln. *Bistrica*) at its entry into Slovenia: 1 m^3/s for ten months a year and 0.85 m^3/s for two months a year (Balant et al. 1999). The significant discharge differences on the Bistrica at the Muta gauging station can thus be primarily attributed to the human impact and less to the altered natural conditions.

Table 3: Rivers with the time series analyzed.

River	Gauging station	Municipality	Elevation (m)	Time series	No. of annual measurements
Drava	Dravograd	Dravograd	330	1965–2018	54
Meža	Otiški Vrh	Dravograd	334	1961–2018	58
Bistrica	Muta	Muta	326	1961–2018	58
Dravinja	Videm	Videm	210	1961–2018	58
Polskava	Tržec	Videm	214	1961–2018	58
Pesnica	Zamušani	Gorišnica	202	1961–2018	58

4 RESULTS

4.1 Climate variables

The following were analyzed in terms of climate variables (Table 1): 1) average annual air temperature trends, 2) annual precipitation trends, 3) trends in the annual days with precipitation over 0.1 mm, and 4) trends in the annual days with snow cover.

4.1.1 Average annual air temperature

The average annual air temperature trends from 1961 to 2018 were similar at all five temperature stations examined, showing a distinct increase (Table 4, Figure 2). A significantly high confidence level of 99.9% can be observed at all the stations.

From 1961 to 2018, temperature at the selected temperature stations increased by 0.043 to 0.047 °C on average a year, which means that the temperature has increased by 2.44 to 2.68 °C over the past six decades. The absolute temperature difference is the smallest at the Starše station, where the temperature has risen by 2.44 °C, and the largest at the Maribor Tabor station, where it has risen by 2.68 °C.

Table 4: Average annual temperature trends, 1961–2018. The trend difference in percentage is calculated based on the absolute (Kelvin) temperature scale.

Temperature station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
	Z	%	*Q*	°C	°C	°C	%
Maribor - Tabor	6.73	99.9	0.047	8.98	11.66	2.68	0.95
Polički Vrh	5.49	99.9	0.045	7.98	10.57	2.59	0.92
Slovenske Konjice (Fig. 2)	6.21	99.9	0.046	8.75	11.36	2.61	0.93
Starše	5.68	99.9	0.043	8.95	11.39	2.44	0.86
Šmartno pri Slovenj Gradcu	6.64	99.9	0.044	7.07	9.57	2.50	0.89

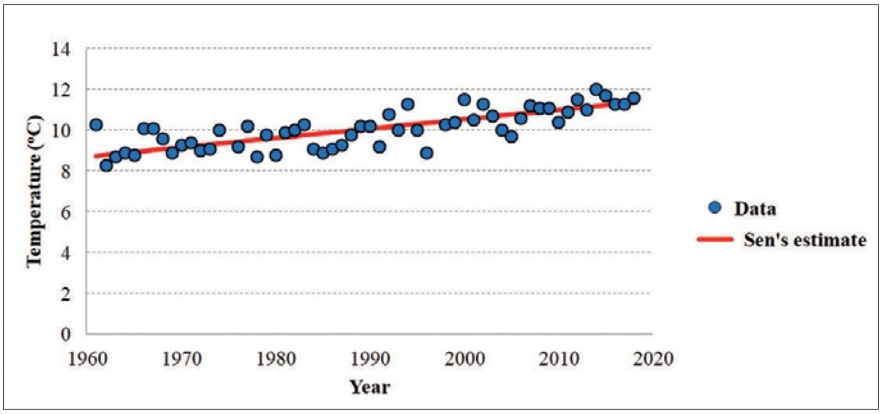

Figure 2: Average annual temperature trend at the Slovenske Konjice temperature station, 1961–2018.

4.1.2 Annual precipitation

In contrast to the increasing temperature trends, the annual precipitation trends from 1961 to 2018 were decreasing at eighteen of the twenty-five precipitation stations observed (Table 5, Figure 3). The confidence level is modest, not even reaching 90% at as many as twenty-two stations. Only at the Kozji Vrh, Maribor Tabor, and Sveti Primož nad Muto stations the confidence level is 90%, but that is still far from being statistically significant (95%).

Most differences in the annual precipitation are relatively small, not exceeding 5% at fourteen out of the twenty-five precipitation stations and not exceeding 10% at twenty stations. The falling annual precipitation trend is the most distinctive at Sveti Duh na Ostrem Vrhu (−181.8 mm or −14.8%), Maribor Tabor (−149.9 mm or −13.9%), and Ptuj (−117.3 mm or −11.4%), and the rising trend is most evident at Kozji Vrh (+160.3 mm or +14.3%) and Sveti Primož nad Muto (+148.3 mm or +12.5%).

Table 5: Annual precipitation trends from, 1961–2018.

Precipitation station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
	Z	%	*Q*	mm	mm	mm	%
Cirkulane	–0.98	under 90.0	–1.425	1112.71	1031.47	–81.24	–7.30
Črešnjevec	–0.74	under 90.0	–0.911	1109.16	1057.21	–51.95	–4.68
Dravograd	–1.51	under 90.0	–2.000	1153.30	1039.30	–114.00	–9.88
Fram	0.33	under 90.0	0.323	1102.67	1121.11	18.44	1.67
Kadrenci	–1.09	under 90.0	–1.413	949.13	868.57	–80.56	–8.49
Koprivna	–0.23	under 90.0	–0.370	1506.04	1484.95	–21.09	–1.40
Kotlje	0.46	under 90.0	0.954	1160.37	1214.74	54.37	4.69
Kozji Vrh	1.93	90.0	2.813	1121.44	1281.77	160.33	14.30
Maribor - Tabor	–1.92	90.0	–2.630	1079.59	929.67	–149.92	–13.89
Mislinja	–0.80	under 90.0	–1.014	1248.93	1191.14	–57.79	–4.63
Oplotnica	–0.17	under 90.0	–0.384	1107.24	1085.37	–21.87	–1.98
Podpeca	0.34	under 90.0	0.536	1429.73	1460.26	30.53	2.14
Polički Vrh	0.52	under 90.0	0.573	948.27	980.95	32.68	3.45
Ptuj	–1.33	under 90.0	–2.057	1031.36	914.10	–117.26	–11.37
Remšnik	0.88	under 90.0	1.679	1128.88	1224.59	95.71	8.48
Ribnica na Pohorju (Figure 3)	–0.67	under 90.0	–0.856	1388.99	1340.17	–48.82	–3.51
Slovenske Konjice	–0.66	under 90.0	–0.732	1104.82	1063.08	–41.74	–3.78
Starše	–0.65	under 90.0	–0.767	1005.93	962.20	–43.73	–4.35
Strojna	–1.44	under 90.0	–1.835	1134.22	1029.64	–104.58	–9.22
Sv. Duh na Ostrem vrhu	–1.26	under 90.0	–3.190	1229.39	1047.57	–181.82	–14.79
Sv. Primož nad Muto	1.65	90.0	2.602	1184.97	1333.30	148.33	12.52
Šentilj v Slovenskih goricah	–0.16	under 90.0	–0.203	990.07	978.52	–11.55	–1.17
Šmartno pri Slovenj Gradcu	–0.36	under 90.0	–0.482	1179.12	1151.63	–27.49	–2.33
Zbelovska Gora	–1.42	under 90.0	–1.955	1208.36	1096.93	–111.43	–9.22
Žetale	–0.62	under 90.0	–0.828	1170.11	1122.90	–47.21	–4.03

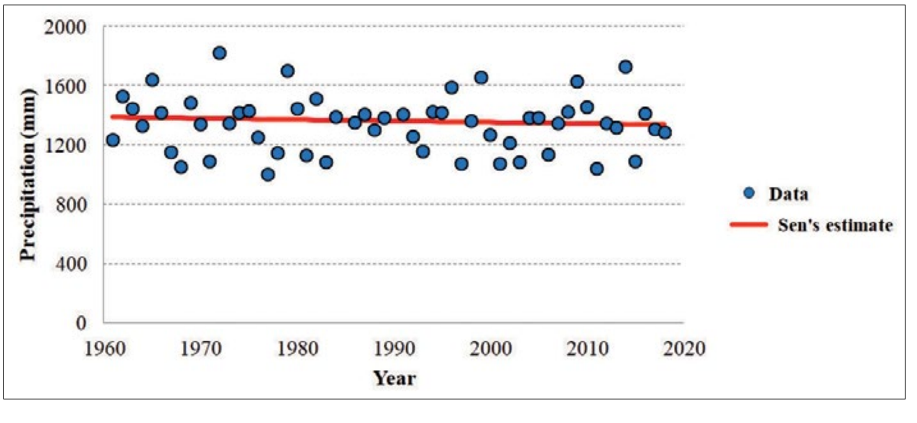

Figure 3: Annual precipitation trend at the Ribnica na Pohorju precipitation station, 1961–2018.

4.1.3 Annual days with precipitation over 0.1 mm

From 1961 to 2018, the annual number of days with precipitation over 0.1 mm increased at nine and decreased at fifteen precipitation stations, and it remained the same at the Remšnik station (Table 6, Figure 4). The confidence level varies significantly: at fourteen stations it does not even exceed 90%, at Sveti Primož nad Muto it reaches 95%, and at ten stations it reaches at least 99%.

Eleven stations show smaller negative or positive trend deviations, not reaching 10%. The decrease in the annual number of days with precipitation over 0.1 mm is the strongest at Strojna (–43.8 days or –28.8%), Oplotnica (–31.5 days or –20.8%), and Ribnica na Pohorju (–30.9 days or –20.5%), and the increase is the most evident at Koprivna (27.1 days or 23.1%), Dravograd (21.0 days or 19.8%), and Kozji Vrh (24.4 days or 19.3%).

Table 6: Trends in the annual days with precipitation, 1961–2018.

Precipitation station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
	Z	%	*Q*	Days	Days	Days	%
Cirkulane	1.41	under 90.0	0.228	103.28	116.26	12.99	12.57
Črešnjevec	1.75	90.0	0.256	118.88	133.47	14.59	12.27
Dravograd	3.00	99.0	0.368	105.83	126.78	20.95	19.80
Fram	–2.97	99.0	–0.444	146.89	121.56	–25.33	–17.24
Kadrenci	–3.40	99.9	–0.400	137.80	115.00	–22.80	–16.55
Koprivna	3.37	99.9	0.476	117.62	144.76	27.14	23.08
Kotlje	–1.69	90.0	–0.250	153.75	139.50	–14.25	–9.27
Kozji Vrh	3.20	99.0	0.429	126.43	150.86	24.43	19.32
Maribor - Tabor	–0.56	under 90.0	–0.075	139.03	134.75	–4.28	–3.08
Mislinja	–1.60	under 90.0	–0.200	139.10	127.70	–11.40	–8.20
Oplotnica	–3.47	99.9	–0.552	151.50	120.02	–31.48	–20.78
Podpeca	–3.35	99.9	–0.478	156.82	129.60	–27.22	–17.36
Polički Vrh	0.59	under 90.0	0.118	128.47	135.18	6.71	5.22
Ptuj (Figure 4)	–3.15	99.0	–0.441	142.46	117.31	–25.15	–17.65
Remšnik	0.07	under 90.0	0.000	141.50	141.50	0.00	0.00
Ribnica na Pohorju	–3.63	99.9	–0.542	150.74	119.84	–30.90	–20.50
Slovenske Konjice	0.45	under 90.0	0.078	137.86	142.31	4.45	3.23
Starše	–0.85	under 90.0	–0.091	132.09	126.91	–5.18	–3.92
Strojna	–4.59	99.9	–0.768	152.03	108.27	–43.76	–28.78
Sv. Duh na Ostrem vrhu	0.26	under 90.0	0.067	118.98	122.82	3.84	3.23
Sv. Primož nad Muto	–2.56	95.0	–0.308	136.46	118.92	–17.54	–12.85
Šentilj v Slovenskih goricah	–1.46	under 90.0	–0.235	137.00	123.59	–13.41	–9.79
Šmartno pri Slovenj Gradcu	–1.75	90.0	–0.250	150.38	136.13	–14.25	–9.47
Zbelovska Gora	–1.72	90.0	–0.286	131.14	114.86	–16.28	–12.42
Žetale	1.08	under 90.0	0.167	125.17	134.67	9.50	7.59

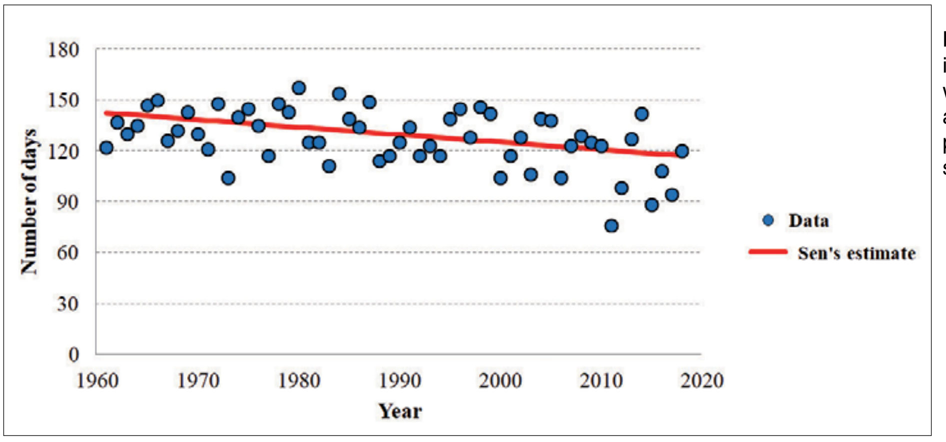

Figure 4: Trends in the annual days with precipitation at the Ptuj precipitation station, 1961–2018.

4.1.4 Days with snow cover

From 1961 to 2018, the annual number of days with snow cover decreased significantly at all precipitation stations (Table 7, Figure 5). The confidence level is high and statistically significant across all stations.

At sixteen out of the twenty-five stations, the number of days with snow cover decreased by 40 to 60 % or 25 to 61 days. A decrease below 40% was recorded at Koprivna (–22.4%), Remšnik (–28.7%), Sveti Primož nad Muto (–31.3%), Podpeca (–33.8%), Mislinja (–38.9%), and Sveti Duh na Ostrem Vrhu (–39.2%). A decrease over 60% was observed at Fram (–70.1%), Dravograd (–64.7%), and Ptuj (–60.9%).

The duration of snow cover expressed in the number of days decreased the least at Slovenske Konjice (–24.9 days), Žetale (–26.5 days), and Oplotnica (–26.8 days), and the most at Strojna (–61.3 days), Šmarto pri Slovenj Gradcu (–55.6 days), and Ribnica na Pohorju (–50.7 days).

Table 7: Trends in the annual days with snow cover, 1961–2018.

Precipitation station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
	Z	%	*Q*	Days	Days	Days	%
Cirkulane	–3.55	99.9	–0.667	66.00	28.00	–38.00	–57.58
Črešnjevec	–3.06	99.0	–0.544	61.96	30.97	–30.99	–50.02
Dravograd	–3.79	99.9	–0.857	75.50	26.64	–48.86	–64.72
Fram	–3.74	99.9	–0.750	61.00	18.25	–42.75	–70.08
Kadrenci	–3.76	99.9	–0.702	68.78	28.76	–40.02	–58.18
Koprivna	–2.70	99.0	–0.549	139.57	108.27	–31.30	–22.43
Kotlje	–2.90	99.0	–0.737	100.16	58.16	–42.00	–41.93
Kozji Vrh	–2.81	99.0	–0.500	62.75	34.25	–28.50	–45.42
Maribor - Tabor	–3.27	99.0	–0.643	67.93	31.29	–36.64	–53.94
Mislinja	–3.44	99.9	–0.758	111.05	67.86	–43.19	–38.89
Oplotnica	–2.20	95.0	–0.469	63.61	36.86	–26.75	–42.05
Podpeca	–3.50	99.9	–0.733	123.70	81.94	–41.76	–33.76
Polički Vrh	–2.49	95.0	–0.571	62.86	30.29	–32.57	–51.81
Ptuj	–3.18	99.0	–0.556	52.00	20.33	–31.67	–60.90
Remšnik	–2.14	95.0	–0.516	102.32	72.92	–29.40	–28.73

Precipitation station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
	Z	%	Q	Days	Days	Days	%
Ribnica na Pohorju	–4.09	99.9	–0.889	104.22	53.56	–50.66	–48.61
Slovenske Konjice	–2.43	95.0	–0.438	50.69	25.75	–24.94	–49.20
Starše	–2.95	99.0	–0.589	64.03	30.45	–33.58	–52.44
Strojna	–4.41	99.9	–1.075	129.25	68.00	–61.25	–47.39
Sv. Duh na Ostrem vrhu	–2.75	99.0	–0.696	101.18	61.50	–39.68	–39.22
Sv. Primož nad Muto	–2.72	99.0	–0.535	97.44	66.95	–30.49	–31.29
Šentilj v Slovenskih goricah	–2.93	99.0	–0.667	72.00	34.00	–38.00	–52.78
Šmartno pri Slovenj Gradcu (Figure 5)	–4.19	99.9	–0.975	97.84	42.26	–55.58	–56.81
Zbelovska Gora	–3.61	99.9	–0.674	72.35	33.93	–38.42	–53.10
Žetale	–2.54	95.0	–0.464	57.57	31.11	–26.46	–45.96

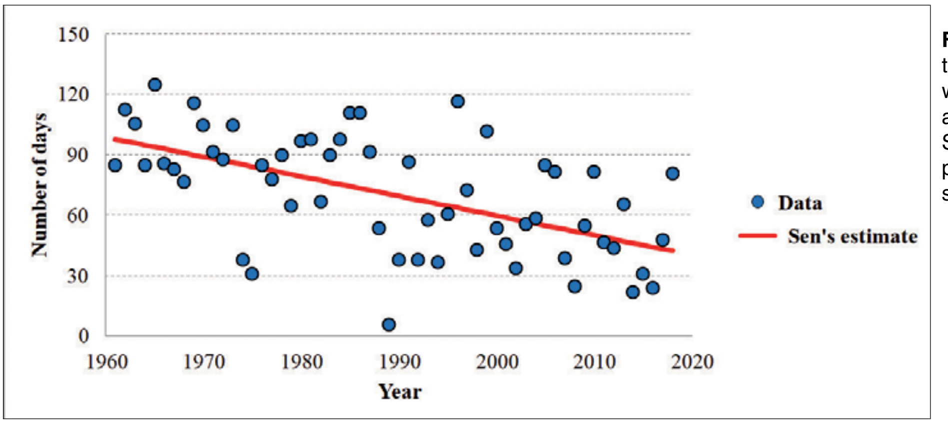

Figure 5: Trend in the annual days with snow cover at the Šmartno pri Slovenj Gradcu precipitation station, 1961–2018.

4.2 Hydrological variables

The following were examined in terms of hydrological variables (Table 1): 1) average annual minimum discharge trends, 2) average annual mean discharge trends, and 3) average annual maximum discharge trends.

4.2.1 Average annual minimum discharge

The average annual minimum discharge trends from 1961 to 2018 were distinctly falling on all six rivers analyzed (Table 8, Figure 6), with the trend difference exceeding at least 17% everywhere. The confidence level varies greatly: it does not exceed 90% on the Polskava and Pesnica, but reaches 95% on the Drava, Meža, and Dravinja, and even 99.9% on the Bistrica due to the additional human impact.

Except on the Drava, the average annual minimum discharge in the period observed decreased by 0.31 to 1.60 m^3/s or 310 to 1,600 l/s; in turn, the discharge of the Drava decreased by 33.59 m^3/s. The Drava and Meža recorded a relative decrease of 15 to 20%, the Dravinja, Polskava, and Pesnica a relative decrease of 25 to 30%, and the Bistrica a full 64.3%. The greatest absolute decrease was recorded on the Drava at Dravograd, where the discharge decreased by 33.59 m^3/s, and the relative difference was the greatest on the Bistrica at Muta, where the average minimum discharge declined by 64.3%.

Table 8: Average annual minimum discharge trends, 1961–2018.

River	Gauging station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
		Z	%	Q	m³/s	m³/s	m³/s	%
Drava	Dravograd	–2.13	95.0	–0.589	193.23	159.64	–33.59	–17.38
Meža (Figure 6)	Otiški Vrh	–2.29	95.0	–0.024	7.47	6.08	–1.39	–18.61
Bistrica	Muta	–5.33	99.9	–0.028	2.49	0.89	–1.60	–64.26
Dravinja	Videm	–2.40	95.0	–0.023	5.08	3.77	–1.31	–25.79
Polskava	Tržec	–1.70	90.0	–0.005	1.10	0.79	–0.31	–28.18
Pesnica	Zamušani	–1.73	90.0	–0.007	1.63	1.20	–0.43	–26.38

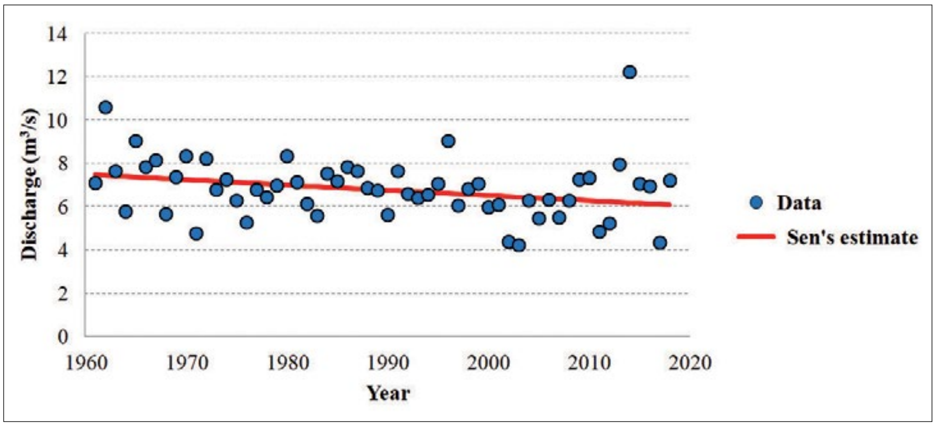

Figure 6: Average annual minimum discharge trend of the Meža at the Otiški Vrh gauging station, 1961–2018.

4.2.2 Average annual mean discharge

The average annual mean discharge trends from 1961 to 2018 were falling on all six rivers or at all six gauging stations analyzed (Table 9, Figure 7). The confidence level varied, reaching 99% on the Meža and Bistrica, and only 90% or less on all other rivers (the Drava, Dravinja, Polskava, and Pesnica).

During the period examined, the annual mean discharge of the Drava tributaries decreased by 0.33 to 3.26 m³/s, and the annual mean discharge of the Drava declined by 34.00 m³/s. Most rivers recorded a relative decrease of 10 to 25%, with a significantly higher decrease observed only on the Bistrica (–63.5%) due to the additional water removal. The absolute trend difference in the average mean discharge between 1961 and 2018 was the greatest on the Drava at Dravograd, where the discharge fell by 34.00 m³/s, and the greatest relative trend difference can be observed on the Bistrica at Muta, where the discharge declined by 63.5%.

Table 9: Average annual mean discharge trends, 1961–2018.

River	Gauging station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
		Z	%	Q	m³/s	m³/s	m³/s	%
Drava	Dravograd	–1.76	90.0	–0.596	268.21	234.21	–34.00	–12.68
Meža	Otiški Vrh	–2.84	99.0	–0.057	13.80	10.54	–3.26	–23.62
Bistrica	Muta	–5.83	99.9	–0.042	3.73	1.36	–2.37	–63.54

River	Gauging station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
		Z	%	Q	m³/s	m³/s	m³/s	%
Dravinja	Videm	–1.74	90.0	–0.049	12.43	9.61	–2.82	–22.69
Polskava	Tržec	–0.89	under 90.0	–0.006	2.60	2.27	–0.33	–12.69
Pesnica (Fig. 7)	Zamušani	–1.27	under 90.0	–0.023	5.34	4.05	–1.29	–24.16

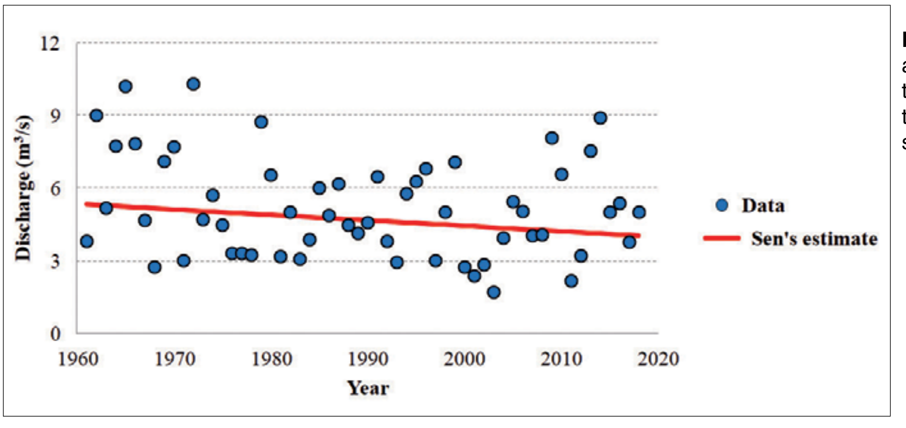

Figure 7: Average annual mean discharge trend of the Pesnica at the Zamušani gauging station, 1961–2018.

4.2.3 Average annual maximum discharge

The average annual maximum discharge trends from 1961 to 2018 were falling on four rivers (the Drava, Meža, Bistrica, and Dravinja) and rising on the Polskava and Pesnica (Table 10, Figure 8). The confidence level is low for the Drava, Dravinja, Polskava, and Pesnica, not reaching even 90%. The picture is completely different with the Meža and Bistrica, with a confidence level of at least 99%.

The average annual maximum discharge trends during the period studied decreased the most on the Bistrica at Muta (–3.87 m³/s or –57.7%) and on the Meža at Otiški Vrh (–11.11 m³/s or –29.0%). A significantly lower trend decrease (in percentage) is evident on the Drava at Dravograd (–17.44 m³/s or –4.2%) and the Dravinja at Videm (–0.69 m³/s or –1.8%).

The average annual maximum discharge increased more significantly on the Polskava at Tržec (+1.05 m³/s or +13.0%) and considerably less on the Pesnica at Zamušani (+0.45 m³/s or +2.3%).

Table 10: Average annual maximum discharge trends, 1961–2018.

River	Gauging station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
		Z	%	Q	m³/s	m³/s	m³/s	%
Drava (Fig. 8)	Dravograd	–0.54	under 90.0	–0.306	417.50	400.06	–17.44	–4.18
Meža	Otiški Vrh	–2.72	99.0	–0.195	38.26	27.15	–11.11	–29.04
Bistrica	Muta	–4.82	99.9	–0.068	6.71	2.84	–3.87	–57.68
Dravinja	Videm	–0.13	under 90.0	–0.012	39.04	38.35	–0.69	–1.77
Polskava	Tržec	0.60	under 90.0	0.018	8.10	9.15	1.05	12.96
Pesnica	Zamušani	0.13	under 90.0	0.008	19.95	20.40	0.45	2.26

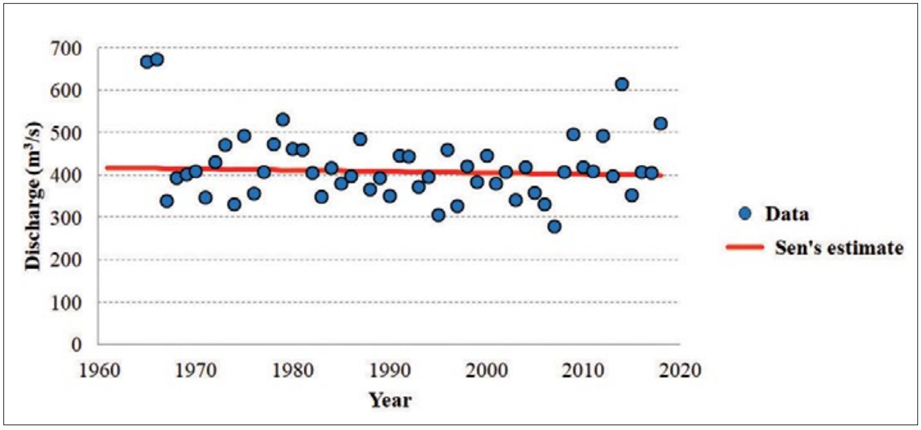

Figure 8: Average annual maximum discharge trend of the Drava at the Dravograd gauging station, 1961–2018.

4.3 Discharge regimes

Long-term changes in temperature and precipitation not only affect the volume of the average minimum, mean, and maximum discharge, but also have a significant impact on changes in the discharge regime.[17] Among the climate indicators examined, changes in the number of days with snow cover seem especially important because they heavily affect all discharge regimes with an expressed snow share. In Slovenia's Podravje Region, the snow share is more or less important for all rivers.

In classifying the discharge regimes based on the 1961–1990 data set, the Drava and Bistrica were categorized among rivers with an Alpine snow regime, the Meža among rivers with a Alpine medium mountain snow-rain regime, the Dravinja among rivers with a Dinaric-Alpine rain-snow regime, and the Pesnica among rivers with a Pannonian rain-snow regime.[18] The Polskava was not among the rivers analyzed.

After nearly three decades, the Drava continues to attain its main discharge maximum in June, even though a secondary rain maximum has now begun to occur in November (Figure 9). The main discharge minimum has moved from January to February, and rudiments of a secondary minimum are beginning to show in September. The current discharge regime of the Drava can be described as an Alpine high-mountain snow-rain regime. The smaller Bistrica River, which used to have a similar discharge regime as the Drava, is now completely dependent on the release of water from the Soboth reservoir on the Austrian side. Its discharge regime has thus been largely altered by human impact.

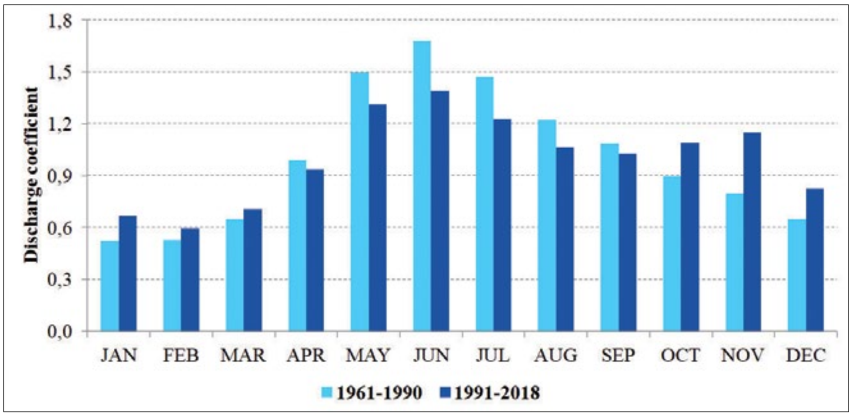

Figure 9: Changes in the discharge regime of the Drava at the Dravograd gauging station between the 1961–1990 and 1991–2018 periods.

17 Hrvatin, M. 1998: Pretočni režimi v Sloveniji. Geografski zbornik, 38; Frantar, P. 2005: Pretočni režimi slovenskih rek in njihova spremenljivost. Ujma, 19; Frantar, P., Hrvatin, M. 2005: Pretočni režimi v Sloveniji med letoma 1971 in 2000. Geografski vestnik, 77 (2); Hrvatin, M., Zorn, M. 2017b: Trendi pretokov rek v slovenskih Alpah med letoma 1961 in 2010. Geografski vestnik, 89 (2).

18 Hrvatin, M. 1998: Pretočni režimi v Sloveniji. Geografski zbornik, 38.

The discharge regime of the Meža has also changed significantly. Its maximums and minimums have changed places. Now the main discharge maximum occurs in November and the secondary one in April, and the main minimum occurs in August and the secondary one in February. Based on the new situation, the river can be categorized as having an Alpine rain-snow regime.

Changes in the discharge regime of the Dravinja, which can still be classified as a river with a Dinaric-Alpine rain-snow regime, have been minor. Due to a more modest snow cover, the main maximum has moved from April to March, and the secondary maximum, which is already entirely equivalent to the spring maximum, is now in December. The main summer minimum is now even more pronounced.

The Polskava can also be classified among rivers with a Dinaric-Alpine rain-snow regime. Its November maximum already slightly exceeds its March maximum, and its August minimum is significantly lower than its secondary minimum in January. From April to September there is typically less water than in January.

Relatively small changes can also be observed in the discharge regime of the Pesnica, which thus remains a river with a Pannonian rain-snow regime. The main minimum has moved from September to August and the secondary maximum has shifted from November to December. A significant decrease in water volume is evident in April due to shorter winters.

A comparison of the discharge regimes based on the 1961–1990 data set and the discharge regimes based on the 1991–2018 data set showed the following differences (Table 11):

– The spring (main) and fall (secondary) discharge maximums are becoming increasingly equivalent and on some rivers the main maximum now occurs in the fall (e.g., on the Meža and the Polskava; they are equal on the Dravinja);

– The impact of winter snow retention has decreased considerably and only remains significant on the Drava and Bistrica;

– The summer minimum is becoming increasingly low on all rivers;

– The November and December water levels are increasing and, in many places, exceed the annual average, implying that winter »is running late.«

The intensity of changes in the monthly discharge coefficients of individual rivers between the two periods studied was also determined using the Pearson correlation coefficient (or Pearson's *r*; Table 11). The results show a moderate correlation between the two data sets for the Meža (0.56), a high correlation for the Dravinja, Polskava, Pesnica, and Bistrica (0.71–0.81), and a very high correlation for the Drava (0.90).

In Slovenia's Podravje Region, the most pronounced changes in the discharge regimes between the 1961–1990 and 1991–2018 periods can be seen on the Meža. The November rain maximum has already heavily exceeded the spring high waters, which primarily result from snow melting in the mountains and hills. At the same time, due to the summer droughts the August minimum has already exceeded the winter minimum, which results from snow retention.

Differences in the monthly discharge rates between the 1961–1990 and 1991–2018 periods (Table 12) are largely uniform in all the examined rivers. They indicate a gradual reduction in the spring and summer discharges, and an increase in the fall and, to a slightly lesser extent, winter discharges. The greatest decrease in the discharge occurs from April to June and the greatest increase from September to December. In addition to increased late-spring evapotranspiration, an important reason for these developments is the gradual temperature increase and the resulting thinner and briefer snow cover. In the past, a significant share of fall precipitation was in the form of snow, which caused snow retention on the rivers, and the thicker snow cover at higher elevations melted until late spring and early summer.

Table 11: 1961–1990 and 1991–2018 monthly discharge coefficients (the blue shading shows the main and secondary minimums, and the red shading shows the main and secondary maximums) and correlation between the two data sets based on the Pearson correlation coefficient.

River	Gauging station	Data set	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Pearson's r
Drava (Figure 9)	Dravograd	1961–1990	0.52	0.53	0.65	0.99	1.50	1.68	1.47	1.22	1.09	0.90	0.80	0.65	0.90
		1991–2018	0.67	0.59	0.70	0.94	1.31	1.39	1.23	1.06	1.03	1.09	1.15	0.83	
Meža	Otiški Vrh	1961–1990	0.66	0.73	1.07	1.53	1.20	1.10	1.01	0.75	0.93	1.00	1.17	0.86	0.56
		1991–2018	0.87	0.81	1.07	1.18	0.97	0.86	0.83	0.77	0.99	1.03	1.43	1.18	
Bistrica	Muta	1961–1990	0.86	0.60	0.71	1.16	1.33	1.22	1.26	1.08	1.05	0.97	0.90	0.86	0.81
		1991–2018	0.86	0.75	0.86	1.07	1.08	1.04	1.09	1.01	1.13	1.06	1.04	1.01	
Dravinja	Videm	1961–1990	0.94	1.10	1.27	1.41	1.00	0.84	0.85	0.71	0.72	0.94	1.15	1.07	0.71
		1991–2018	0.99	1.08	1.29	1.12	0.88	0.72	0.70	0.58	1.05	1.05	1.27	1.29	
Polskava	Tržec	1961–1990	1.16	1.14	1.29	1.20	0.84	0.81	0.83	0.81	0.72	0.92	1.16	1.13	0.77
		1991–2018	1.02	1.24	1.30	0.99	0.86	0.68	0.72	0.51	0.92	1.13	1.37	1.28	
Pesnica	Zamušani	1961–1990	0.94	1.31	1.71	1.33	0.77	0.74	0.70	0.65	0.61	0.89	1.29	1.06	0.80
		1991–2018	0.92	1.43	1.47	0.98	0.86	0.60	0.59	0.58	0.99	0.92	1.29	1.37	

Table 12: Changes in the monthly discharge regimes between the 1961–1990 and 1991–2018 periods (the blue shading indicates decreasing ratios and the red shading shows increasing ratios).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Drava - Dravograd	0.14	0.07	0.05	–0.05	–0.19	–0.29	–0.25	–0.16	–0.06	0.20	0.35	0.18
Meža - Otiški Vrh	0.20	0.09	0.00	–0.34	–0.23	–0.24	–0.18	0.02	0.06	0.03	0.26	0.32
Bistrica - Muta	0.00	0.14	0.15	–0.09	–0.25	–0.18	–0.17	–0.07	0.07	0.09	0.14	0.15
Dravinja - Videm	0.05	–0.02	0.03	–0.28	–0.12	–0.12	–0.15	–0.13	0.32	0.11	0.12	0.21
Polskava - Tržec	–0.14	0.10	0.02	–0.20	0.02	–0.13	–0.11	–0.30	0.20	0.21	0.22	0.15
Pesnica - Zamušani	–0.02	0.12	–0.24	–0.35	0.10	–0.14	–0.12	–0.07	0.38	0.02	0.00	0.31

5 FLOODS

The flood-prone areas along the Drava can be affected by lowland floods, whereas flashfloods may also occur along its tributaries.[19] These flashfloods develop not only in the narrow gorges of the hilly Drava Valley below the Pohorje Mountains, but also in the low hills. The all-Slovenian spatial-temporal analysis showed that approximately one-third of all flashfloods developed in the Podravje Region.[20] A special threat factor is the heavy summer downpours, which can cause catastrophic flashfloods, such as the one in Haloze Hills in early July 1989.[21]

Floods are connected with the absolute maximum discharge. In this regard, the increasing trends in certain rivers are the main cause for concern. Between 1961 and 2018, the absolute annual maximum discharge trends were falling on the Drava, Meža, and Bistrica, and rising on the Dravinja, Polskava, and Pesnica (Table 13, Figure 10). The confidence level is low, not even reaching 90% on five rivers. The only exception is the Polskava at Tržec, but even there the confidence level is only 90%.

During the 1961–2018 period, the absolute annual maximum discharge decreased the most on the Meža at Otiški Vrh (–28.58 m³/s or –20.0%) and on the Bistrica at Muta (–2.67 m³/s or –14.3%). A less than 10% relative decrease in the absolute annual maximum discharge was recorded on the Drava at Dravograd (–113.77 m³/s or –9.1%), and a less than 10% relative increase was recorded on the Pesnica at Zamušani (+5.16 m³/s or +7.4%). The absolute annual maximum discharge increased the most on the Polskava at Tržec (+14.56 m³/s or +65.2%) and Dravinja at Videm (+19.79 m³/s or +15.0%).

Table 13: Absolute annual maximum discharge trends, 1961–2018.

River	Gauging station	Mann-Kendall test	Confidence level	Sen's slope	1961 trend value	2018 trend value	1961–2018 trend difference	1961–2018 trend difference
		Z	%	*Q*	m³/s	m³/s	m³/s	%
Drava	Dravograd	–0.66	under 90.0	–1.996	1246.96	1133.19	–113.77	–9.12
Meža	Otiški Vrh	–1.23	under 90.0	–0.501	143.27	114.69	–28.58	–19.95
Bistrica	Muta	–0.79	under 90.0	–0.047	18.69	16.02	–2.67	–14.29
Dravinja (Figure 10)	Videm	0.76	under 90.0	0.347	131.76	151.55	19.79	15.02
Polskava	Tržec	1.94	90.0	0.256	22.35	36.91	14.56	65.15
Pesnica	Zamušani	0.24	under 90.0	0.090	69.52	74.68	5.16	7.42

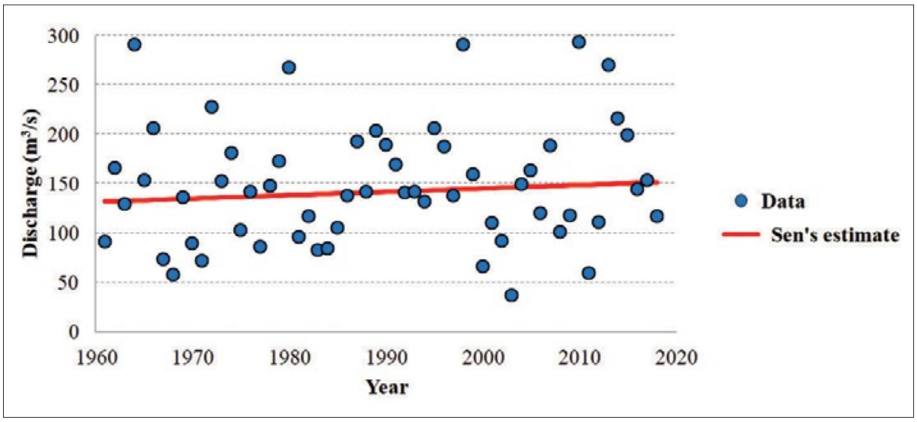

Figure 10: Absolute annual maximum discharge trend of the Dravinja at the Videm gauging station, 1961–2018.

19 Komac, B., Natek, K., Zorn, M. 2008: Geografski vidiki poplav v Sloveniji. Geografija Slovenije, 20. Ljubljana, Založba ZRC.

20 Trobec, T. 2016: Prostorsko-časovna razporeditev hudourniških poplav v Sloveniji. Dela, 46.

21 Natek, K. 1990: Geomorfološke značilnosti usadov v Halozah. Ujma, 4.

In terms of flood occurrence, the ratios of variation in the absolute annual maximum discharge between the 1961–1990 and 1991–2018 periods were also established. Specifically, the variation ratios show the dispersion of data: the higher the ratio, the greater the dispersion.[22] The calculations showed that from 1991 to 2018 the variation ratios increased for the Drava, Meža, Bistrica, and Dravinja, and decreased for the Polskava and Pesnica. Based on these ratios, greater deviations in the absolute annual maximum discharge, including »catastrophic« events, can be expected for the Drava, Meža, Bistrica, and Dravinja.

For example, in Figure 10, which shows the absolute annual maximum discharge trend of the Dravinja at the Videm gauging station, the trend line varies between 131.8 m^3/s and 151.6 m^3/s, whereby certain annual values stand out significantly in the upward direction. The 1964, 1980, 1998, 2010, and 2013 absolute maximum discharges reached nearly 300 m^3/s. With the Dravinja this is especially alarming because its flood-prone area is the second largest in Slovenia (6,554 hectares).[23]

With regard to the potential occurrence of floods, the increasing fall maximum discharge should also be highlighted; in some places, it already exceeds the spring maximum because it is primarily the November and December water levels that are rising as a result of winter »running late.« At the same time, the summer (August) minimum is falling increasingly (Table 11). The former indicates an increased probability of high water and floods in the fall months and a smaller one in the spring. The second indicates the occurrence of summer droughts. Other researchers have also reported a higher probability of floods in the fall and winter.[24]

However, it is not only climate change that affects changes in the hydrological regime and consequently the occurrence of floods. One must not forget the human impact, such as changes in land use, river training, barriers, and urbanization.[25] Here, the Bistrica can be highlighted due to the Soboth reservoir. Flood hazard can be increased by inappropriate decisions of hydroelectric plant managers, like in November 2012. Poor decisions by the Austrian managers of the hydroelectric plants on the Drava (Ger *Drau*) caused the most devastating floods along Slovenia's Drava in the history of recorded measurements.[26] Floods hazards in the Podravje Region are further increased by improper land use, especially development in flood-prone areas.[27]

6 CONCLUSION

The key findings about changes in the selected climate and hydrological variables between 1961 and 2018 largely overlap with the trends presented by other researchers.[28] They can be summarized as follows:

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22 Sagadin, J. 2003: Statistične metode za pedagoge. Maribor, Obzorja.

23 Natek, K. 2005: Poplavna območja v Sloveniji. Geografski obzornik, 52 (1).

24 E.g.: Lóczy, D., Dezső, J., Gyenizse, P. 2017: Climate change in the eastern Alps and the flood pattern of the Drava river. Ekonomska i ekohistorija, 13; Žiberna, I. 2017: Trendi vodne bilance v severovzhodni Sloveniji v obdobju 1961–2016. In: Geografije Podravja. Maribor, Univerzitetna založba Univerze.

25 Uhan, J. 2007: Trendi velikih in malih pretokov rek v Sloveniji. Ujma, 21; Bormann, H. 2010: Runoff regime changes in German rivers due to climate change. Erdkunde, 64 (3); Zampieri, M., Scoccimarro, E., Gualdi, S., Navarra, A. 2015: Observed shift towards earlier spring discharge in the main Alpine rivers. Science of the Total Environment, 503-504; Šraj, M., Menih, M., Bezjak, N. 2016: Climate variability impact assessment on the flood risk in Slovenia. Physical Geography, 37 (1).

26 Zorn, M. 2018: The economic role of the Drava River in Slovenia: From navigation to hydropower. Podravina, 17 (33).

27 Žiberna, I. 2014: Raba tal na območjih z veliko poplavno nevarnostjo v Sloveniji. Revija za geografijo, 9 (2).

28 E.g.: Uhan, J. 2007: Trendi velikih in malih pretokov rek v Sloveniji. Ujma, 21; Ulaga, F. 2002: Trendi spreminjanja pretokov slovenskih rek. Dela, 18; Frantar, P., Kobold, M., Ulaga, F. 2008: Trend pretokov. In: Vodna bilanca Slovenije 1971–2000. Ljubljana, Agencija Republike Slovenije za okolje; Ulaga, F., Kobold, M., Frantar, P. 2008a: Trends of river discharges in Slovenia. IOP Conference Series: Earth and Environmental Science, 4 (1); Ulaga, F., Kobold, M., Frantar, P. 2008b: Analiza časovnih sprememb vodnih količin slovenskih rek. In: 19. Mišičev vodarski dan. Maribor, Vodnogospodarski biro; Kobold, M., Dolinar, M., Frantar, P. 2012: Spremembe

– From 1961 to 2018, the average annual air temperature increased by 0.043 to 0.047 °C on average a year at all five temperature stations analyzed, which means that during that period the atmosphere warmed up by 2.5 °C. The temperature difference is the smallest at the Starše station, where over the six decades temperature rose by 2.44 °C; the largest difference was recorded at the Maribor Tabor station, where temperature increased by 2.68 °C.

– From 1961 to 2018, annual precipitation decreased at eighteen out of twenty-five weather stations. Most differences in annual precipitation are relatively small, not exceeding 10% at twenty stations. The falling annual precipitation trend is the strongest at Sveti Duh na Ostrem Vrhu, Maribor Tabor, and Ptuj (the differences exceed –10%), whereas the rising trend is the most distinct at Kozji Vrh and Sveti Primož nad Muto (the differences exceed +10%).

– From 1961 to 2018, the annual number of days with precipitation over 0.1 mm increased at nine precipitation stations and decreased at fifteen, and it stayed the same at the Remšnik station. At eleven stations, the negative or positive trend deviations are smaller (i.e., below 10%). A stronger decrease was recorded at the Strojna, Oplotnica, and Ribnica na Pohorju stations (with differences ranging from –30 to –20%), and the greatest increase was recorded at Koprivna, Dravograd, and Kozji Vrh (the differences are around +20%).

– During the period studied, the number of days with snow cover decreased significantly at all precipitation stations. At most stations (i.e., sixteen out of twenty-five) the number decreased by 40 to 60% or 25 to 61 days. The duration of snow cover shortened the least at Slovenske Konjice, Žetale, and Oplotnica (25 to 27 days), and the most at Strojna, Šmartno pri Slovenj Gradcu, and Ribnica na Pohorju (over 50 days).

– From 1961 to 2018, all six rivers had a sharply decreasing average annual minimum discharge trend, with an over 17% trend difference on all rivers. The average minimum discharge of the Drava tributaries decreased by 0.31 to 1.60 m³/s, and that of the Drava decreased by 33.59 m³/s. The Drava and Meža recorded a relative decrease of 15 to 20%, the Dravinja, Polskava, and Pesnica a decrease of 25 do 30%, and the decrease on the Bistrica, which is under a strong human impact, even exceeded 60%.

– During the period studied, all six rivers had a decreasing average annual mean discharge trend. The annual mean discharge of the Drava tributaries decreased by 0.33 to 3.26 m³/s and that of the Drava declined by 34.00 m³/s. Most rivers recorded a relative decrease of 10 to 25%, with a significantly greater decrease observed only on the Bistrica (–63.5%) due to additional water removal.

– During the period studied, four rivers had a decreasing average annual maximum discharge trend and two had an increasing trend. Among the rivers with a negative trend, the discharge decreased the most on the Bistrica (–58%) and on the Meža (–29%), and significantly less on the Drava (–4%) and the Dravinja (–2%). Among the rivers with a positive trend, the discharge increased the most on the Polskava (+13%) and Pesnica (+2%).

– From 1961 to 2018, three rivers had a falling absolute annual maximum discharge trend and three had an increasing trend. Among the rivers with a negative trend, the discharge decreased the most on the Meža (–20%) and Bistrica (–14%), and among the rivers with a positive trend, the discharge increased the most on the Polskava (+65%) and Dravinja (+15%). The absolute annual maximum discharge trend of the Drava was slightly falling (–9%).

– A comparison of the discharge regimes based on the 1961–1990 data set and the discharge regimes based on the 1991–2018 data set shows that the spring (main) and fall (secondary) discharge maximums

vodnega režima zaradi podnebnih sprememb in drugih antropogenih vplivov. In: Zbornik: 1. kongres o vodah Slovenije. Ljubljana, Fakulteta za gradbeništvo in geodezijo; Kovačič, G., Kolega, N., Brečko Grubar, V. 2016: Vpliv podnebnih sprememb na količine vode in poplave morja v slovenski Istri. Geografski vestnik, 88 (1); Makor, S. 2016: Trendi spreminjanja pretokov rek v Sloveniji. Diplomsko delo. Ljubljana, Univerze v Ljubljani, Fakulteta za gradbeništvo in geodezijo; Hrvatin, M., Zorn, M. 2017a: Trendi temperatur in padavin ter trendi pretokov rek v Idrijskem hribovju. Geografski vestnik, 89 (1); Hrvatin, M., Zorn, M. 2017b: Trendi pretokov rek v slovenskih Alpah med letoma 1961 in 2010. Geografski vestnik, 89 (2); Hrvatin, M., Zorn, M. 2018: Recentne spremembe rečnih pretokov in rečnih režimov v Julijskih Alpah. In: Triglav 240. Ljubljana.

are becoming increasingly equal and on some rivers the main maximum now occurs in the fall (e.g., on the Meža and the Polskava; they are equal on the Dravinja). The impact of winter snow retention has decreased considerably and only remains significant on the Drava and Bistrica. The summer minimum is becoming increasingly pronounced on all rivers, and the November and December water levels are increasing and, in many places, exceed the annual average, implying that winter »is running late.«

– An increase in the absolute annual maximum discharge, increased deviations in the absolute annual maximum discharge of some rivers, and an increase in the fall discharge can imply a greater flood hazard, despite the overall smaller volumes of water.

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IZVLEČEK

V prispevku obravnavamo različne letne trende podnebnih in hidroloških spremenljivk na območju slovenskega dela porečja Drave med letoma 1961 in 2018. Prve se odražajo predvsem v rasti povprečne letne temperature in močno skrajšanem trajanju snežne odeje. Pri drugih pa je opazno padanje povprečnih minimalnih in srednjih letnih pretokov, povprečni maksimalni in absolutni maksimalni pretoki pa ponekod naraščajo. Poleg vodnih količin se pri rekah spreminjajo tudi pretočni režimi, ki po eni strani lahko kažejo manjšo možnost spomladanskih poplav, po drugi strani pa večjo možnost jesenskih poplav.