Chapter 6
Hydrological Characteristics of the Drava River in Croatia

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Abstract The Drava River is one of the biggest right-bank tributary of the Danube and one of the most important rivers in continental Croatia. Its great environmental value is in conflict with its economic potential in hydroelectricity, navigation, and irrigation. During the history, many hydraulic structures were constructed on the river and caused changes in its hydrological regime. In addition, in the early 1980s, climate change manifested in less precipitation and higher air temperature became more evident. A hydrological analysis of the Croatian section of the Drava River pointed out the consequences of both trends. There are three different sections of the Drava River:

- the upstream section dependent on dam constructions;
- the middle part affected by the tributaries and
- the lower section under the influence of the Danube River backwater.

Analyses of water level and discharge time series between 1960 and 2015 were made for five hydrological gauging stations in Croatia. All characteristic minimum, average, and maximum values of these two parameters have shown a decreasing trend with two exceptions in the most upstream part of the river where three dams were constructed. Extreme hydrological events, floods and droughts were also analyzed. High water levels, which were a great threat in the past, are better controlled by dykes today, but they still endanger the area along the confluence of the Drava and Mura and the lowermost section due to the backwater effect of the Danube River. Droughts or periods of low discharges are becoming a more and more serious problem in the last 15 years, but, according the standardized streamflow index for detected drought severity, there is no clear increasing trend in drought frequency.

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6.1 Introduction

Out of its total length (749 km), the middle section of the river in Croatia is
322.8 km long to Terezino Polje (152.350 rkm). Here the Drava is mostly a low-
land river with a small gradient and numerous meanders, to its confluence with
Danube River (1,382.300 rkm). The area of its catchment in Croatia is 7,015 km^2,
less than 20% of the total catchment area of 41,238 km^2. According to its hydro-
logical regime, the Drava River is a typical glacial river with highest water levels in
late spring and summer (May, June, and July) and lowest water levels during winter
period (January and February). Recently, however, important shifts in these char-
acteristic periods occur. In 1993 and 1998, high water levels were observed in
October and in 2012 in November. The hydrological characteristics of the Drava
River, like most European rivers, have been changing over time caused by human
impact, including construction works carried out at various dates in history. It is
obvious that river length has been significantly shortened and accumulation has
happened at Varaždin. In the past, the riverbed with meanders and side-arms in
wide alluvial lowland had a completely different hydrological regime than nowa-
days (Fig. 6.1). More recently, river regime modifications are partly attributed to
climate change.

In addition to the overall morphological division of the Drava River to upper,
middle and lower sections, the Croatian section can be divided into three units by
river regime (Fig. 6.2). On the upstream section (A), three multipurpose dams and
reservoirs were established (hydropower plants Varaždin in year 1975, Čakovec in
1982 and Dubrava in 1989). This section ends at 255.050 river km, downstream
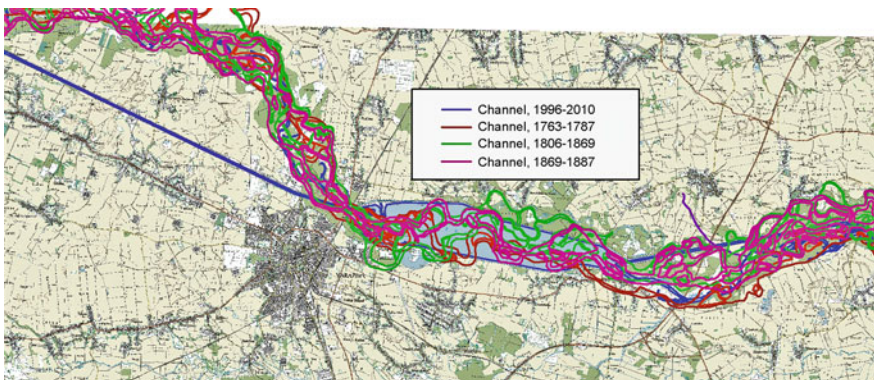
Fig. 6.1 Changes in the Drava riverbed on the Varaždin section from the 19th to 21st century
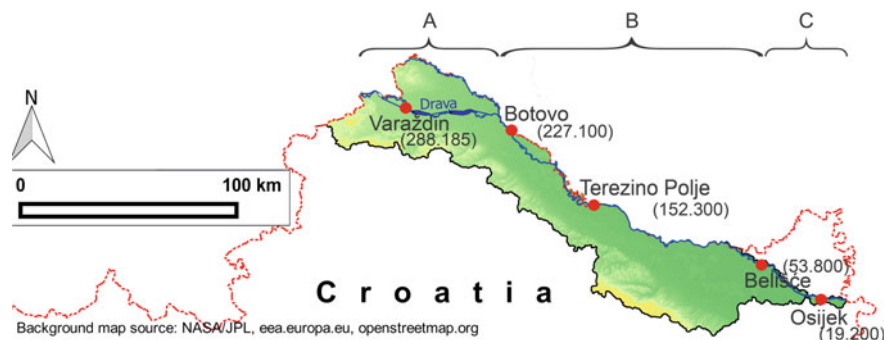
Fig. 6.2 Drava River in Croatia with gauging stations and the sections identified

from the last dam and it is significantly influenced by accumulations. The representative gauging station for analysis is Varaždin (288.145 rkm). Second section (B) is influenced by tributary catchments and ends at 53.800 rkm. The time series from three stations were analyzed for this section: Botovo (226.500 rkm), downstream from confluence of the Mura River, Terezino Polje (52.350 rkm) and Belišće (53.800 rkm). The third section (C) stretches from the gauge Belišće to the confluence with the Danube River. The representative gauging station for this section is Osijek (19.100 rkm) (Fig. 6.2). This entire section is influenced by the Danube River backwater, which has a significant impact on high water levels. Therefore, this section is endangered by floods from both the Drava and Danube rivers. The impact of high water levels from the Drava River is much weaker after dam constructions in the upstream catchment.

In the last decade, many papers have been published on river hydrology, including the hydrological properties of the Drava River. Different authors were motivated by the observed changes in river regimes and they sought to find the cause of these changes. Water levels and discharges were analyzed regarding climate change and water balance of the catchment.

An overview of most significant research is presented in chronological order. In the lower section of the Drava River, the period between 1900 and 1995 was characterized by an increase of potential evapotranspiration and reduction of surface runoff and soil moisture content (Zaninović and Gajić-Čapka 2000). It is also observed that a negative deviation of the Drava River water levels completely follows the positive air temperature deviation (Bonacci and Gereš 2001). The discharge analysis of the Drava River showed a negative trend, similar to the discharge trends for other Croatian rivers (Pandžić et al. 2008). The comparison of the number of precipitation days which are significantly reduced in the cold period and slightly rose in the warmer period with the Drava River discharges, also showed a negative discharge trend. In this case, the coefficient of variation of mean annual discharges decreases and the variation coefficient of the mean discharges of the colder period increases (Gajić-Čapka and Cesarec 2010).

There are also papers in which authors cite anthropogenic influences as well as climate change as the main cause of hydrological changes. After construction of the three hydropower plants on the Drava River, alterations in discharges, water levels, and sediment transport can be detected. Minimum and average discharges and all characteristic water levels of the lower Drava River are being reduced (Bonacci and Oskoruš 2010). Besides dams and hydropower plants, numerous barriers on the upper section in Austria and Slovenia have been built on the Drava River.

Hydrological observations on the Drava River started at the beginning of the 20th century, in year 1926, but not at all stations. For this reason, the hydrological properties of the Croatian section of the Drava River will be analyzed based on the time series of discharges and water levels observed at five gauging stations between 1960 and 2015.
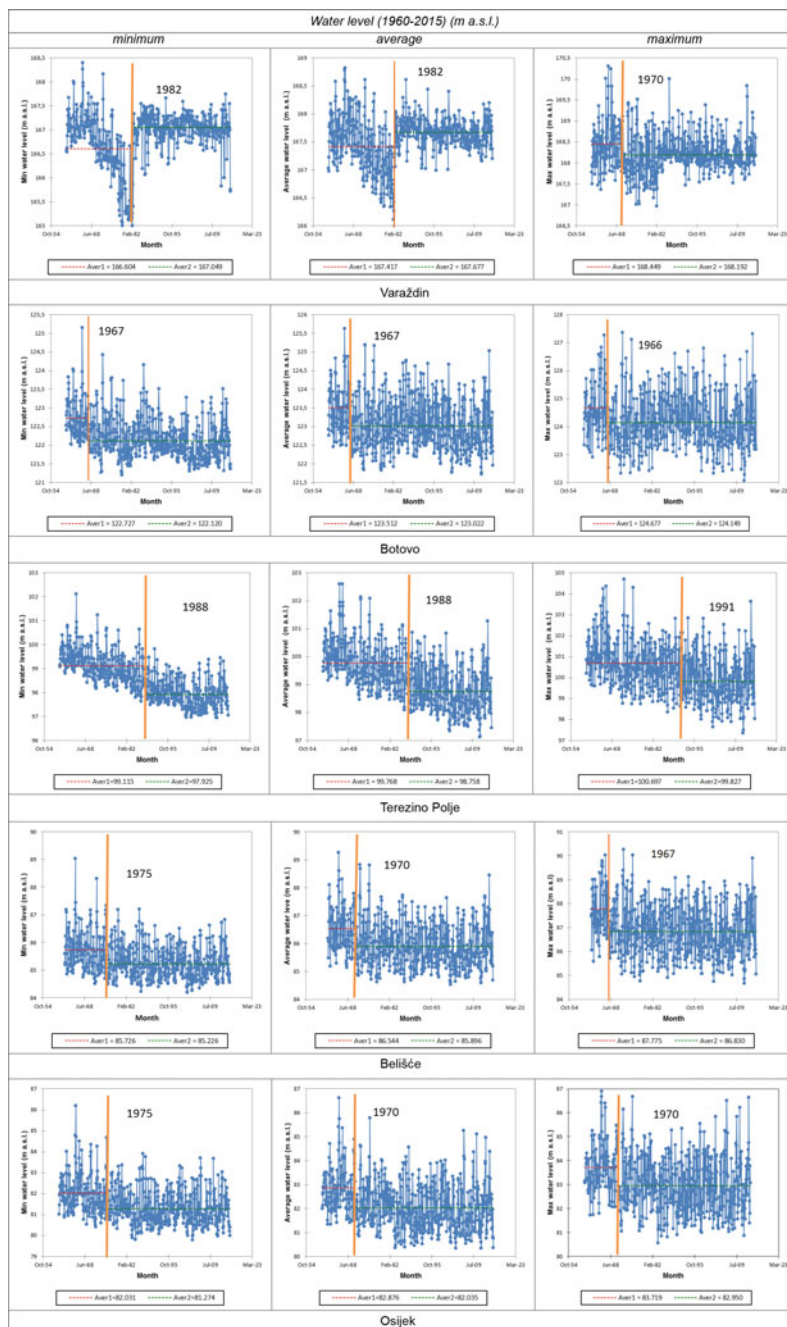
6.2   Water Levels

Minimum, average, and maximum water levels observed at five hydrological gauging stations (Varaždin, Botovo, Terezino Polje, Belišće and Osijek) in the period between 1960 and 2015 were studied. Declining linear trends of water levels were found for all marked water levels and all gauging stations except for Varaždin. Minimum and average water levels for this gauging station showed a positive trend and maximum water levels negative, but least emphasized in relation to other stations. The impact of dams is evident in this case. The intensity of water levels reduction is clear from the linear regression equations listed in Table 6.1. Other stations showed no variation in the slope of the linear regression lines, but the declining trend of the minimum water levels at the Terezino Polje station is remarkable.

Monthly water levels were tested according to Standard Normal Homogeneity Test (SNHT) in order to define homogeneity of the time series or presence of any significant differences in the occurrence of the minimum, average, and maximum water levels. Figure 6.3 shows sub-periods of characteristic water levels obtained by Standard Normal Homogeneity Test.

Table 6.1 Linear regression equations for all characteristic water levels

Hydrological gauging station	Water level (m a.s.l.)		
	Minimum	Average	Maximum
Varaždin	$y = 1 \times 10^{-5} + 166.4$	$y = 8 \times 10^{-6} + 167.32$	$y = -6 \times 10^{-6} + 168.14$
Botovo	$y = -4 \times 10^{-5} + 123.35$	$y = -2 \times 10^{-5} + 123.86$	$y = -2 \times 10^{-5} + 124.83$
Terezino Polje	$\mathbf{y = -0.001x + 101.98}$	$y = -9 \times 10^{-5} + 102.3$	$y = -8 \times 10^{-5} + 102.94$
Belišće	$y = -3 \times 10^{-5} + 86.46$	$y = -3 \times 10^{-5} + 87.121$	$y = -4 \times 10^{-5} + 88.18$
Osijek	$y = -5 \times 10^{-5} + 83.2$	$y = -5 \times 10^{-5} + 83.72$	$y = -4 \times 10^{-5} + 84.39$

Fig. 6.3 Sub-periods of characteristic water levels obtained by Standard Normal Homogeneity Test for all gauging stations

For all gauging stations and for all characteristic water levels, the time series were split up into subperiods. In the most cases, the breaking year between the subperiods is in the late 1960s and early 1970s. At the hydrological station Varaždin, there is a more pronounced impact of dam construction and downstream controlled water regime. The second subperiod starts in 1982 and it is characterized by higher minimum and average water levels by 26 cm and 44 cm, respectively. Besides, maximum water levels are lower in the second sub-period by 26 cm, and the breaking year corresponds with the construction of the first dam in 1970. In the second subperiod average, water levels are lower from 40 to 120 cm at the stations Botovo, Terezino Polje and Belišće. The largest-scale lowering of minimum water levels during second subperiod (1988–2015) is detected at the gauging station Terezino Polje with the magnitude of 120 cm in the first subperiod. The lowering of average water levels between 76 and 84 cm is characteristic for second subperiod for downstream station Osijek which is under influence of the Danube River backwater.

To better define observed changes in water levels, coefficients of variation were analyzed. Major oscillations of water levels can have severe negative consequences for the ecological system, water management, water use and, particularly, water quality. In Fig. 6.4, coefficients of variation for subperiods are shown.

According to Fig. 6.4, the range of monthly water level oscillation decreased for most of the gauging stations. The reduction is the most remarkable for the most upstream station Varaždin because of dam construction. The reduction in the variability of water levels is negligible for the middle and lower sections, where Osijek is situated, where the coefficients of variation for maximum water levels increased. The main reason for this is the cumulative influence of Drava and Danube high water levels.
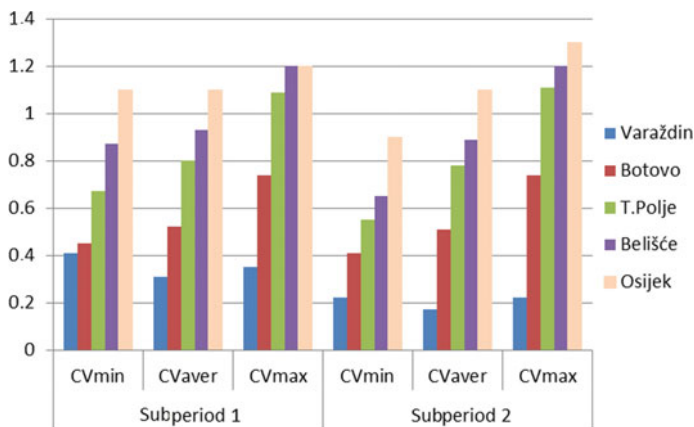

Fig. 6.4 Coefficients of variation of characteristic water levels for subperiods

6.3   Discharges

Based on the analyzed water levels, it can be concluded that the hydrological regime of the Drava River is dominated by anthropogenic influence since most of the changes in precipitation and air temperature have occurred in 1980s (Gajić-Čapka and Cesarec 2010; Tadić et al. 2016a, b). Discharge analysis was carried out for the time series of the period 1960–2015 for three hydrological stations: Botovo, Terezino Polje, and Belišće. For the upstream gauging station Varaždin, since accumulations were built, discharges are no longer measured and for Osijek, because of the backwater influence of the Danube, discharges have never been measured. In Fig. 6.5, results of homogeneity test are shown. Subperiods have been detected with breaking years between 1967 and 1980. Comparing to the first subperiod to the second, discharges have been reducing. The greatest difference is between average and maximum discharges in the first and second subperiods at Belišće station. (It should be mentioned that between 1994 and 2002 discharges were not recorded.)

The breaking years between the first and second subperiods for water levels and for discharges correspond. Thus, it can be concluded that significant riverbed
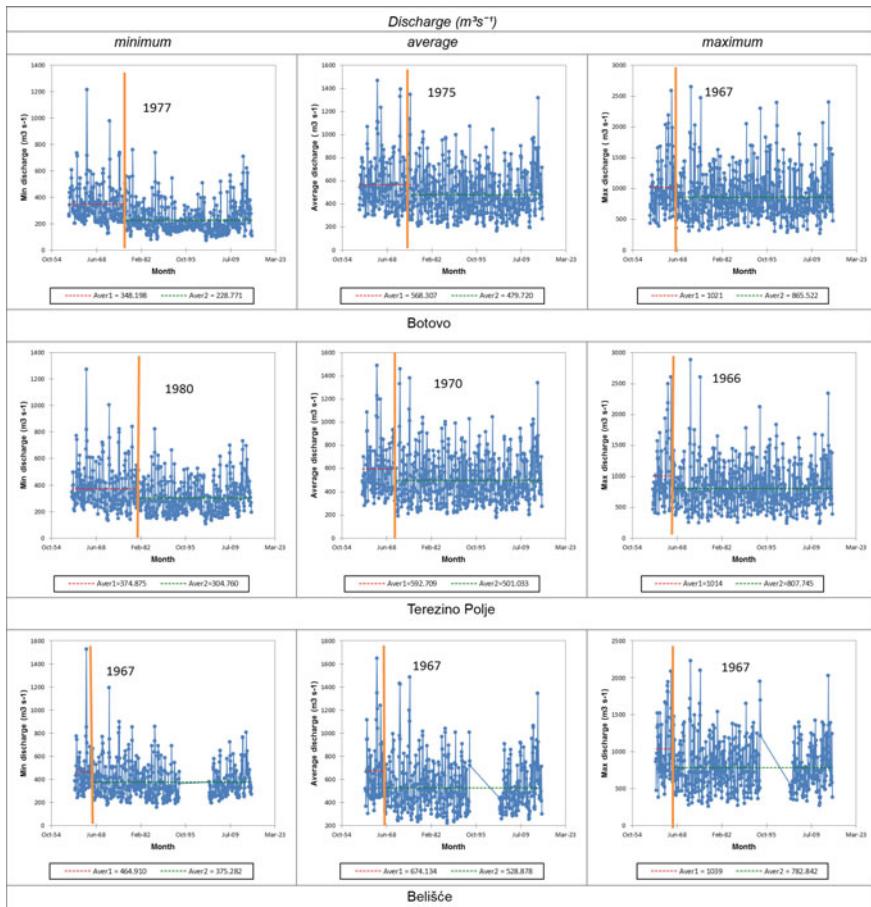

Fig. 6.5 Homogeneity test of the discharge series for three gauging stations

deepening occurred. Considering the changes of precipitation in the 1980s (Tadić et al. 2016a, b), it can be claimed that climate change has been the main cause of reduction in discharge. The impact of the snow and its contribution to total discharge should be also mentioned. Since the early 1970s, the number of days with snow cover in continental Croatia has been reduced (Bonacci et al. 2012). Changes in land cover also caused changes in the surface drainage in smaller subcatchments of the Drava River in Croatia and Hungary (see Chap. 5 in this volume). However, numerous dams were built on the Drava and its tributaries in Croatia and in countries upstream. Therefore, anthropogenic influence on river regime can be considered a predominant factor.

6.4   Maximum Water Levels (Floods)

Organized flood protection activities in the Croatian part of the Drava River basin started in the 19th century. In the last one hundred years, several disastrous floods occurred (in 1926, 1965, 1966, and 1972). After each flood, flood protection system was reconstructed and improved. In total, 435 km of dykes were built along the Drava River. The most important turning point in flood control was the major flood in 1972. Since then has been developed modern approach to the flood protection including technical and non-technical measures. Construction of dyke system and three dams significantly reduced flood frequency and damage. Table 6.2 presents five the most extreme water levels in the period 1960–2015. On only the most downstream section (C), represented by gauging station Osijek, three of five floods have occurred in the 21st century. All of them were caused not by the Drava River, but high water levels on the Danube.

Table 6.2 shows that from the flood protection point of view, the lowermost section of the Drava River (to ca 20 km upstream the confluence) is highly endangered since it is under the influence of the Danube. The hydrological analysis of the occurrence of maximum water levels on this section showed that until 1970s the majority of floods were caused by high water levels on the Drava River and after that date all floods (except in 2014) were caused by the Danube River backwaters. Coincidence of high water levels of both rivers would afflict enormous damage on the surrounding area. Fortunately, it has never happened yet, but this event cannot be excluded (Tadic et al. 2016a, b—Fig. 6.6).

There were 1,000 random pairs of water levels in Osijek and Bezdan generated (blue dots in Fig. 6.6) using the Normal copula function. Horizontal and vertical bars represent water levels at the Osijek gauging station on the Drava River and the Bezdan gauging station on the Danube River, which correspond with the first and second stage of flood warning. There is 0.7% probability of simultaneously occurring water levels that correspond to the 2nd stage or higher in Osijek and in Bezdan and 34.7% probability of simultaneous occurrence of the water level that corresponds to the 1st stage or higher at Osijek and at Bezdan (Tadić et al. 2016a, b).

Table 6.2 Five year with the most extreme maximum water levels (in bold: years of the 21st century)

Varaždin	Botovo	Terezino Polje	Belišće	Osijek
Maximum water levels, 1960–2015				
1965	1972	1972	1972	1965
1966	**2014**	1966	1966	1975
1964	1966	1975	1975	**2013**
1986	1975	1965	**2014**	**2006**
1975	1965	**2014**	1965	**2010**
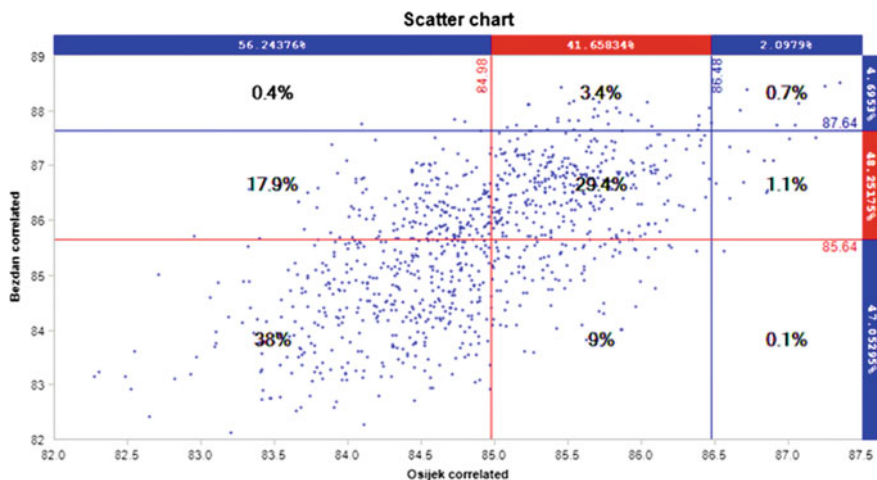
Fig. 6.6 The probability of coincidence of maximum water levels of the Drava and Danube rivers (Tadić et al. 2016a, b)
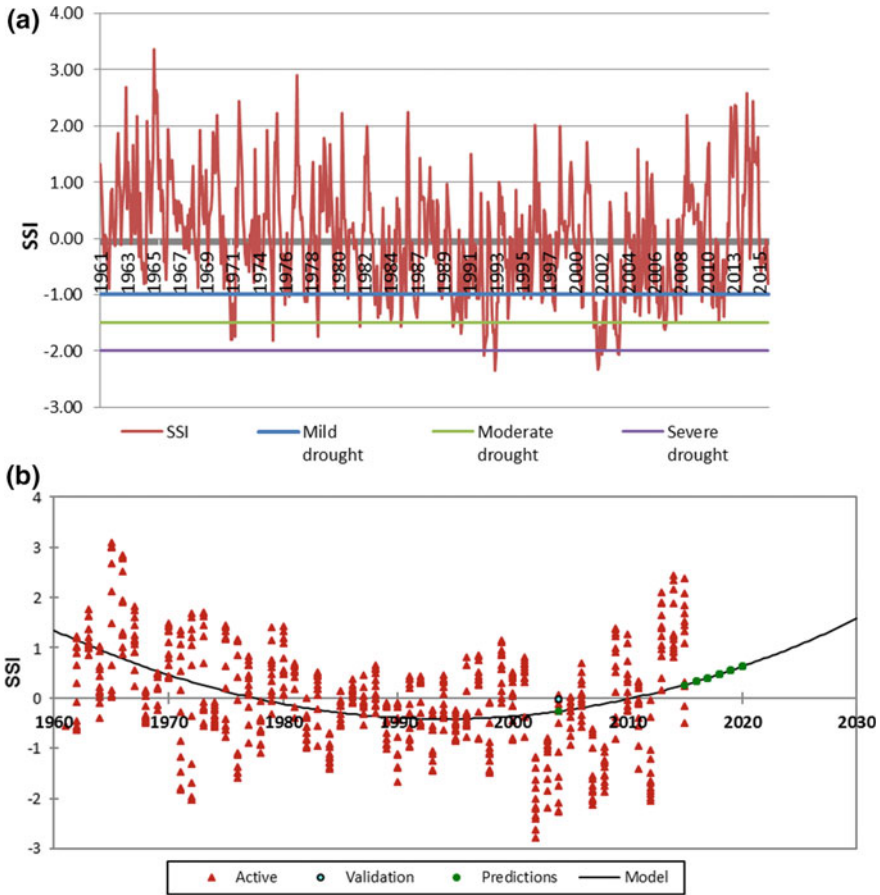
6.5 Minimum Water Levels (Droughts)

Increasing flood frequency is only one of the climate change impacts. Hydrological droughts or extreme low water levels are also becoming more and more common. In order to study this phenomenon, five extreme minimum water levels on representative gauging stations have been analyzed (Table 6.3). At the upstream gauging stations, Varaždin and Botovo, a clear influence of constructed reservoirs can be detected. Besides, the most downstream section (C) represented by the gauging station Osijek is under the Danube backwater influence. The section between 152 and 53 rkm is the most endangered by hydrological drought. This section depends on the Drava River tributaries and the runoff from their catchments. The early 21st century is characterized by several extremely dry years (2001, 2003, and 2011) in this area (Tadić et al. 2015).

Especially on the middle Drava section, we can expect more pronounced drought periods (Table 6.3), which may have enormous impact on water utilization (irrigation, navigation) and the environment in general. All the five years with the

Varaždin	Botovo	Terezino Polje	Belišće	Osijek
Minimum water levels (1960–2015)				
1982	1978	**2012**	**2002**	**2003**
1979	1971	**2002**	1987	1985
1978	1979	**2003**	**2003**	1983
1981	1972	**2011**	**2006**	**2011**
1982	**2001**	**2001**	**2001**	**2002**

Table 6.3 Five years with the most extreme minimum water levels (in bold: years of the 21st century)

Fig. 6.7 Standardized streamflow index (SSI) calculated for the Terezino Polje gauging station (**a**). Nonlinear regression analysis for the same gauging station with prediction period of five years (**b**)

lowest water levels obtained from the gauge of Terezino Polje occurred in the 21st century. To inspect this problem more deeply, standardized streamflow index (SSI) was calculated using average monthly discharge time series (1961–2015).

According to this drought index, values between 1 and −1 represent normal years (Ljubenkov and Cindrić-Kalin 2016). SSI values below −1 represent mild, moderate, or severe drought (Fig. 6.7a). The application of nonlinear regression analysis on calculated SSI values with a prediction period of five years (Fig. 6.7b) shows that a lower frequency of extreme low water levels and hydrological droughts can be expected.

6.6 Conclusions

The hydrological analysis of the Drava River in Croatia is presented in the chapter based on water level and discharge measurements at five hydrological gauging stations which operated in the period between 1960 and 2015. Characteristic water levels (minimum, average and maximum) show a decreasing trend with the exception of the gauging station Varaždin which is under the influence of a hydropower plant on the upstream river section. The homogeneity test (SNHT) applied on the water level time series indicates two sub-periods with a breaking year in the late 1960s and early 1970s. Characteristic discharges also decrease and time series are also non-homogeneous. The breaking years between two subperiods appear between 1967 and 1980.

The analysis of extreme hydrological events, floods and droughts, points out that floods endanger the lowermost section (designated as C). Besides, hydrological droughts are more significant in the middle section (B) which is under the influence of small tributaries. On the uppermost Croatian section (A) there are no extreme events in recent times due to the influence of dams, constructed in the period 1975–1989. Because of last-century anthropogenic impact, the first of all dam constructions, the Drava River regime has been changed and controlled. These activities are reducing negative effects of the extreme water levels, but, at the same time, have caused major and lasting deterioration of the environment.

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