

# **European Journal of Geography**

Volume 11, Issue 1, pp. 006 - 022

Article Info:

Received: 27/01/2020; Received in revised form: 13/02/2020; Accepted: 19/10/2020

Corresponding Author: \*ksejmenou@uni-sofia.bg

https://doi.org/10.48088/ejg.k.sey.11.1.6.22

# Spatial and temporal aspects of high streamflow periods within the Danube drainage basin in Bulgaria

Kalin SEYMENOV1\*

<sup>1</sup> Sofia University, Bulgaria

### **Keywords:**

high flow, floods, threshold method, Danube River, Bulgaria

#### **Abstract**

High flow events are the main prerequisites for floods with negative social and environmental consequences. Their study under uncertain and changing climate gives informative knowledge for further management decisions. This paper seeks to analyze the spatio-temporal parameters of high flow periods within the Danube drainage basin in Bulgaria. Three characteristics of the hazard phenomena: time of occurring, frequency and duration are investigated. The analysis is based on daily discharge data collected from 20 gauging stations for the period 2000–2005. The surplus water quantities are identified by the Threshold level method using fixed values – Q25 and Q5, derived from the flow duration curve. Results show a concentration of the high flow periods during the spring hydrological season, with an average duration up to six weeks. The calculations establish positive correlations between the duration of high flow, the altitude of catchments, and the density of drainage network. The resulting information can serve as a support for the development of preliminary flood risk assessments in the Danube River Basin.



The publication of the European Journal of Geography (EJG) is based on the European Association of Geographers' goal to make European Geography a worldwide reference and standard. Thus, the scope of the EJG is to publish original and innovative papers that will substantially improve, in a theoretical, conceptual or empirical way the quality of research, learning, teaching and applying geography, as well as in promoting the significance of geography as a discipline. Submissions are encouraged to have a European dimension. The European Journal of Geography is a peer-reviewed open access journal and is published quarterly.

© Association of European Geographers

#### 1. INTRODUCTION

The study of hydrological extremes (floods and droughts) under changing global and regional climate conditions with proven positive air temperature trends represents an important scientific challenge facing modern hydrology in the 21<sup>st</sup> century. Unlike droughts, floods occur suddenly, causing a multiple of natural damages, social issues, economic losses, and even life-threatening situations. In addition to all this, "...the process of flooding is basically complex, uncertain and unpredictable due to its nonlinear dependence on meteorological and topographic parameters..." (Thirumalaiah et al., 2002). From a theoretical point of view, high streamflow shows a discharge of surplus water quantities and represents a boundary condition of the river systems.

The International Glossary of Hydrology defines "high streamflow" as an increase, in a relatively short time, of the river water levels to a peak, where they overflow from natural or artificial riverbanks and return to a slower pace. "A flood" is named a dangerous high flow event that causes submerges of usually dry lands followed by damages to property or losses of lives (Tudorache, 2018). Until now, the hydrological studies about high streamflow events in Bulgaria were focused to show genetic, theoretical, and descriptive aspects of their temporal and quantitative characteristics (Gerasimov et al., 1964, Panayotov, 1965, Penkov et al., 1983, 1992). Most of the abovementioned works analyzed or mapped the duration and frequency of the hazard phenomena. The water-related disasters were explained as a consequence of natural conditions, such as snow melting, heavy and prolonged rainfalls, or due to the overflow of dams (Abadzhiev, 1939, Angelov, 1940, Zyapkov, 1997, Penkov, 2006, 2012, Zlatunova et al., 2013). In the last decade, the scientific aspirations were aimed to prepare preliminary flood risk assessments - similar models were created for the drainage basins of the Malki Iskar River (Nikolova et al., 2009), the Yantra River (Nikolova et al., 2011), and the Rositsa River (Penkov, 2012, Zlatunova et al., 2013, Göppert et al., 2014). Simulation flood maps for the entire catchment area of the Danube River were also prepared ("Danube Flood Risk", 2013).

Furthermore, as the only European river flowing through ten countries, the Danube River holds a transnational flood risk program ("Flood Risk Management Program", 2016). All works listed above dealing with the increased river water levels have given important information for many water planning activities, such as the construction of dams, the design of hydroelectric power plants, the preparation of water management plans, etc. Therefore, despite the efforts made by the hydrologists in recent years in this field by the development of tools, concepts, and approaches for quantification of flood characteristics, the application of more and more new methods continues to be a priority task. As regards the social dimension of floods, the frequency, severity, and damage effects of all natural hazards, including the water-related disasters, are expected to increase with climate change in the foreseeable future.

Using the Threshold level method (TLM) (proven as a reliable approach for detection of water extremes), the current paper aims to perform a spatio-temporal analysis of the high streamflow periods within the Danube drainage basin in Bulgaria. The implementation of the stated objective is supported by the fact that almost all historical water-related disasters have occurred in anthropogenic-pressured areas situated near large rivers. It makes sense because if the river water levels rise due to rainfall, snow melting, or other reasons, a flood can easily occur. Furthermore, along riverbanks are often situated settlements or industrial units – this is an aggravating

factor, which increases the amount of damages (Tali et al., 2016) (e.g. near the investigated rivers are located the Bulgarian capital city – the town of Sofia and seven more district centers). Finally, the realization of this goal is expected to enrich previous theoretical studies, giving new knowledge about the characteristics of hydrological extremes.

# 2. BACKGROUND

In the last two decades, floods have affected more people across the world than any other natural hazard. According to the Emergency Events Database (EM-DAT 2018), floods have been the most common (45% of all events), most affecting (45% of all affected people), and most damaging (22% of all economic losses) natural disasters worldwide (Milanović-Pešić, 2019). Usually, the floods inflict the greatest amount of damages in developing countries due to poor water management practices, a lower socioeconomic status, etc. However, an increased number of severe floods in Europe have also been reported since the beginning of this century, especially in the catchment area of the Danube River – a trans-boundary basin, shared among more than 80 million people from 14 countries.

The Water Framework Directive (WFD) 2007/60/EC on the assessment and management of flood risks, entered into force on 26th November 2007, stated: "In 2005 the International Danube River Basin struggled to cope with devastating floods sweptwing through the region, ravaging communities and causing millions of euros worth of damage". Then heavy rains fell in Bavaria (Germany), Tyrol (Austria), the Pannonian Basin (Hungary), and the Wallachian Plain (Romania), resulting in very high river water levels and extreme discharge values. The WFD pointed out that the Central and Southeastern European countries are most vulnerable to experience severe floods in the coming decades due to climate change, which brings a higher intensity of rainfalls and because of unsustainable land use practices on the floodplains, which reduce their capacity to absorb surface water. Nikolova et al. (2013) stated: "For the period 2000–2009 the highest number of severe floods in Southeastern Europe was registered in Romania (30), Greece (14) and Bulgaria (11)". Merz et al. (2014) and Thieken et al. (2016) reported extreme floods in Southern and Eastern Germany in June 2013: "The June 2013 flood was, in hydrological terms, the most severe flood in Germany, at least for the last six decades for which a hydrological flood severity has been calculated" (Merz et al., 2014). Bovan et al. (2018) concluded that a total of 182 municipalities in Croatia were affected by floods during the months of May 2014 and February 2015. Milanović-Pešić (2019) indicated a number of devastating floods in Serbia in June 2010 and May 2014. Over the last couple of years, the Bulgarian part of the Danube basin has also suffered from severe water-related disasters, mostly during the extremely wet year 2005. More comprehensive information about their spatial and temporal characteristics will be presented below.

# 3. STUDY AREA

The study region covers an area of 28 688 km<sup>2</sup> situated in the central part of the Danube drainage basin in Bulgaria, which represents 61.2% of the region and 25.8% of

the country's territory. The researched area comprises the river basins of six right tributaries of the Danube River – the Ogosta River, the Iskar River, the Vit River, the Osam River, the Yantra River, and the Rusenski Lom River (Figure 1, Table 1).

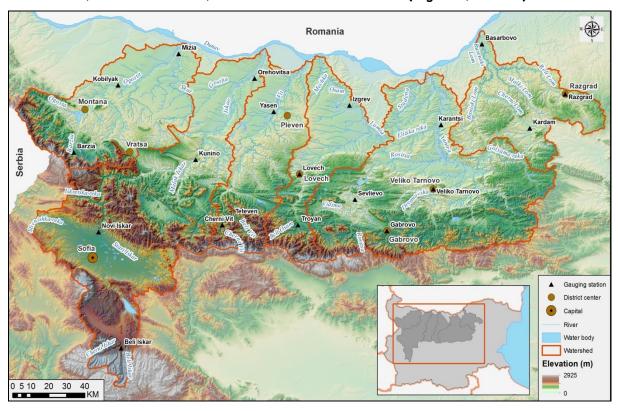


Figure 1 Map of the relief, hydrographic structure and hydrometric network in the study area

The Bulgarian Danube's watershed also includes the catchment of the Nishava River, the Sub-basins of the rivers west of the Ogosta River, (whose extreme flow characteristics were analyzed till now by Hristova et al, 2011, Hristova, 2014, Hristova et al., 2017) and the dry river valleys situated in the Dobruja Plateau. The catchment areas cover parts of different geomorphological units – the Rila Mountain, the Vitosha Mountain, the Balkan Mountains, the Fore-Balkans, the Danubian Plain, and the Sofia Valley. The relief is alpine, hilly, and plain (Figure 1). The study area belongs to the region of temperate-continental climate. The mean annual air temperature ranges from -2°C (at the Musala Peak) to 11°C (along the Danube riverbank). The average annual rainfall varies from 500-550 mm (along the Danube riverbank) to 1200 mm (in the high-mountainous areas). The rainiest months are May and June, while the driest months are February and March. The seasonal flow regime has classified as a first subtype of temperate-continental type, meaning the flow normally peak in spring (March to June) and then decreases continuously until early autumn (until September). An exception is the upstream section of the Iskar River located in Rila Mountain because there is an alpine discharge regime, which means the low runoff phase occurs in the winter months (December to February) (Hristova, 2004).

The described regimes are sometimes interrupted by the effect of heavy summer-time rains. Although the hydro-climatic conditions are main driving forces for flooding, physical land features, including rock permeability, soil mechanical structure and vegetation cover, also influence the flood outcomes. Steep slopes and impermeable rocks (Paleozoic granites, diorites, and gneisses) create large surface runoff and peaks



Table 1 Hydrographic information about the main rivers and catchments

Main river	The longest tributary	Length (km)	Catchment area (km²)	Altitude (m)		Geographic coordinates				
				Source	Mouth	Source		Mouth		
						Х	Υ	Х	Υ	
Ogosta	Skat	141.5	3157.1	1573	27	22.808	43.339	23.885	43.746	
Iskar	Malki Iskar	368.0	8646.2	2669	25	23.510	42.109	24.441	43.732	
Vit	Kamenitsa	188.6	3252.1	2198	22	24.417	42.752	24.743	43.681	
Osam	Lomia	314.0	2824.2	2165	21	24.633	42.776	24.855	43.701	
Yantra	Rositsa	285.5	7861.6	1494	19	25.418	42.738	25.570	43.640	
Rusenski Lom	Cherni Lom	196.9	2946.9	479	16	26.488	43.440	25.931	43.835	

Sources: Hydrological Reference book of the rivers in the Republic of Bulgaria (1981); Hristova (2012)

of the hydrograph after rains or snow melting in the mountainous valleys. These mount landscapes are covered by dense pine, spruce, beech, and oak forests, intercepting the rainwater through their leaves and reducing the flood risk. On the other hand, flat relief and anthropogenic practices in the Danubian Plain and the Sofia Valley, such as agriculture, deforestation, urbanization, etc., are potential causes for flooding. However, the flood risk is reduced due to the widespread distribution of permeable rocks (Jurassic limestones, Quaternary loess, sands, etc.), provoking the process of infiltration. Over 320 dams in the investigated area are constructed, manifesting as a regulator of the natural hydrological regime, but also as a significant risk factor for flooding.

#### 4. DATA AND METHODS

In this work, daily discharge data recorded in 20 gauging stations within the Danube drainage basin in Bulgaria are used. Each catchment area is presented with three to four hydrometric stations. The measuring points are selected so that they cover parts of the upper, middle and lower reaches of the rivers (Figure 1, Table 2). Study period comprises the first six years of the 21<sup>st</sup> century (2000–2005). Although the relatively short duration of the period, it includes two dry years (2000, 2001), three normal water years (2002, 2003, and 2004) and extremely wet year (2005). In our previous works, we established the annual flow volumes measured in 2001 (6143\*106m³) and 2005 (32580\*106m³) have been the minimum and maximum values since the beginning of this century in Bulgaria. The stated values represent approximately 33% and 175% of mean annual flow in the country, compared to the reference norm for the periods 1961–1990 (18391\*106m³) and 1971–2000 (18455\*106m³).

Exploring the annual flow dynamics in the Bulgarian part of the Danube basin, Hristova et al. (2018) and Hristova et al. (2019) concluded the annual runoff volume in  $2005 (13597^*10^6\text{m}^3)$  exceeded with 28% the previous maximum, measured in 1956 ( $10582^*10^6\text{m}^3$ ), suggesting the flow volume in 2005 has been the absolute maximum value recorded within the Danube drainage basin in Bulgaria since the beginning of hydrometric observations (since the 1930s). At the same time, annual flow volume in the driest year (2001) during the investigated period  $-2427^*10^6\text{m}^3$  was above the current minimum in this region  $-1714^*10^6\text{m}^3$ , measured in 1990 (Hristova et al., 2019).

**Table 2** Hydrometric information about the gauging stations

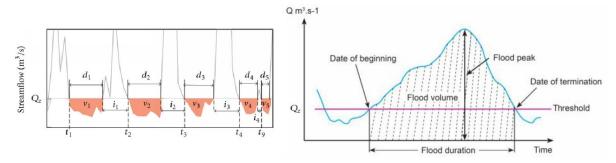
Catchment area	River	Gauging station	Catchment area (km²)	Altitude (m)	Length to the source (km)	Length to the mouth (km)	Density of river network (km/km²)
Ogosta	Barzia	Barzia	5.2	1364	4.4	30.6	2.19
	Ogosta	Kobilyak	2250.0	496	81.9	59.1	0.96
	Ogosta	Mizia	3112.0	395	133.6	7.4	0.73
Iskar	Iskar	Beli Iskar	328.0	1826	23.5	344.5	2.05
	Iskar	Novi Iskar	3668.0	945	113.8	254.2	1.39
	Iskar	Kunino	6697.0	831	233.1	134.9	1.27
	Iskar	Orehovitsa	8366.0	706	340.5	27.5	1.08
Vit	Cherni Vit	Cherni Vit	155.4	1032	20.7	6.0	1.01
	Beli Vit	Teteven	306.0	1007	25.6	163.0	0.64
	Vit	Yasen	2407.0	489	128.2	60.4	0.61
Osam	Osam	Troyan	458.0	1034	37.1	276.9	0.89
	Osam	Lovech	907.0	723	74.1	239.9	0.51
	Osam	Izgrev	2154.0	448	206.2	107.8	0.44
Yantra	Rositsa	Seulieuo	1084.0	684	48.3	115.9	1.02
	Yantra	Gabrovo	286.7	781	25.8	259.7	0.95
	Yantra	V. Tarnouo	1289.0	545	81.7	203.8	0.79
	Yantra	Karantsi	6574.0	440	208.0	77.5	0.64
Rusenski Lom	Beli Lom	Razgrad	377.8	327	40.3	156.6	0.58
	Cherni Lom	Kardam	424.8	320	36.2	93.8	0.46
	Rusenski Lom	Basarbouo	2870.0	273	183.9	13.0	0.42

Source: Hydrological Reference book of the rivers in the Republic of Bulgaria (1981)

High flow events are identified using the Threshold level method (TLM). Figure 2 gives a general illustration of this method. The Indicators of Hydrologic Alteration (IHA) recommend the TLM as "...a reliable approach, describing flood indices from daily data. Its analysis includes multiple characteristics it can be restricted to a specific season or a specific flow generation mechanism...". To select a suitable threshold, indicating the relationship between daily discharges and the probability of their occurrence, percentile values derived from the flow duration curve (FDC) are applied. Different criteria for the determination of threshold values, as well as different techniques for threshold derivation (constant or daily, monthly, and seasonal variable threshold levels), are used. In this study, the constant value of the  $25^{th}$  percentile ( $Q_{25}$ ) to detect high runoff periods is calculated. In order to determine the highest river waves or the extremely high flow, the value of the  $5^{th}$  percentile ( $Q_5$ ) is selected.

The surplus flow periods are defined when the time-series data are continuously above the fixed threshold values. Three important temporal characteristics of these periods: time of occurring, duration, and frequency, are investigated in this work. The basic statistical procedures are implemented using the software package for hydrology, geoscience, and data science researches Hydro Office. Referring to recent researches in the field of hydrological extremes, the TLM is one of the most commonly used approaches to identify droughts and floods worldwide. During the last decade, this method was widely applied for individual catchment areas in Bulgaria (Hristova et al., 2011, Hristova, 2014, Lukarska, 2015, Hristova et al., 2017, Seymenov, 2018a, 2018b). The current work represents the first more spatially-extended research from this series

of studies in the country. Also, correlation and regression coefficients, describing the spatial changes in high streamflow characteristics, are calculated.



**Figure 2** Characteristics of the Threshold level method (TLM) with fixed constant values. Source: a modified graph after Yu et al. (2014) and Hristova et al. (2017)

#### 5. RESULTS

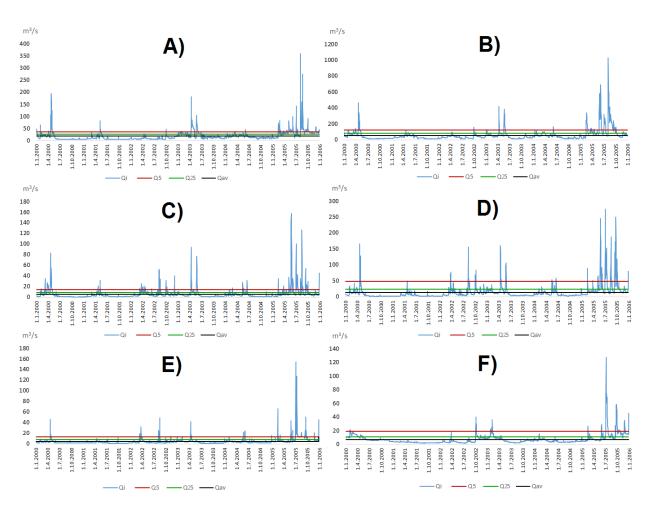


Figure 3 Hydrographs: A) Ogosta River at Kobilyak; B) Iskar River at Kunino; C) Beli Vit River at Teteven;
D) Osam River at Izgrev; E) Yantra River at Gabrovo; F) Rusenski Lom River at Basarbovo

# 5.1 High streamflow

High flow events every year in the spring hydrological season (March-June), less often during the winter season (November-February), and rarely in the summer and autumn months (July-October) are detected (Figure 3). The average duration of winter high flow reaches up to four weeks, while the spring high runoff continues up to six weeks. Despite the mentioned similarities, there are spatial and temporal differences in the average dates of beginning and termination of high flow periods. The 25<sup>th</sup>-percentile discharges, or the minimum flow values derived from the FDC required to record a high flow event, range from 0.26 m³/s (Barzia River at Barzia) to 73.06 m³/s (Iskar River at Orehovitsa) (Table 3).

**Table 3** Threshold flow values (Q25) and average dates of beginning and termination of high streamflow periods

River	Gauging station	Q au. 2000-2005 (m <sup>3</sup> /s)	Q <sub>25</sub> (m³/s)	_	drological son	Spring hydrological season		
				Average dates of beginning	Average dates of termination	Average dates of beginning	Average dates of termination	
Barzia	Barzia	0.18	0.26	04.02.	19.02.	26.04.	28.05.	
Ogosta	Kobilyak	18.24	23.75	28.12.	23.01.	06.04.	24.04.	
Ogosta	Mizia	21.70	28.19	24.12.	17.01.	03.04.	19.04.	
Iskar	Beli Iskar	6.71	8.43	_	_	07.05.	13.06.	
Iskar	Novi Iskar	23.36	31.21	20.01.	18.02.	24.04.	21.05.	
Iskar	Kunino	49.23	65.18	13.01.	05.02.	20.04.	11.05.	
Iskar	Orehovitsa	54.74	73.06	30.12.	26.01.	13.04.	02.05.	
Cherni Vit	Cherni Vit	3.02	4.39	04.02.	17.02.	25.04.	18.05.	
Beli Vit	Teteven	5.42	7.92	26.01.	21.02.	21.04.	16.05.	
Vit	Yasen	14.61	21.15	29.12.	23.01.	03.04.	21.04.	
Osam	Troyan	6.87	9.43	06.02.	24.02.	24.04.	18.05.	
Osam	Louech	9.28	12.92	30.12.	29.01.	10.04.	29.04.	
Osam	Izgrev	13.12	22.16	26.12.	24.01.	02.04.	18.04.	
Rositsa	Seulieuo	9.59	14.19	15.01.	11.02.	22.04.	16.05.	
Yantra	Gabrovo	4.24	6.58	17.01.	08.02.	21.04.	10.05.	
Yantra	V. Tarnouo	13.00	20.32	30.12.	24.01.	13.04.	04.05.	
Yantra	Karantsi	45.28	61.46	24.12.	21.01.	03.04.	24.04.	
Beli Lom	Razgrad	0.76	1.10	18.12.	08.01.	28.03.	09.04.	
Cherni Lom	Kardam	1.98	2.86	16.12.	09.01.	30.03.	10.04.	
Rusenski Lom	Basarbovo	5.89	8.81	13.12.	03.01.	24.03.	05.04.	

Spring high waters are most typical in the researched area. They begin from the second half of March or first half of April in the low-altitude catchment areas (e.g. the Ogosta River at Mizia or the Beli Lom River at Razgrad), and from the second half of April or first half of May in the mountainous river basins (e.g. the Iskar River at Beli Iskar or the Osam River at Troyan). The termination of spring high flow starts from the third week of April in the lower reaches of the rivers and from the second half of May or the first week of June in the high-elevation drainage basins (Table 3). Most frequently high flow events occurring in April are detected in the catchments of the Ogosta River at Kobilyak (to 43% of all spring high flow cases), the Yantra River at Karantsi (41%), the Ogosta River at Mizia (40%), the Iskar River at Orehovitsa (38%) and the Osam



River at Izgrev (36%). More typical are the March high streamflow events only at the Beli Lom River near Razgrad (to 48% of all cases) and at the Rusenski Lom River near Basarbovo (40%). High streamflow events mainly occurring in May are most typical in the catchments of the Iskar River at Beli Iskar (to 52% of all cases), the Barzia River at Barzia (47%), the Cherni Vit River at Cherni Vit (40%), the Iskar River at Novi Iskar (40%) and the Rositsa River at Sevlievo (37%). An explanation of the listed spatial and temporal differences gives the later start of snow melting in the mountainous valleys caused by the longer period of sub-zero air temperatures. The torrential and prolonged rainfall is the main source for the formation of considerable discharge values in spring. The influence of Icelandic cyclones is growing in spring in the regions of temperatecontinental climate in Europe, and this leads to increased amounts of precipitation in the months of April, May, and June in Northern Bulgaria. Additionally to the increased rainfall amounts, the snowmelt runoff formed in March, resulting from the rapid rise of air temperature above 0°C, also influences the spring high flow. Some of the most considerable raises in the river water levels and discharge values, as a result of strong and prolonged precipitation combined with surface runoff produced from the melting snow during the spring months, are established.

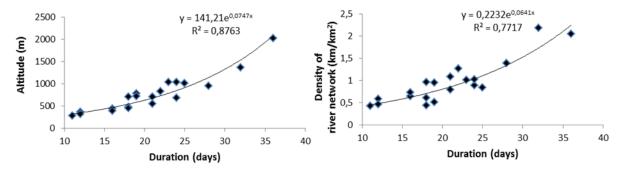


Figure 4 Correlations between the duration of spring high flow and two key parameters of catchment

There are strong positive correlations between the duration of spring high streamflow, the average altitude of catchment areas, and the average density of the drainage network (Figure 4). The coefficient of determination (R<sup>2</sup>) achieves even better results if it is computed for one drainage basin:  $R^2 = 0.902$  and  $R^2 = 0.939$ , respectively (a case for the Iskar River basin). We can explain the first relationship with the different genetic structures of runoff in the mountainous valleys compared to the lower reaches of the rivers (a variable share of precipitation and snow cover as main driving forces acting on the hydrological processes). The second correlation result is an effect of morpho-hydrographic factors (an influence of the drainage network configuration and geomorphological specifics of the terrain, etc.). Although the relatively short duration of the observation period, we can summarize the spring high flow periods coincide with the high flow phase within the Danube drainage basin in Bulgaria.

Winter high flow is less typical and shorter in duration. It begins from the second half of December or throughout the month of January and continues to the second half of January or to the third week of February, respectively. There are two exceptions: 1) Winter high flow occurs a month earlier in the Rusenski Lom river basin due to the lower altitude of catchment area, which provokes warmer winter air temperatures resulting in an earlier melting of the snow cover; 2) A winter high flow event in the Iskar River basin at Beli Iskar, because of the alpine climate conditions in the Rila Mountain provoking prolonged freezing of the surface streams, is not detected (Table 3). Most frequently high flow events occurring in January are established in the drainage basins of the Osam River at Lovech (to 41% of all winter events), the Yantra River at Veliko Tarnovo (39%), the Vit River at Yasen (39%), the Ogosta River at Kobilyak (38%), etc. More typical are the February high waters at the Cherni Vit River near Cherni Vit (to 44% of all events), the Beli Vit River near Teteven (38%), the Barzia River at Barzia (33%), and the Osam River near Troyan (32%). The short-term precipitation and the repeated passage of air temperature through 0°C, which leads to snow melting, are the main factors for the formation of winter high flow in the investigated catchment areas.

# 5.2 Extremely high streamflow

A total of 454 extremely high streamflow events within the Danube drainage basin during the entire observation period are recorded. Their number varies from 11 (the Rusenski Lom River at Basarbovo) to 36 (the Beli Vit River at Teteven) for each gauging station. The 5<sup>th</sup>-percentile discharge values range from 0.47 m<sup>3</sup>/s (at the Barzia River near Barzia) to 130.85 m<sup>3</sup>/s (at the Iskar River near Orehovitsa) (Table 4).

Years Σ Gauging Q5 River 2000station  $(m^3/s)$ Barzia Barzia 0.47 Ogosta Kobilyak 35.46 Ogosta Mizia 49.72 Iskar Beli Iskar 16.81 Iskar Novi Iskar 51.87 Iskar Kunino 104.23 Iskar Orehovitsa 130.85 Cherni Vit Cherni Vit 9.21 Beli Vit Teteven 15.28 Vit Yasen 46.02 Osam Troyan 23.99 Lovech Osam 31.30 Osam Izgrev 48.18 \_ Rositsa Seulieuo 29.12 Yantra Gabrovo 12.87 Yantra V. Tarnovo 38.45 Karantsi Yantra 124.72 Beli Lom Razgrad 3.82 Cherni Lom Kardam 5.90 Rusenski Lom Basarbouo 19.04 

Table 4 Threshold flow values (Q5) and number of extremely high streamflow events

Most extremely high runoff events – a total of 253, or 55.7% of all cases for the entire period were detected in 2005 (Table 4). Then in many European countries, such as Germany, Austria, Hungary, Poland, Romania, and Bulgaria, devastating floods were reported. The 2005 floods were driven by extreme meteorological circumstances,



especially by strong and prolonged precipitation. The whole year 2005 can be characterized as a period of unstable weather with intense cyclonic activity. Several cyclonic systems passed over the region during the months of May, July, August, and September in 2005, bringing significant rainfall amounts. Nikolova et al. (2005), exploring the long-term summer-time precipitation variability in the Danube Plain, concluded: "According to Rainfall Anomaly Index (RAI) the period from May to October in 2005 has been the wettest for the 1961–2005. The precipitation anomaly increased to above 184% for area averaged data and above 200% for some station data". The maximum precipitation deviation reached up to 538% above the monthly norm at the Veliko Tarnovo rain gauge station in September 2005<sup>1</sup>. The described meteorological conditions led to extremely high water levels and runoff values. In hydrological respect, the whole year 2005 was exceptional with the fact that high waves along almost all rivers in Bulgaria were detected throughout the year due to extremely heavy and prolonged rainfalls (Nikolova et al., 2011). In the catchment area of the Yantra River, for example, the maximum river water level reached up to 940 cm on 5th July 2005, while the maximum discharge value increased to 1593 m<sup>3</sup>/s on 15th September 2005 (Penkou, 2006, Nikolova et al., 2011). As a result of this, sharp peaks of the hydrograph were recorded, and severe floods were registered (Figure 5). On the other side, due to prolonged meteorological droughts in 2001, 2002, and 2004, extremely high flow events for one to ten gauging stations were not detected (Table 4).

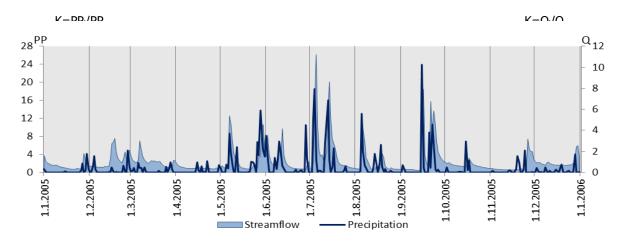


Figure 5 Complex "precipitation (PP) – streamflow (Q)" hydrograph expressed in modular coefficients (K) of the Yantra River at Veliko Tarnovo

The geographical analysis reveals a decreasing number of extremely high flow events as moving from upper towards lower reaches of the rivers. According to the results obtained, this change occurs in an inverse relationship compared to the fixed threshold

 $Source: StringMeteo\ (\underline{https://www.stringmeteo.com/})\ Accessed:\ 2018-11-30.$ 

<sup>&</sup>lt;sup>1</sup> The annual precipitation in 2005 reached: Veliko Tarnovo (in the catchment area of the Yantra River): 1132.2 mm (an average value for 1961–1990: 663.0 mm), Vratsa (Ogosta River): 1292.3 mm (773.8 mm), Razgrad (Rusenski Lom River): 975.2 mm (563.7 mm), Sofia (Iskar River): 970.8 mm (591.8 mm), Lovech (Osam River): 958.4 mm (609.4 mm), and Pleven (Vit River): 914.4 mm (564.8 mm). The rainfall amounts were extremely increased, especially in the months of May, July, August, and September – from 110% to 538% above the monthly norms for 1961–1990. The maximal daily precipitation were the following: 105.8 mm/24 h at the Murgash Peak (on 5<sup>th</sup> August 2005) and 101.8 mm/24 h at the Veliko Tarnovo station (on 15<sup>th</sup> September 2005) – to 43.0% of the monthly amount).

discharges whose values increase towards the mouths of the rivers (Table 4). Although there is a clearly expressed change, the correlation relationships "an average altitude of catchment areas (m) – number of extremely high flow events" and "threshold flow values  $Q_5$  (m³/s) – number of extremely high flow events" are not statistically satisfying – the coefficients of correlation (R) are 0.37 and (-0.43), respectively. These results confirm the nonlinear character of the floods.

The annual and internal-annual distribution of the extremely high flow periods within the Bulgarian Danube basin is shown in Figure 6. As seen, an increased number of extremely high flow events mainly during the hydrological years 1999/2000 and 2002/2003 is detected, but the most affected year being 2004/2005. At a seasonal level, the hazard phenomena occur mainly in spring. In terms of distribution during the year, April, May, and June are observed to have the highest number of floods. An exception is the wettest year 2004/2005 when extremely high flow events every month from February to October are recorded (Figure 6).

Table 5 Duration and frequency of extremely high streamflow periods

	Gauging station	Average duration (days)	Maximal duration (days)	Frequency (%) with a certain duration (days)						
River				1-7	8 – 14	15 – 21	22 – 28	29 – 35	36 – 42	
Barzia	Barzia	4	24	72	19	6	3	_	-	
Ogosta	Kobilyak	4	25	75	21	_	4	_	_	
Ogosta	Mizia	5	28	80	10	_	10	_	-	
Iskar	Beli Iskar	6	25	65	25	5	5	_	_	
Iskar	Novi Iskar	6	26	66	22	6	6	-	_	
Iskar	Kunino	7	36	62	15	15	_	_	8	
Iskar	Orehovitsa	5	22	75	17	_	8	_	-	
Cherni Vit	Cherni Vit	4	22	77	13	7	3	_	-	
Beli Vit	Teteven	4	18	77	17	6	_	_	_	
Vit	Yasen	4	17	81	15	4	_	_	-	
Osam	Troyan	4	16	76	21	3	-	-	-	
Osam	Louech	4	18	80	17	3	_	_	_	
Osam	Izgrev	4	16	83	14	3	_	_	_	
Rositsa	Seulieuo	5	24	81	16	_	3	_	-	
Yantra	Gabrovo	6	30	79	13	4	_	4	_	
Yantra	V. Tarnouo	5	26	81	14	_	5	_	_	
Yantra	Karantsi	4	19	82	12	6	_	_	_	
Beli Lom	Razgrad	4	16	84	8	8	-	_	_	
Cherni Lom	Kardam	3	18	93	_	7	_	_	_	
Rusenski Lom	Basarbouo	3	13	91	9	_	_	_	_	

Results of the frequency analysis indicated that extremely high streamflow periods with an average duration up to one week are predominant in the investigated area – from 62% to 93% of all events for the entire observation period (Table 5). The calculations do not find spatial relationships between the duration of floods and the altitude of catchment areas. The maximum duration of hazard phenomena varies from 13 to 36 days. Analyzing the maximum duration of floods, we find that for all drainage basin these periods are concentrated during the wettest year 2005. The longest flood



periods continue over a month in the catchment areas of the Iskar River at Kunino (36 days: from 5<sup>th</sup> August to 9<sup>th</sup> September) and the Yantra River at Gabrovo (30 days: 13<sup>th</sup> July to 12<sup>th</sup> August). Extremely high runoff periods continuing up to 30 days are isolated, as follows: 28 days (the Ogosta River at Mizia: 9<sup>th</sup> May to 5<sup>th</sup> June), 26 days (the Iskar River at Novi Iskar: 8<sup>th</sup> May to 2<sup>nd</sup> June and the Yantra River at Veliko Tarnovo: 21<sup>st</sup> July to 16<sup>th</sup> August), 25 days (the Ogosta River at Kobilyak: 4<sup>th</sup> to 29<sup>th</sup>

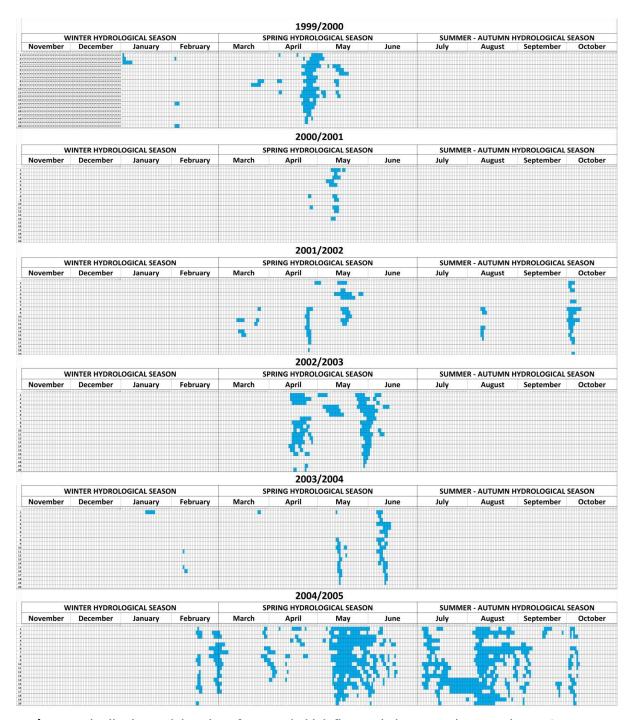


Figure 6 Distribution and duration of extremely high flow periods: 1 – Barzia at Barzia; 2 – Ogosta at Kobilyak; 3 – Ogosta at Mizia; 4 – Iskar at Beli Iskar; 5 – Iskar at Novi Iskar; 6 – Iskar at Kunino; 7 – Iskar at Orehovitsa; 8 – Beli Vit at Teteven; 9 – Cherni Vit at Cherni Vit; 10 – Vit at Yasen; 11 – Osam at Troyan; 12 – Osam at Lovech; 13 – Osam at Izgrev; 14 – Rositsa at Sevlievo; 15 – Yantra at Gabrovo; 16 – Yantra at

Veliko Tarnovo; 17 – Yantra at Karantsi; 18 – Beli Lom at Razgrad; 19 – Cherni Lom at Kardam; 20 – Rusenski Lom at Basarbovo.

August and the Iskar River at Beli Iskar: 12th May to 5th June), 24 days (the Barzia River at Barzia: 9th May to 1st June and the Rositsa River at Sevlievo: 15th July to 7th August), 22 days (the Iskar River at Orehovitsa: 7th to 29th August and the Cherni Vit River at Cherni Vit: 9th to 30th May). Less than 20 days continue the listed events: 19 days (the Yantra River at Karantsi: from 21st July to 9th August), 18 days (the Beli Vit River at Teteven: 8<sup>th</sup> to 25<sup>th</sup> May, the Osam River at Lovech: 9<sup>th</sup> to 26<sup>th</sup> May and the Cherni Lom River at Kardam: 7<sup>th</sup> to 24<sup>th</sup> August), 17 days (the Vit River at Yasen: 4<sup>th</sup> to 20<sup>th</sup> July), 16 days (the Osam River at Troyan: 9th to 24th May, the Osam River at Izgrev: 4th to 19th July and the Beli Lom River at Razgrad: 5th to 20th August), and 13 days (the Rusenski Lom River at Basarbovo: from 5th to 17th August 2005). We can explain the obtained spatial and temporal differences by landscape features in each catchment. For example, most of the shorter floods occur along rivers flowing through karst regions with limestone rocks - e.g. the Osam River flows over the permeable terrain of the Devetashko Plateau. Similarly, the Rusenski Lom River flows through a self-formed limestone canyon-like valley. The karst forms provoke increased infiltration rates and reduce the duration of the floods. Despite the listed differences, a lot of similarities in the occurrence of the floods are established. For instance, the longest floods in all drainage basins occur during rainy months characterized by extremely strong and prolonged precipitation. This fact confirms the high-sensitive response of river systems to meteorological conditions.

#### 6. CONCLUSION

Applying the Threshold level method on daily discharge data collected from 20 gauging stations within the Bulgarian part of the Danube drainage basin for the period 2000-2005, the implementation of this work was an attempt to enrich previous studies. Even if short, the observation period gave us grounds to estimate the main characteristics of the floods. The results based on constant threshold values indicated the Danube drainage area experienced severe floods for most of the years, even for a short period. The hazard events occurred mainly in spring and continued up to six weeks, being especially protracted during 2005. The water-related disasters were largely influenced by heavy and prolonged precipitation. Basing on the conducted analysis, both high flow and extremely high flow had large spatial and temporal variations, depending on meteorological circumstances and landscape features in each catchment area. However, a lot of similarities in their occurrence were also established. As per the results obtained, several important questions remain unsolved: how to quantify the spatiotemporal changes in flood risk, how to improve the analysis of the theory for high flow pulses, how to mitigate the disastrous effect of the floods, etc. A fuller hydrological picture of the hazard phenomena in the studied area could be achieved using variable threshold levels. The resulting information can serve as a support for the development of preliminary flood risk assessments and water resources management plans in the Danube River Basin District.

# **REFERENCES**

Abadzhieu, P. (1939). The catastrophic flood of the Rositsa River. — BIA, 17, 221—224.

- Angelov, A. (1940). The flood of the Rositsa River basin in 1939. *Journal of Bulgarian Geographical Society*, 37–70.
- Bouan, K., B. Banai and I. P. Banai. (2018). Do Natural Disasters Affect Voting Behavior? Evidence from Croatian Floods. *PLoS Curr*, Edition 1, 1–15.
- Gerasimov, S. and T. Panayotov. (1964). High waves of the rivers in Bulgaria. *Journal of Hydrology and Meteorology*, 2, 37–104.
- Göppert, H., M. Fritz, A. Bernereuther and D. Zlatunova. (2014). Flood hazard in Sevlievo (the Rositsa River basin) *Annual Book of Sofia University Faculty of Geology and Geography*, Part 2,106, 67–92.
- Hristova, N. (2004). Types of river flow regime in Bulgaria. Annual Book of Sofia University Faculty of Geology and Geography, 2 (96), 129–153.
- Hristova, N. (2012). Hydrology of Bulgaria. Book: "Tip-Top press", Sofia, 832 pp.
- Hristova, N. (2014). Extreme low flow of two Danube tributaries. Annals of the University of Craiova Series Geography, XIII (1), 34–38.
- Hristova, N. and K. Seymenov. (2019). Annual flow dynamics in large and small drainage basins in Northern Bulgaria during the last two decades. *SocioBrains*, 54, 123–131.
- Hristova, N. and Ts. Tsenova. (2011). Extreme flow in Nishava River basin. *International conference Global changes*, 15–16 April 2011, Sofia.
- Hristova, N., E. Ivanova and K. Seymenov. (2017). Geographical aspects of floods in Northwest Bulgaria. *International Knowledge Journal*, 16.2., 907–914.
- Hristova, N., I. Penkov and K. Seymenov. (2018). Annual streamflow of major catchment areas in Bulgaria in the beginning of XXI century. *International Scientific Conference "Air and Water: Components of the Environment"*, 15<sup>th</sup>—17<sup>th</sup> March 2018, Cluj-Napoca, Romania.
- Hydrologic Reference book of the rivers in Bulgaria. B: Hydrology and Meteorology, 2, 1981.
- Lukarska, S. (2015). Characteristics of the extreme waters in the Arda River valley. *Problems of Geography*, 1–2, 198–206.
- Merz, B., F. Elmer, M. Kunz, B. Muhr, K. Schröter, S. Uhlemann-Elmer (2014). The extreme flood in June 2013 in Germany. *La Houille Blanche*, 1, 5—10.
- Milanović-Pešić, A. (2019). Hydrological Aspects of the Floods in the Kolubara River basin (Serbia) Analyses and Flood Mitigation Measures. SPRINGER Book Series Key Challenges in Geography: Smart Geography, 117–127.
- Monthly and daily data about precipitation sums: StringMeteo (<u>www.stringmeteo.com/</u>) (Accessed: 2018-11-30).
- National plan for river basin management in the Danube Region; Flood risk management program (2016): Danube River Basin: (<u>www.bd-dunav.org/</u>) (Accessed: 2018-11-30).
- Nikolova, M. and V. Nikolov. (2011). Assessment of the impact of geomorphologic and hydroclimatic factors on the flood hazard in Yantra River basin. *Studia Geomorphologica Carpatho-Balcanica*. XLV, 121–135.
- Nikolova, M., St. Nedkov and V. Nikolov. (2013). Flood Hazard in Bulgaria: Case Study of Etropolska Stara Planina. *Geomorphological Impacts of Extreme Weather. Case Studies from Central and Eastern Europe. Publisher: Springer Geography.* DOI: 10.1007/978-94-007-6301-2\_12, 189-201.

- Nikolova, M., St. Nedkov, V. Nikolov, M. Genev, Ts. Kotsev, R. Vatseva and J. Krumova. (2009). Implementation of "KINEROS" Model for Estimation of the Flood Prone Territories in the Malki Iskar River basin. *International Scientific Journal "Informational&Security"*, Vol. 24, 76–88.
- Nikolova, N. and S. Vassilev (2005). Variability of summer-time precipitation in Danube Plain, Bulgaria. *Geographical Institute "Jovan Cvijic" Collection of papers*, Vol. 54, 19–32.
- Panayotov, T. (1965). About some characteristics of the spring high waters in the Rila Mountain. *Journal of the Institute of Hydrology and Meteorology*, Vol. X, 133–150.
- Penkou, Iu. (1992). The intense rainfalls and their role for the high waves in the upstream section of the Yantra River. *Scientific works: Veliko Tarnovo University*, Vol. 1, 23—32.
- Penkov, Iv. (2006). The floods in Bulgaria during 2005. *International Conference "Global change and regional challenges"*. 28–29 April, Sofia, 107–110.
- Penkou, Iu. (2012). Description of historical floods for the aims of a preliminary assessment of flood risk in the Rositsa River basin. *Annual Book of Sofia University Faculty of Geology and Geography*, 2, Vol. 104, 79–90.
- Penkov, Iv. and G. Rachev. (1983). Synoptic conditions for occurring of high waves in the river basins of the Rositsa and Varbitsa. Annual Book of Sofia University Faculty of Geology and Geography, 2, Vol. 77, 62–83.
- Seymenov, K. (2018a). Extremely high streamflow within the Alpine catchments in the Rila Mountain. *Journal of Bulgarian Geography Society*, Vol. 40, 17–23.
- Seymenov, K. (2018b). Extreme streamflow in the catchments of the Strandzha Mountain. *SocioBrains*, Vol. 41, 249–256.
- Tali, M., A. Naeimi, M. Esfandiary. (2016). Physical development of Arak city applying natural indicators. *European Journal of Geography*, Vol. 7, No 3, 99–110.
- Thieken, A. H., T. Bessel, S. Kienzler, H. Kreibich, M. Müller, S. Pisi and K. Schröter. (2016). The Flood of June 2013 in Germany: how much do we know about its impacts? *Nat. Hazards Earth Sci.*, Vol. 16, 1519–1540.
- Thirumalaiah, K. and M. C. Deo (2002). Real-Time Flood Forecasting Using Neural Networks. *Computer-Aided Civil and Infrastructure Engineering*, Vol. 13, 101–111.
- Transnational Cooperation Program "Danube Flood Risk" (2013): (<u>www.danube-floodrisk.eu/)</u> (Accessed: 2018-11-30).
- Tudorache, A.-V. (2018). The impact of excess rainfall on the maximum flow rate in the upper and middle basin of the Prahova River. International Scientific Conference "Air and Water: Components of the Environment", 15<sup>th</sup>–17<sup>th</sup> March 2018, Cluj-Napoca, Romania, 111–118.
- Water Framework Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26<sup>th</sup> November 2007 (The EU Floods Directive: Floods and their impact): (<u>www.ec.europa.eu/environment/water/flood\_risk/</u>) (Accessed: 2018-11-30).

- Yu P., Yang, T.-Ch., Kuo, Ch.-M., Tseng, H-W., Chen, Sh-Ts. (2014). Climate change Impacts of Streamflow: A Case Study in Tseng-Wen Reservoir Catchment in Southern Taiwan. *Climate Journal*, Vol. 3 (1), 42–62.
- Zlatunova, D. and V. Gabrosky. (2013). The information for historical floods in the Rositsa River basin as a tool for flood risk assessment. *Annual Book of Sofia University Faculty of Geology and Geography*, Part 2, Vol. 105, 95–104.
- Zyapkov, L. (1997). About some genetic characteristics of the floods in Bulgaria. *Journal of Bulgarian Academy of Sciences*, Vol. 2, 14–18.