LOW FLOW AND DROUGHT ANALYSIS OF BULGARIAN DANUBE TRIBUTARIES

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Abstract: Bulgarian area contributes Danube river basin with thirteen right tributaries generating its flow from 29069 km^2 catchments area. The Bulgarian tributaries inflow into Danube was obtained. The annual, summer and minimum flows of the tributaries are analyzed. The low Flow Index was introduced for estimated the low flow and drought severity. The low flow severity is presented in four grades. The annual, summer and minimum flow data series with the common observation period the last 30 years for 21 gauging stations were analyzed. The significant diminishing of the inflow into Danube is observed since 1982. The applied quantity criteria of Low Flow Index shows that the flow of more than 60% of cases can be refer as drought. A cases with extraordinary drought (LFI> 3 or 4) and duration from 3 to 8 years have been extracted during period 1982-2000. This extraordinary severity of drought very often is a cause of inadequate water management to the poor precipitation fallen during the last decades.
Key words: drought identification, drought threshold, low flow, minimum flow, Danube.

Introduction

At the beginning of the XXI sentry, the sustainable use of water is a priority question for water scarce regions like Bulgaria, for its water supply, agriculture, all sectors of industry and resilience of aquatic ecosystems. Imbalances between availability and demand, degradation of surface and ground water quality, inter-regional and internal conflicts all bring water issues to foreground. Solving the water crisis in its many aspects is but one of the several challenges is facing the low flow availability and hydrological drought reveal. The term drought has more or less climatologic sense in Bulgaria. Hydro-engineer design practice commonly uses terms low flow, minimum flow and dryness of the river.

The purpose of this research study is to improve the understanding and analysis of low flow and drought in terms of their severity. The objective of this paper is to estimate when the scares of flow in Bulgarian Danube tributaries can be adopted as “exceptional drought circumstances”, when these conditions are beyond those that could be considered part of normal risk management.

Description of Bulgarian Danube tributaries basin

Bulgarian tributaries contribute Danube river basin with on 29069 km^2 catchments area. The density of hydrographical network is 203 km/km^2 in mountain and decreases gradually to 0, 1-0, 2 km/km^2 close to Danube. The Bulgarian Danube tributaries are right bank. The main Bulgarian tributaries listed from West to East are: Topolovetz, Vojnishka, Vidbol, Archar, Lom, Tzibritza, Ogosta, Skat, Iskar, Vit, Osm, Jantra and Roussenski Lom. All rivers take its sources from the Stara planina mountain (except Iskar which rise from Rila mountain), running northern in a narrow riverines plain with a steep bank, cross Danube Plain in a well developed alluvial plains and flow by estuary into Danube river. All rivers formed the streamflow in Moderate Continental Climatic conditions. The runoff has a rain-snow or rain origin. During 1950-1970 channel correction works and flood levees were constructed in the lower reaches of all large Danube tributaries. The big irrigation systems including more than 860 reservoirs (most of them small capacity), canals and operational hydraulic constructions have been built also during this period. The total volume of the reservoirs is 2678x10^6 m^3. Besides, nine reversal pumping stations intake about $0,8\text{-}1x10^9$ m^3 water from Danube and its terraces for irrigation and water-supply. At the same time, the cleaned water in the treatment sewerage stations inflow into the river also. All these human activities have leaded to significant changes of the flow regime and particularly of the summer and the low flow.

Selection of the time series, data analyses and assessment

The data used in the communication of low flow and droughts are monthly discharges and calculated from them annual, summer (of dry period) flow and minimum monthly flow values. The monthly data have been obtained from the observations in 21 gauging stations of the National Hydrological network, installed on the Danube tributaries. The length of discharge series is different. The longest series include data from the very beginning of the regular observation (1936) up to 2000 and 2003 (for one Basin- of Osam River) i.e. the length of discharge values is from 67 or 70 years. The shortest one is since 1975 i.e. the available data are from 25 years.

In order to studied low flow and to estimate the tributaries influent discharge into Danube River, the interpolation should to be applied. Therefore, for this procedure the important requirements are the consistency and homogeneous of data. Having in mind the changed flow regime caused by man's activities, the time series were divided in three periods: first period of natural flow is before active man's intervention in the river network and basin, second on is during the process of active hydro-technical construction and the last one covers the period with relatively steady human activities i.e. since 1970 up to 200 or 2003. The total **O**bserved **P**eriod (OP), period with the intensive **H**uman **A**ctivities (HA), total **N**umber of **R**eservoirs constructed on each river basin (NR) and their **T**otal volume (TW) in $m^3\ x10^3$, and also the hydrographs characteristics of the basin such as catchment's area(F) in km^2, mean elevation of the basin (H) in *m* , basin slope *‰* and **D**ensity of the river network (D) in $km/\ km^2$, of the close to Danube station are shown in table 1.

Tabl.1. Hydrographic characteristics of Danube tributaries at gauging station of the Hydrological

№	**river and sit**	**OP**	**HA**	**NR**	**TW**	**F**	**H**	**J**	**D**
12700	Topolovetz-v.Akatzievo	1938-2000	1958-1967	5	21 322	305	250	6.48	0.56
12850	Vojnishka	1946-2000	1956-1971	6	18 152	269	260	12.7	0.64
14850	Lom -v.Trajkovo	1959-2000	1957-1970	15	46 748	1132	442	0.2	0.67
15580	Tzibritza -Ignatovo	1952-2000	1956-1969	22	21 335	845	193	7.4	0.31
16850	Ogosta-Mizija	1936-2000	1956-1963	55	21 728	3112	395	12.1	0.73
18850	Iskar Orjahovo	1936-2000	1956-1975	70	757 943	8366	706	7.3	1.08
21800	Vit -Tarnjane	1936-2000	1953-1965	31	105 266	2236	489	16.4	0.61
22800	Osam Izgrev	1971-2003	1953-1965	96	498 293	2154	515	8.17	0.44
23850	Jantra -Karantzi	1936-1970	1953-1970	145	410 674	6860	440	6.4	0.75
32700	Rus. Lom Besarbovo	1936-1995	1956-1965	69	60 245	2869	273	2.8	0.46

network

Because the flow of period 1970-2000 could be accepted as flow generated in the present conditions, it is examined here. The evaluation on homogeneity and randomness by Hosking&Wallies test, Test of number of runs and Man's test show that each series of annual, summer and minimum flow satisfied the requirement conditions. The procedure of preliminary analyses and calculation the characteristics of time series are implemented using software "Statistic". The examine discharge elements show a good correlation with the hydrographic characteristics except with mean basin altitude, as it is laid down in table 2. This is reasonable, because the river basins in this part of Bulgaria have a plain character. The mean basin altitude isn't used further.

Tabl. 2 Correlation coefficients matrix

	Qann	Qsum	Qmin
Qann	1	0.98	0.96
Qsum	0.98	1	0.99
Qmin	0.96	0.99	1
L	0.86	0.93	0.96
H	-0.38	-0.45	-0.46
F	0.905	0.96	0.98
D	0.59	0.57	0.45
Jbas	-0.94	-0.97	-0.985

All mentioned above allow applying extrapolation methods in the case of disturbed flow regime. The total water volume inflowing into Danube River have been calculated and are follow: annually inflow is 5976 $x10^3$ m^3, during the summer (during dry period) is 3911 $x10^3$ m^3 and the minimum inflow is 2349 $x10^3$ m^3. The distribution of the inflow in m^3 $x10^3$ under river basins is given in Table 3.

Table 3. Values of inflow into Danube River under tributaries

Rivers	**Wann** $x10^3$ m^3	**Wsum** $x10^3$ m^3	**Wmin** $x10^3$ m^3
Topolovetz	47.03	33.12	28.30
Vojnishka	23.27	12.80	8.40
Lom	183.66	85.96	43.18
Tzibritza	62.58	34.67	21.18
Ogosta	664.21	345.14	126.21
Iskar	1403.60	743.27	422.00
Vit	523.16	348.05	111.71
Osam	467.11	319.17	138.97
Jantra	2462.71	1869.43	1389.16
Russenski	139.28	119.06	59.90

The received values of annual flow are significantly smaller with about 21 % than these obtained by Mandadajiev (1996) for the period 1936-1994. The data series with values under normal are included into both investigations, but now the dry period is longer (from 1982-2000).

Low flow and drought severity

The severity of low flow can be estimated by Low Flow Index (LFI). This is a normalized value of the discharge obtained by the follow equation:

$$LFI = (Ki - 1) / C_v \qquad (1)$$

Were $Ki = Q_{i\,mean} / Q_i$ and $C_v = \sigma / Q_{i\,mean}$ $\sigma = [\, n \sum Q_i^2 - (\sum Q_i)^2 \,]^{½}$

$Q_{i\,mean}$ is the mean flow of the series, Q_i is the flow of each year, σ is the standard deviation of the series.

The motives proving LFI as suitable tool to quantify the severity of low flow are develop in (Dakova, 2004). The low flow severity is presented in four grades (Table 4). When BFI is lower zero it is a indication of low flow. The severity of low flow is inversely proportional of the LFI value. When the value of BFI is between zero and minus one the scarce of flow is in the frame of common low flow. But, when the value of BFI is lower minus one this scarce of flow is named river drought.

Table 4. Hydrological drought index categories

Value of LFI	Severity	
O to – 0.99	Low flow	LFL
-1 to –1.5	Moderate drought	MHD
-1.5 to – 2	Severe drought	SHD
< -2	Extraordinary/ extremely drought	EHD

The LFI of annual, summer and minimum flow have been estimated for each time series and laid down in Tables 5 and 6.

Tabl.5 Number of dry years for annual flow

NGSt	**river and sit**	**CP**	**N**	**NDY**	**LFI<1**	**LFI>1**
12700	Topolovetz-v.Akatzievo	1967-2000	33	**21**	14	4
12850	Vojnishka	1971-2000	29	**16**	8	8
14850	Lom –v.Trajkovo	1960-2000	40	**20**	10	10
15580	Tzibritza -Ignatovo	1970-2000	30	**4**	3	1
16850	Ogosta-Mizija	1970-2000	30	**17**	12	5
18850	Iskar Orjahovo	1975-2000	25	**14**	9	5
21800	Vit -Tarnjane	1970-2000	30	**17**	11	6
23850	Jantra -Karantzi	1970-2000	30	**7**	6	1

31830	R. Lom Besarbovo	1970-2000	30	**17**	9	8

* CP-returned period, N total number of years, NDY –total number of dry years, LFI-number of years with respective values of Low Flow Index.

Tabl.6. Number of dry years for summer and minimum flow

NGSt	**river and sit**	**N**	**NDY**	**LFIs<1**	**LFIs>1**	**LFI>2**	**NDm**	**LFIm<1**	**LFIm>1**	**LFIm>2**
12700	Topolovetz-v.Akatzievo	33	**32**	4	25	0	**28**	14	6	8
12850	Vojnishka	29	**17**	8	6	3	**23**	3	1	19
14850	Lom -v. Trajkovo,Mladenovo	40	**30**	18	12	0	**25**	18	7	0
15580	Tzibritza –Ignatovo	30	**18**	10	8	0	**14**	6	5	3
16850	Ogosta-Mizija	30	**16**	16	0	0	**22**	16	6	0
18850	Iskar Orjahovo	25	**16**	14	2	0	**14**	10	4	0
21800	Vit –Tarnjane	30	**21**	20	1	0	**17**	14	3	0
23850	Jantra –Karantzi	30	**15**	15	0	0	**15**	9	6	0
31830	Russenski Lom Besarbovo	30	**24**	16	8	0	**26**	17	9	0

* CP-returned period, N total number of years, NDY –total number of dry years, LFI-number of years with respective values of Low Flow Index.

As it can be seen the years having LFI values lower zero are about 68% (Table 5) of total number of years i.e. these are the years with flow under normal. These dry years are since 1982. The longest interval with consecutive values below median is 5.

Regarding to summer flow (tabl.6) series the percent of dry years are 64%. From all dry years 64% can be referred as low flow, 32% as drought and 16 % with extraordinary drought (1994-2000). About ten- eleven successive years 1989-2000 the tributaries have a sever drought. Very often these extraordinary droughts are results of gathering climate dry conditions with non-balanced water management. For instance, the difference between natural annual flow variability and respectively summer and minimum flow are shown in Fig.1. The gauging station is situated under 6 reservoirs. About 40% of the annual flow is hold up into the reservoirs which reflected to summer and minimum flow.

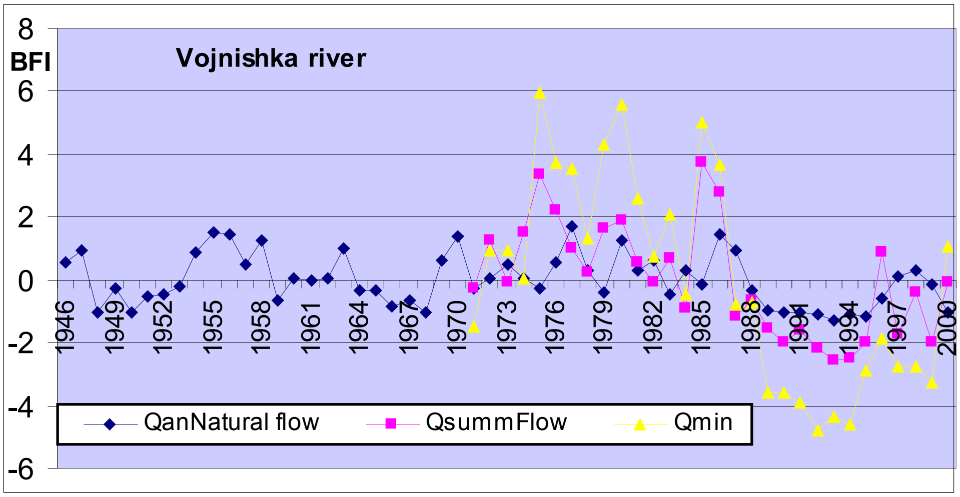

Fig. 1. Comparison among variability of LFI of natural annual flow for period 1946-2000 of Vojnishka river and its summer and minimum flow during the period 1970-2000.

Conclusions and comments

The analyses of annual, summer and minimum flow data series with 30 years observation period, presented the present conditions, for 21 gauging stations on the Bulgarian Danube River's tributaries show the follow:
- The significant diminishing of the inflow into Danube is observed since 1982. The available data to 2003 of Osam river show that this dry period is extending for summer and low flow series only.
- The applied quantity criteria of Low Flow Index shows that the flow of more than 60% of cases can be refer as drought.
- A cases with extraordinary drought (LFI> 3 or 4) and duration from 3 to 8 years have been extracted during period 1982-2000.
- The extraordinary severity of drought, obtained on some of Bulgarian tributary, is a cause of inadequate water management to the poor precipitation fallen during the last decades.
- For Bulgarian part of Danube basin, the study of droughts frequency is not reasonable because here drought is cause not only of the respective climate conditions but also of human's activities. The question of wise management is to be in the foreground

Decades ago water was viewed as a non-limited natural resource because it was renewed every year in the course of the seasons. For a variety of purposes river flow has been undertaken without sufficient care, without view to very long period (1982-200) with rain deficit. Thus nowadays, water is becoming scarce in spite of much number of seasonal flow regulating reservoirs built on the Danube plain area.

Referances

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