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Extreme low flow of the Topolovets and Voinishka Rivers (Danube tributaries, Bulgaria)

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Abstract

The minimal stream flow is the most sensitive characteristic of stream flow. The aim of the paper is the assessment of the duration and the frequency of low flow through threshold method on daily discharges. The daily data of the two Danube tributaries (the Topolovets and Voinishka) have been used. The results present the following: low flow typically appears in the summer and episodically in the spring and winter; the duration varies between some days to month; the spatial distribution of extreme minimum flow is discrete and depends on climatic and anthropogenic activities. The method of quantiles gives good threshold level for defining extremely low stream flow, but have to apply in keeping with concrete conditions and purposes.

Keywords: *low flow, threshold level method, the Danube tributaries*

Rezumat. Valori extreme ale scurgerii minime pentru râurile Topolovets şi Voinishka (afluenţi ai Dunării, Bulgaria)

Debitul minim reprezintă cea mai sensibilă caracteristică a scurgerii râurilor. Scopul acestei lucrări este de a evalua durata și frecvența debitelor reduse prin metoda pragurilor bazată pe valorile debitelor zilnice. Pentru aceasta, am folosit datele zilnice pentru doi afluenți ai Dunării (Topolovets și Voinishka). Rezultatele obținute indică faptul că scurgerea minimă este tipică pentru sezonul cald și apare episodic primăvara și iarna; durata variază de la câteva zile până la o lună, distribuția spațială a debitelor minime este redusă, depinzând de factorii climatici și antropici. Metoda cuantilă oferă praguri ce pot fi folosite foarte bine pentru definirea valorilor extreme ale scurgerii minime, dar trebuie aplicată ținând cont de condițiile concrete și scopul studiului.

Cuvinte-cheie: *scurgere minimă, metoda pragurilor, afluenți ai Dunării*

Introduction

Low flow and especially its lower limit, minimal flow is very important for some economic activities as public water supply, irrigation, hydro-electric and industrial productions, and also for water quality management and the status of the aquatic ecosystems. It is a basic parameter of analysis of the hydrological drought. There are a lot of publications devoted to the methods used for estimation the minimum flow (minimum monthly flows, Wood et al., 2000; annual minimum flows, Wood et al., 2000, Clausen & Biggs, 2000; low flow index, Poff and Ward, 1989; Julian date of annual minimum, Clausen &Biggs, 2000, Richter et al., 1996, 1998; three kind baseflow indexes, Clausen and Biggs, 1997, 2000, Richter et al., 1998; Poff, 1996; for duration of low flow – annual minima of daily discharge, Richter et al., 1996, 1998; means of minima of daily discharge, Clausen & Biggs, 2000; low flow pulse duration, Richter et al., 1996, 1998, number of zero-flow days; percent of zero-flow months and etc.). The threshold level method (originally named method of crossing theory), although very popular worldwide, is not widely used in Bulgaria. Bulgarian engineering practice uses values of mean annual flow with different probability. For instance, a discharge value of or below 75% P (probability) is considered a dry period for irrigation systems, 80% P – for hydro-power plants, 95% P – for water supply. This work analyzes the extreme low and low flow for two tributaries of the Danube River through the threshold level method on daily discharges and compares the results with those obtained by other methods.

The two Danube tributaries that we analysed are the Topolovets River (L – 67.6 km, F – 582.8 km^2) and the Voinishka River (L – 55.2 km, F – 276.5 km^2). These rivers are the first and second order tributary of the Danube on Bulgarian territory. They pertain to the Danube North-west river basin of Danube hydro-geographical region (Hristova, 2011, Hristova, 2012). The rivers collect their waters from the northern slopes of the Balkan Mountains. They are classified as „medium" according to the length and also to catchment area (Sarafska, 2003). The Topolovets and Voinishka Rivers have similar hydrographic parameters (length and catchment area, average density – 0.5–0.6 km/km^2, few tributaries), natural conditions (prevalent hill and flat relief, canyon-like valleys; European-Continental climate (minimum air temperature in January and maximum – in July, continental regime of precipitation – with maximum June and minimum – in February), Sarmatian and Pliocene sediments, Quaternary loess and Alluvium in lower reaches;

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small reserves of groundwater, small areas of oak forests) and economic activities (8 small dams in the catchment area of the Topolovets River and 6 small dams in the catchment area of the Voinishka River, large agricultural areas) (Fig. 1).

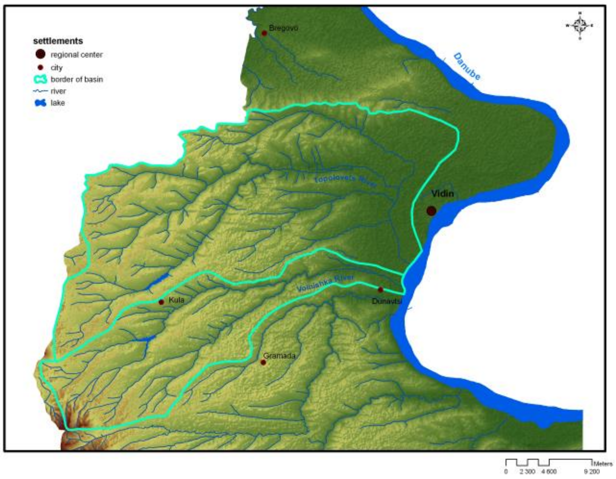


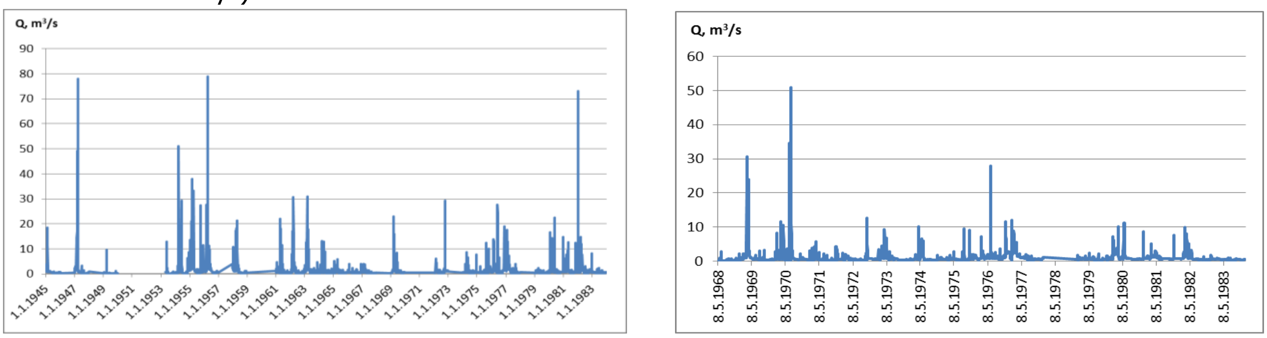
Fig. 1: River network and relief

River regime for the two rivers is similar – the period with high waters is from February till June, the period of low waters – from July till October (about 100–140 days).

November, December and January are months with transitional river flow. All rivers belong to continental type regime, second below type (Hristova, 2004). The monthly and seasonal variations are very big (Hristova, 1986), reflection of large fluctuation of daily discharges (Fig. 2).

The volume of low flow during the period with low waters is 5.22.106 m^3 (18,1% of the annual flow) for the Topolovets River and 3.06.106 m^3 (12,9% of the annual flow) for the Voinishka River (Dakova, 1976). Mean annual low flow for the Topolovets River is 0.164 m^3/s and for Voinishka River – 0.206 m^3/s. Maximum of mean monthly low flow is in March for the Topolovets River and during April for the Voinishka River (Table 1).

The minimum of mean monthly low flow appears in October for the Topolovets River and in August for the Voinishka River. The value of index $I=Q_{min}/Q_{an}$ (Q_{min} is smallest monthly low flow, Q_{an} – annual flow), proposed by Hamilton & Bergersen, (1984), is 0.10 (Voinishka River) and 0.20 (Topolovets River) and shows small stability of low flow. Absolute minimum stream flow for Topolovets River is 0.129 m^3/s, for Voinishka River – 0.073 m^3/s.



a) b)

Fig. 2: Hydrograph of: a) the Topolovets River; b) the Voinishka River

Table 1: Mean monthly low flow

River	Months											
	J	F	M	D	D	J	J	A	S	O	N	D
Topolovets – Akatsievo	0201	0.212	0.226	0.142	0.140	0.109	0.107	0.117	0.064	0.030	0.039	0.095
Voinishka – Tarnjane	0.210	0.222	0.243	0.255	0.122	0.093	0.036	0.016	0.024	0.060	0.115	0.178

Methods

The low flow and extreme low flow are extracted by threshold level method. „A threshold level which is too low might lead to a high number of no-drought years making the few identified drought events statistically uncertain to evaluate. On the other hand, with a high threshold level, the likelihood for a series of small single drought events being combined into one severe multi-year drought (drought lasting longer than a year) increases‟ (Lehner &Döll, 2001). The threshold might be chosen in a number of ways – percentage of the mean flow or a percentile from the duration curve (Hisdal et al., 2006). Usually, the threshold method uses monthly discharge data.

This work accepts quantiles, which are proposed by the National Institute of Meteorology and Hydrology – 10% quartile (Q10) for extreme low waters, which are defined trough 50% quartile

(Q50) of all daily discharges. The length during which the stream flow is below the threshold level is termed duration of extreme low flow (D_{lf}), the volume below threshold – deficit volume.

Frequency of extreme minimum flow (F_{lf}) is presented in percentages per months. It is also calculated according to the coefficient of Hughes & James (1989), which is total number of low flow spells (threshold equal to 5% of mean daily flow) divided by the record length). A low flow frequency analysis evaluates the probability of flow occurring and remaining below a specified (low) threshold for a given length of time.

The number of classes for the frequency and the duration of extreme low runoff are isolated according to Sturges' formula.

$$K = 1 + 3.322 \log N \quad (1)$$

where K = number of class

log N = logarithm of total number of observations

The class width is obtained using the formula

$$h = (h_{max} - h_{min})/k. \quad (2)$$

The series from daily discharges for the Topolovets and Voinishka Rivers are the base for counting. There are available daily hydrological data for 38 years (1945–1983 period) (13,870 daily discharges) for the Topolovets River and 36 years (1947–1983 period) (13,140 daily discharges) for Voinishka River. The series of daily discharges are very long and representative. The data after 1983 is not available.

Discussion

The threshold discharge of the Topolovets River for low flow is 0.62 m^3/s (51% of the annual stream flow) and for extreme low flow – 0.21 m^3/s (17% of the annual runoff) (Table 2).

The magnitude of extreme low flow is not conform to minimum flow, calculated for different theoretical probabilities (Table 3). It is more than 5% (Q5 is 0.06 m^3/s) of the annual runoff, recommended by Hughes & James (1989) and more than 10% (Q10 is 0.12 m^3/s), recommended by the Bulgarian standard for ecological discharge. The threshold discharge of the Topolovets River for extreme low flow is more than the ecological discharge of 0.015 m^3/s, which is calculated by Zaharieva (2006) according to her method.

Table 2: Threshold level discharges (m^3/s)

River	For low flow (Q50) of whole daily discharges	For extreme low flow (Q10) of low river flow
Topolovets	0.62	0.21
Voinishka	0.52	0.09

Table 3: Minimum flow (m^3/s) with different probability

River	Probability, %			
	75	90	95	99
Topolovets	0.140	0.080	0.042	0.000
Voinishka	0.060	0.042	0.033	0.006

Source: Dakova (1980)

Extreme low stream flow for the Topolovets River is between 0.05 and 0.21 m^3/s and it is not recorded every year. It is typical for August, September and October, rare in June and July and occurs sometimes during the winter (Table 4). The average duration is between 1 to 14 days, the probability for appearance – from 1% (the winter months) to 28% (August).

The frequency of low flow, calculated according to the coefficient of Hughes & James (1989) is 5 days per year. The duration of extreme low flow over the years is between one to 55 days (1949 year). The longest periods of extremely low waters are registered until 1960.

Extreme low flow was especially protracted during 1949 (143 days). Other years with long low flow are 1947 (67 days), 1953 (104 days) and 1954 (67 days). The picture of days with extremely low water shows the decrease of duration of this hydrological parameters and advent only in summer-autumn season (Fig. 3).

The statistical analysis presents the following: the distribution of extreme low stream flow is negatively asymmetric – mode: 0.20 m^3/s, median: 0.16 m^3/s and average: 0.14 m^3/s; dominate discharges more than 0.18 m^3/s; the typical duration is one and two days; the most common value is 0.18-0.21 m^3/s (Fig. 4).

Table 4: Duration (D_f, days) and frequency (F_f, %) of extreme low flow

River basin		Months											
		J	F	M	D	D	J	J	A	S	O	N	D
Topolovets – Akatsievo	D_{lf}	2	1	2	4	7	8	7	10	14	11	1	2
	F_{lf}	8	5	2	8	5	10	26	28	23	23	8	8
Voinishka – Tarnjane	D_{lf}	–	–	8	8	11	9	17	19	14	12	–	–
	F_{lf}	–	–	3	8	8	8	18	18	19	18	–	–

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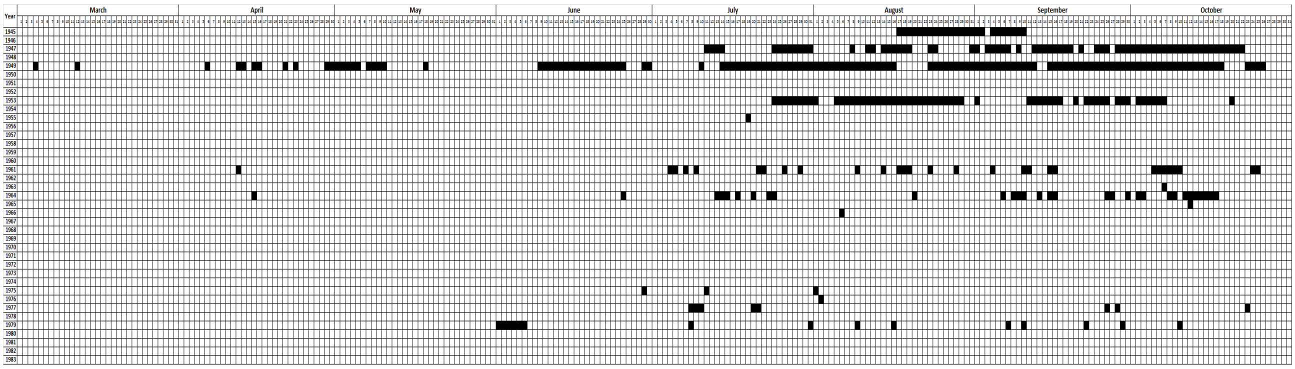

Fig. 3: Days with extreme low flow for the Topolovets River

The threshold discharge of the Voinishka River for extreme low flow is 0.09 m^3/s (Table 2). It is more than 5% and 10% of the annual runoff and more than 0.015 m^3/s, which is calculated by Zaharieva (2006). Extremely low flow for the Voinishka River is 0.02–0.09 m^3/s. It is not recorded every year and unlike the Topolovets River, it is not registered in winter (Table 2, Fig. 5).It normally occurs during the summer and autumn months. The average duration is between 8 to 19 days, the probability for appearance – from 3% (the spring months) till 19% (September).

Typical duration is one or two weeks (Table 5). Extreme low river flow was especially protracted during 1947, 1949, 1953, 1967 and 1968. The duration of extremely low flow over the years varies between one to 54 days (1949).

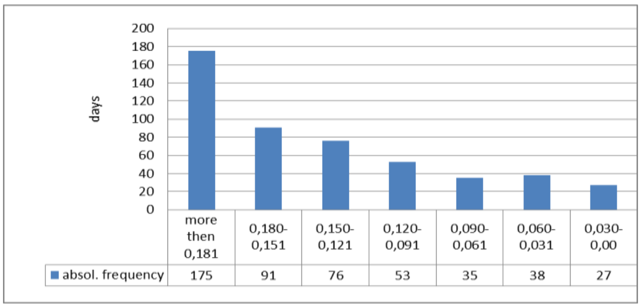

Fig. 4: Frequency of extreme low flow with definite value for the Topolovets River

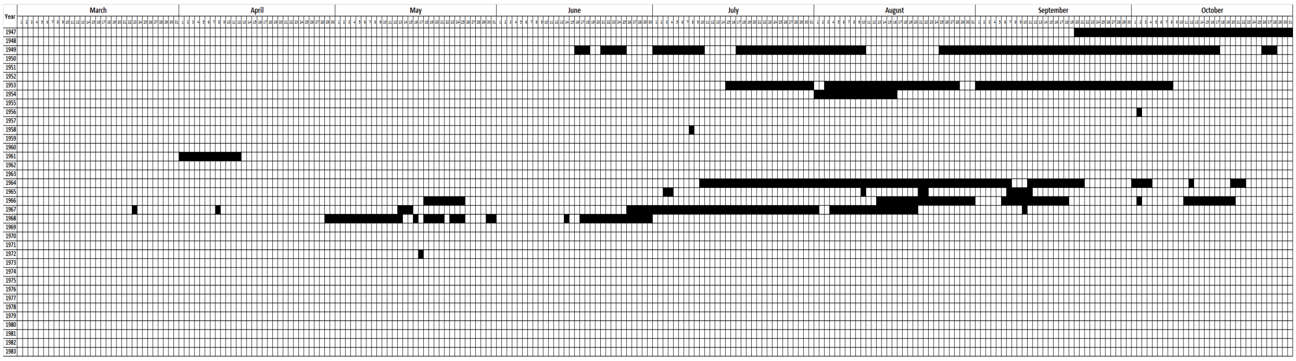

Fig. 5: Days with extreme low flow for the Voinishka River

Table 5: Number of causes with definite duration and definite value of extremely low flow for the Voinishka River

Duration			Value		
Days	Causes		m^3/s	Causes	
	number	%		number	**%**
1-8	30	60	0,02	10	1,9
9-16	10	20	0,03	31	5,7
17-25	3	6	0,04	97	18,0
26-34	3	6	0,05	27	5,0
35-42	2	4	0,06	77	14,2
43-49	1	2	0,07	116	21,4
50-58	1	2	0,08	53	9,8
			0,09	130	2,04

The extremely low flow is most common 0.04 m^3/s, 0.07 m^3/s and 0.09 m^3/s. Its distribution is negative asymmetric too – the mode: 0.07 m^3/s, the median: 0.09 m^3/s and the average:0.06 m^3/s.

Conclusion

Extremely low flow, calculated by threshold method in this work, occurs normally during summer and autumn and continues between one day and two months. It was especially protracted during 1949. This year is the driest up to now, so the duration of low flow in this year could be accepted as a top end. A lot of days with very low flow for the Topolovets and Voinishka Rivers are established for 1947 and 1953. Extremely low river flow has large temporal and spatial variations depending of climatic and hydrogeological conditions and also of the economic activities. Its values, as opposed to the duration, can be predicted. Extremely low flow is less than the Baseflow index by Tennant (1976) for the two rivers and greater than 10% of the average flow (the mean daily flow average over all years of record) for the Topolovets River and less than for Voinishka River. Its value, calculated through the chosen method, for these rivers is very different as compared to those calculated according to other methods. So, the threshold level method, which is proposed by National Institute of Meteorology and Hydrology (50% quartile of all daily discharges for low flow and 10% quartile from low waters for extremely low flow), maybe have to be corrected for low flow. Extremely low river flow should be defined as hydrological drought.

References

Clausen, B Biggs, B.J.F. (2000). Flow variables for ecological studies in temperate streams: groupings based on covariance. Journal of Hydrology, 237, 184-197.

Clausen, B. Biggs, B.J.F. (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biology, 38, 327-342.

Dakova, Sn. (1976). Varhu minimalnija ottok na rekite v severozapadna Bulgaria. Hidrologia i meteorologia, 5, 20–25.

Dakova, Sn. (1980). Problemi na minimalnia ottok pri narushen regim na rekite ot Secerna Bulgaria. Hidrologia i meteorologia, 2, 18–27.

Hamilton, K., E. P. Bergersen. (1984). Methods to estimate aquatic habitat variables. Colorado Cooperative Fishery Research Unit; 201 Wagar, Colorado State University Fort Collins, CO.

Hisdal, H, L. M. Tallaksen, K. Stahl, M. Zaidman, S. Demuth and A. Gustard (2006). Hydrological drought – streamflow. In: Drought Event Definition, Technical Report №6, 8-15.

Hristova, N. (1986). Monthly and seasonal variations of the river flow in North Bulgaria. Izv. BGD, XXV, 37–46.

Hristova, N. (2012). Hydrology of Bulgaria. Tiptoppres, 93–95.

Hristova, N. 2004. Types of river flow regime in Bulgaria. – Annuaire de l'Universitete de Sofia "St. Kliment Ohridski", Faculte de Geologie et Geographie, 2, 96, 2004.

Hristova, N. 2011. Major basins in Danube hydro-geographical region in Bulgaria. – Annals of the University of Craiova – Series Geography, XIV, 26–34.

Hughes, J.M.R., B.James. (1989). A hydrological regionalization of streams in Victoria, Australia, with implications for stream ecology. Australian Journal of Marine and Freshwater Research, 40, 303-326.

Lehner, B., Döll, P. (2001). EuroWasser: EUROPE'S DROUGHTS TODAY AND IN THE FUTURE.

Lehner, B., Henrichs, T., Döll, P., Alcamo, J. (2001): EuroWasser – Model-based assessment of European water resources and hydrology in the face of global change. Kassel World Water Series 5, Center for Environmental Systems Research, University of Kassel, Germany.

Poff, N. L. (1996). A hydrogeography of unregulated streams in the United States and an examination of scale-dependence in some hydrol ogical descriptors. Freshwater Biology, 36, 71-91.

Poff, N. L., Ward, J.V. (1989). Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences, 46, 1805-1818.

Richter, B.D., Baumgartner, J.V., Braun, D.P., Powell, J. (1998). A spatial assessment of hydrologic alterations within a river network. Regulated Rivers: Research & Management, 14, 329-340.

Richter, B.D., Baumgartner, J.V., Powell, J., Braun, D.P. (1996). A method for assessing hydrologic alteration within ecosystems. Conservation Biology, 10, 1163-1174.

Sarafska, N. (2003). Classification of river in Bulgaria by length and watershed. – Annuaire de l'Universite de Sofia "St. Kliment Ohridski", Faculte de Geologie et Geographie, 2, 93, 167–196.

Tennant, D.L. (1976). Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries, 1, 6-10.

Wood, P.J., Agnew, M.D., Petts, G.E. (2000). Flow variations and macro invertebrate community responses in a small groundwater-dominated stream in south-east England. Hydrological Processes, 14, 3133-3147.

Zaharieva, V. 2006. Regional relationships for ecological flow determination. Bulakva, 1, 1–5.