The Role of Precipitation Variability in Water Content at Four Reservoirs in Central Western Bulgaria for the Period 2016–2019

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Abstract. The main objective of this study is to analyze the meteorological causes of the water supply crisis for the town of Pernik, Bulgaria in 2019. The water content of four reservoirs in central western Bulgaria (Studena, Iskar, Beli Iskar and Dyakovo) for the period 2016–2019 is considered. The amount and regime of precipitation in five nearby meteorological stations were analyzed and the Standardized Precipitation Index (SPI) was calculated. The values of SPI3 show the presence of three periods of severe dry conditions in the region under consideration - in the autumn of 2018, early spring and autumn of 2019. The main reason for the observed drought in 2019 is the low precipitation in February and March 2019. Despite the adverse meteorological conditions, problems with water content arise in only one of the four reservoirs under consideration, indicating that the water crisis for the town of Pernik in 2019 could be avoided by adequately regulating water consumption from Studena reservoir.

Keywords: Precipitation · Drought · Reservoir content

1 Introduction

The IPCC Fifth Assessment Report (AR5) states that climate change is altering hydrological systems, affecting water resources in terms of quantity and quality [1]. Some of the observed hydrological changes are the increase of the surface air temperature, increases of the frequency and intensity of the floods and droughts, decreases of the snow cover, changes in the precipitation patterns and others. In many regions of the world the water security is reduced due to increased air temperature extremes, rainfall variability and drought.

Reservoir storage plays an important role in freshwater supply, especially during dry seasons. Sustainable drinking water supply depends not only on the variability of precipitation, but also reservoir regulation [2]. The projected risks and impacts caused by a climate change include more frequent and intense extreme weather and climate events, such as heat waves, floods and droughts, therefore a careful regulation of reservoir water use is needed.

N. Dobrinkova and O. Nikolov (Eds.): EnviroRISKs 2022, LNNS 638, pp. 308–317, 2023.
https://doi.org/10.1007/978-3-031-26754-3_27

Studena reservoir is the main source of drinking water for the town of Pernik, western Bulgaria. In 2019, the amount of water in the reservoir dropped to a critical level and a crisis arose with the water supply during the autumn and winter months of the year. The dynamics of the surface water area of the Studena reservoir using satellite images from Sentinel 2A and 2B is studied by Jelev [3]. The analysis of the satellite imagery data confirms the clear tendency to decrease the water surface area in 2019. Another study of the water crisis in the town of Pernik was carried out by Nitcheva et al. [4]. The authors conclude that the main reason for the poor inflow to the reservoir in 2019 was the low precipitation in this year and, above all, the scarce snowfall in the winter months.

2 Data Sets

The study region is shown in Fig. 1. It includes part of the territory of central western Bulgaria. The four reservoirs under consideration are marked with blue circles. These are as follows: Studena – used to supply drinking water to the town of Pernik; Dyakovo - used to supply drinking water to the town of Dupnitsa; Iskar and Beli Iskar – used to supply drinking water to the city of Sofia.

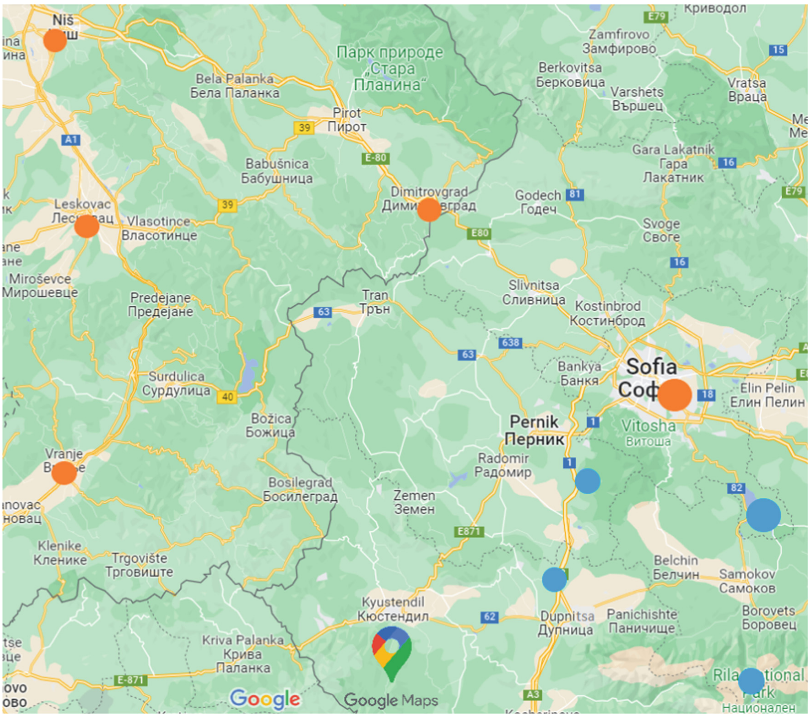

Fig. 1. Locations of reservoirs (blue circles) and meteorological stations (orange circles) under consideration. An image from Google Maps was used [5], with additions made by the author.

The meteorological data (monthly air temperatures and precipitation for the period 1960–2020) are obtained from the European Climate Assessment & Dataset project [6]. The data from five weather stations in the framework of the World Meteorological Organization are used – Sofia (Bulgaria), Nis, Dimitrovgrad, Leskovac and Vranje (Serbia) (Fig. 1). These stations were chosen because it is well known that the precipitation over the study area is primarily related to the movement of cyclones in the direction from northwest to southeast. Moreover, Studena reservoir is located on the western slope of Vitosha Mountain. Additional meteorological information is obtained from the national meteorological services of Bulgaria (http://meteo.bg/) and Serbia (https://www.hidmet.gov.rs/). The Standardized Precipitation Index (SPI) is calculated [7].

The hydrological data for the reservoir storage and for the Struma River runoff are obtained from the monthly bulletins of the Ministry of environment and water of Bulgaria for the period 2009–2020 (https://www.moew.government.bg/). All data used is freely available on the Internet.

3 Results

It is well known that the precipitation over the territory of Bulgaria is characterized by significant spatial and temporal heterogeneity. As a result, droughts and floods are frequent phenomena, especially in the case of observed climate change [8]. Figure 2 shows annual air temperature and precipitation at Sofia station for the last 60 years.

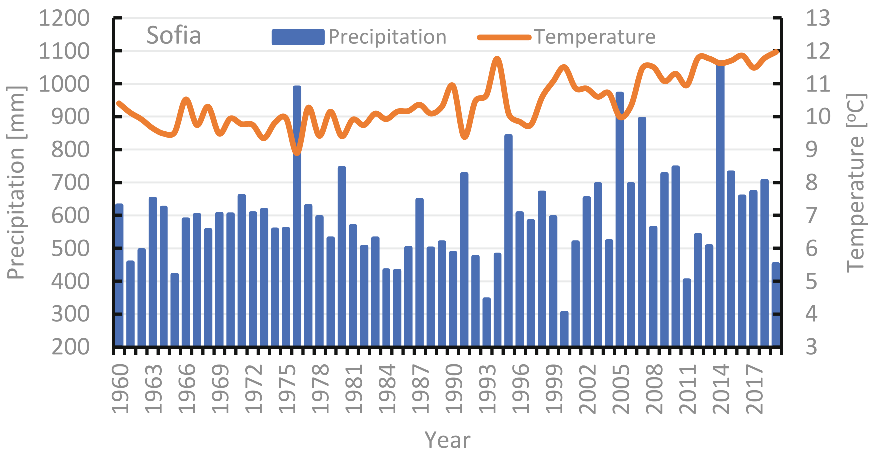

Fig. 2. Annual air temperature and precipitation at Sofia weather station for the period 1960–2019.

The estimated surface air temperature trend for the period 1960–2019 is 0.35 °C per decade, but the rate of warming over the past 40 years increases. Higher air temperatures lead to increased evaporation, decreased soil moisture and reduced river runoff.

The annual precipitation is characterized by significant increases in interannual amplitude over the last three decades. There are years with precipitation significantly below the climate normals (1993, 2000, 2011, 2019) and years with abundant precipitation (1995, 2005, 2014). During the 1994 there was a water supply crisis at Sofia city due to low water level of Iskar reservoir [8]. There were problems with water supply of town of Pernik during this year, also. It is worth noting that the average precipitation for Sofia during the period 1991–2020 increased by 41 mm compared to the average precipitation for the period 1961–1990. Nevertheless, the significant temporal variability in the amount of precipitation is a prerequisite for the occurrence of floods and droughts.

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought intensity. The values of SPI are expressed in standard deviations with positive SPI values indicating greater than median precipitation and negative values indicating less than median precipitation [7]. The SPI can be calculated for different periods, using monthly input data. More often the SPI3 and SPI6 (3 and 6 months SPI) are used, because a time lag exists between precipitation falling and being converted into terrestrial water [9].

Figure 3 shows the SPI3 index for Sofia station. The above-mentioned periods of droughts and floods are clearly visible. The most severe drought was in the period 1992–1994, when the values of SPI3 were predominantly negative for about 3 years. Values of SPI between −1 and −1.5 correspond to moderate drought. Such were the years 1984–1985 and 2000–2001, but the summer of 2000 was extremely dry. SPI values below −1 for a long period is an indication of the beginning of a drought [7].

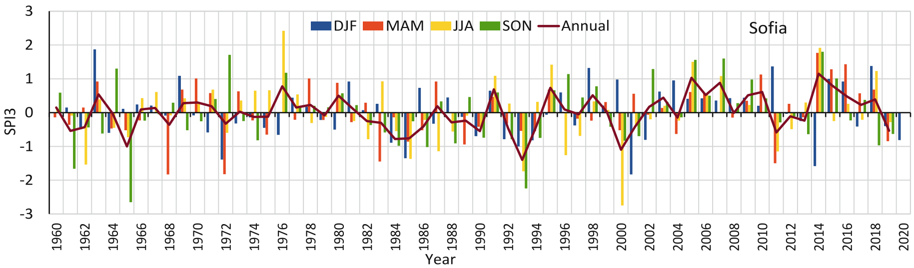

Fig. 3. Seasonal and annual values of the SPI3 index for Sofia weather station.

Monthly data for water storage of the four reservoirs under consideration are used to calculate the average filled volume for the period 2009–2018 (Fig. 4). The water storage maximum is in May and the minimum is in winter months (December, January, February). The exception is the Beli Iskar reservoir, which is at an altitude of 1894 m, the snow melting begins later, and the maximum is in June. Due to the low air temperatures, the minimum is in March.

The significant interannual variability of the water content can be clearly seen in Fig. 4. The water content of the reservoirs is the highest in 2018 and the lowest in 2019. The water content of the four reservoirs in the years 2016, 2017 and 2018 is close to the annual averaged values, showing adequate control of water consumption, regardless of the different meteorological conditions during this period. Some deviations from the average are observed in the first months of the year, due to both the available water from the previous year and the amount of precipitation and the beginning of snow melting.

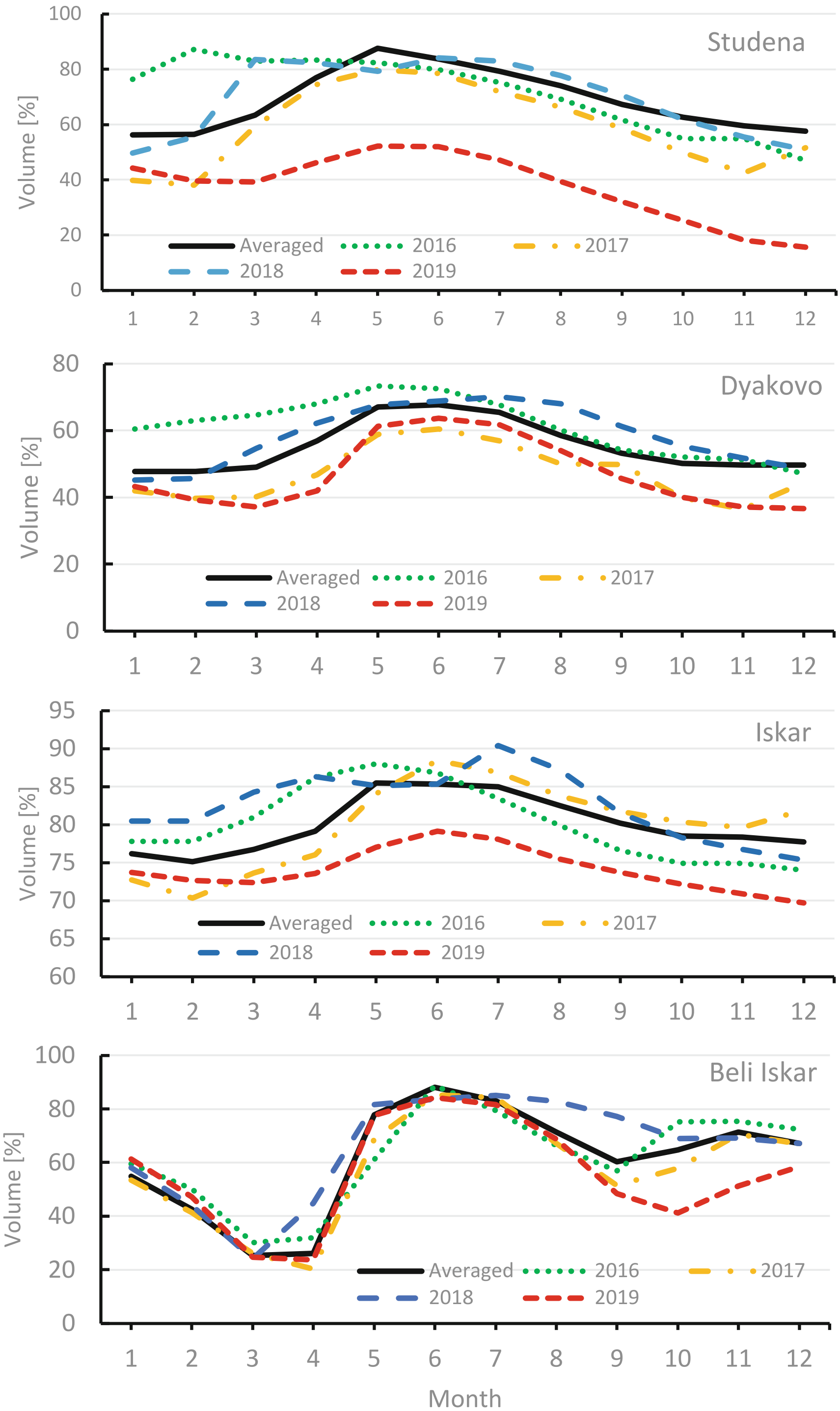

Fig. 4. Water storage of reservoirs Studena, Dyakovo, Iskar and Beli Iskar (in percents of maximum volume) for the years 2016–2019. The average water storage for the period 2009–2018 is presented, also.

It should be noted the steady downward trend in water content in all reservoirs in the second half of the 2018. As a result, the water contents of the Iskar, Dyakovo and Sudena reservoirs in the beginning of 2019 are below the annual averaged volumes.

At the beginning of 2019 the water content of the reservoirs continues to fall and reaches minimum values in March, that is 1–2 months later than normal. The main reason is the abnormally low rainfall in February and March. The water content of the reservoirs Studena and Iskar in the spring of 2019 is significantly below the normal, respectively by 35% and 8%. It is important to note the significant difference between the water content of the Studena and Dyakovo reservoirs in 2019. The maximum volumes of the two reservoirs are 25 10^6 m^3 and 35 10^6 m^3, respectively, but taking into account the allowed maximum filling, they should contain about 23 10^6 m^3 in May. The water content of Dyakovo reservoir increases in the spring of 2019 and almost reaches normal values in May, while the amount of water in the Studena reservoir (13 10^6 m^3) remains significantly below normal for this period of the year. In the summer and autumn of 2019, the water content of the Studena reservoir gradually decreases and in December reaches a critical level of filling of 15.4%, while the filling of the Dyakovo reservoir in December is 36.5% (Fig. 4). Obviously, different strategies have been used in the operation and management of the two reservoirs and the one for the Studena reservoir was not optimal.

The variations in water content of the four reservoirs can be explained by analyzing the amount of precipitation over the area under consideration. Figure 5 shows the anomalies of precipitation and air temperature at Sofia station, relative to 1961–1990. Figure 6 presents the average precipitation at the five weather stations considered for the period 2016–2019. The increase in the water content of the reservoirs (Fig. 4) in February 2016 is related to the large amount of precipitation in January 2016 (Fig. 5, 6) and the abnormal warming in February (Fig. 5), leading to intense snowmelt. In the summer and autumn of 2016, the precipitation at Sofia station is less than normal, while the precipitation at the other 4 weather stations is close to and above normal. This difference can explain the more significant reduction of the water content of Iskar reservoir in the summer and autumn of 2016 (Fig. 4).

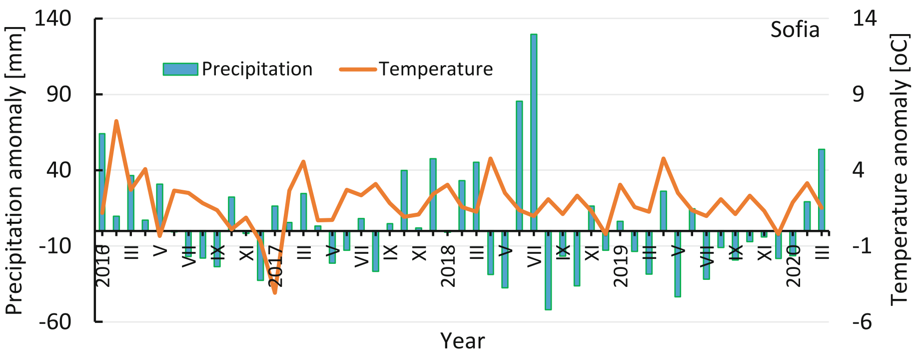

Fig. 5. Air temperature and precipitation anomalies for the period 2016–2019 at Sofia station, relative to the period 1961–1990.

Although the distance between the weather stations under consideration is not large (between 40 and 140 km) and there is consistency between the amounts of precipitation, during certain periods there is significant differences in the precipitation regime at weather stations. For example, the amount of precipitation at Sofia in June and July 2018 significantly exceeded the normal ones (Fig. 5), while the precipitation in stations Dimitrovgrad, Leskovac and Vranje was slightly above the normal. As a result, the water content of Iskar reservoir markedly increased in July 2018 (Fig. 4). After these heavy rains in the middle of 2018, there is a long period of one and a half years with precipitation below and around the normal at Sofia station (Fig. 5). At the same time, air temperatures are above normal. The average air temperature at Sofia in 2019 is 2.06 °C above the normal for the period 1961–1990. The regimes of precipitation and air temperatures are similar in the other stations under consideration, as the most significant difference with Sofia station is in May 2019, when the average precipitation for the region is around the normal (Fig. 6), but at Sofia they are only half of it (Fig. 5).

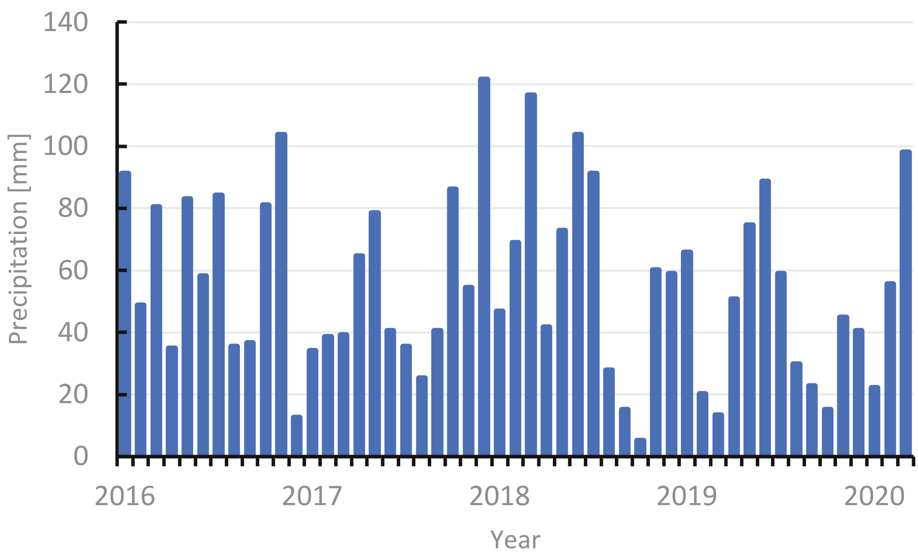

Fig. 6. Precipitation amount averaged for weather stations Sofia, Nis, Dimitrovgrad, Leskovac and Vranje.

The Standardized Precipitation Index better characterize periods of meteorological drought and floods. Figure 7 shows five cases of meteorological drought conditions in the period 2016–2019. The first two are in the beginning and in summer of 2017. SPI3 values are not below −1.0 and they are classified as mild droughts [7]. Deviations in the water content of the reservoirs are visible in Fig. 4, but they do not lead to a crisis with the water supply, probably due to the proper management of water consumption. The next three periods of dry conditions in the region under consideration are in the autumn of 2018, early spring, and autumn of 2019. Values of SPI3 index are between −1.0 and −1.5 and the meteorological conditions are classified as moderate drought.

The calculation of the SPI6 index uses the precipitation data for the previous 5 months and thus the hydrological processes with a longer period are taken into account. It can be used as an indicator for reduced stream flow and reservoir storage [7, 9]. Values of SPI6 index show drought conditions from May to October 2017 and from November 2018 till February 2020. The minimum value of −1.24 is reached in January 2020, and it corresponds to moderate drought (Fig. 7). The highest positive values of SPI6 index are during the period from the end of 2017 and the first half of 2018, when the conditions in the region can be classified as very wet. This can be seen in Fig. 4, also.

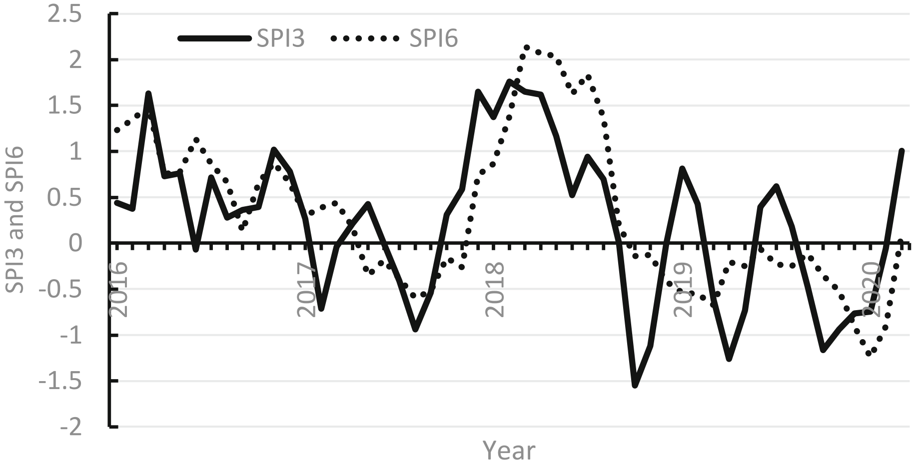

Fig. 7. Values of SPI3 and SPI6 indexes, averaged for weather stations Sofia, Nis, Dimitrovgrad, Leskovac and Vranje.

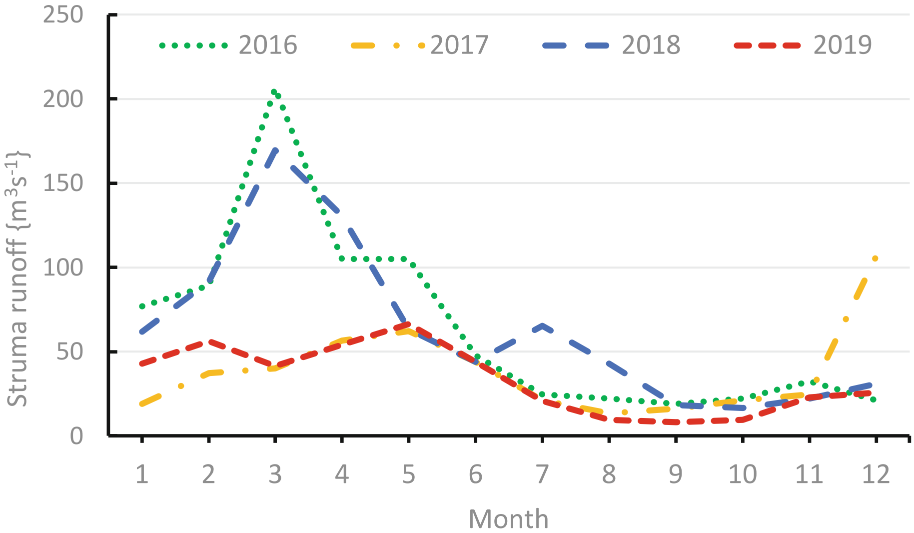

Fig. 8. The Struma River runoff at Boboshevo for the period 2016–2019.

The river runoff can be used as an indicator of future drought, also. Figure 8 shows the river runoff of the Struma River at Boboshevo (south of the town of Dupnitsa, Fig. 1). The catchment area of the Struma River covers the area of the present study and provides information on the amount of precipitation.

The above-mentioned features of the precipitation regime are visible in Fig. 8, also: wet periods in the beginning of 2016 and 2018, December 2017, July 2018; the dry periods in the beginning of 2017 and 2019. The extremely low outflow in the summer and autumn of 2019 is clearly visible (Fig. 8).

It should be noted that the National Institute of Meteorology and Hydrology provides the responsible services with information on precipitation, river runoff, SPI indices, as well as other information concerning droughts, such as Standardized Runoff Index (SRI) and Soil moisture index (SMI) (www.meteo.bg). This information, together with long-term weather forecasts, is sufficient to predict future droughts and to take an adequate response from the responsible water managers to prevent the negative consequences. Obviously, this was not done for Studena reservoir in 2019. In October 2019 the water content of the reservoir was 26.4%, but only in December actions were taken to prevent the water crisis in the town of Pernik, when the filled volume of the reservoir was only 15.4%.

The study of Santurdjian and Ilcheva [10] shows that filling of the Studena reservoir in the spring is essential. The conducted simulations show that in the presence of two consecutive dry years it is impossible to avoid a crisis with the water supply of the town of Pernik, if there is no reduction in water consumption. In order to avoid a water supply crisis in the case of two consecutive dry years, it is necessary to introduce a water use limit of 50% from the beginning of the second year.

4 Conclusion

The analysis of the precipitation, air temperature, Struma River runoff, Standardized Precipitation Index and water content of four reservoirs in Central Western Bulgaria shows the presence of two cases of drought in the period 2016–2019. The first drought was in 2017 and was relatively short and mild, while the second one was moderate and last from the autumn of 2018 till the beginning of 2020. The main reason for the observed drought in 2019 was the low precipitation in February, March, and autumn of 2019. Despite the adverse meteorological conditions, problems with water content arose in only one of the four reservoirs under consideration, indicating that the water crisis for the town of Pernik in 2019 could be avoided by adequately regulating water consumption from Studena reservoir.

Acknowledgments. This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577 17 08 2018 and supported by the Ministry of Education and Science of Bulgaria (Agreement № Д01 279 03 12 2021).

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