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Hydrological droughts in the Južna Morava river basin (Serbia)

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Abstract

Spatial and temporal analysis of hydrological droughts, defined by two variables: deficit and duration of drought, is presented in this paper. Time series of deficits and drought durations are derived using threshold level method for 15 hydrological stations in basin of Južna Morava (Serbia). Since Q90 was used as threshold level for drought definition, these time series are ready for frequency analysis of extreme droughts. The longest average duration of drought is observed on Visočica River at Braćevci, then on Vlasina River at Vlasotince, and shortest droughts on upstream stations of Južna Morava, Vladičin Han and Grdelica. There is a direct relationship between absolute values of drought deficits and catchment area or mean annual water discharge, while standardize deficits have similar spatial distribution as drought duration. Regional deficit index (RDI) was calculated, which enabled insight in spatial-temporal drought characteristics in defined regions, like seasons when droughts most often occur, and derivation of largest droughts, both in terms of their duration, and covered area.

Keywords: hydrological drought, threshold level method, drought deficit, RDI, Južna Morava, Serbia

Introduction

Hydrological extremes (floods and hydrological droughts) are natural hazards that are not limited to specific regions, but occur worldwide and, therefore, impact a very large number of people. In recent years, many severe drought events occurred. Currently, the state of California (USA) is in fourth year in one of the most severe multiyear droughts on record, resulting in extremely low reservoir and groundwater levels and restricting water use (Internet 1). In 2014, a winter drought in Scandinavia caused severe wildfires, while in 2013 drought disaster relief was needed in Namibia and Angola, Brazil, central Europe, and New Zealand. In 2012, a simultaneous drought in central and southern USA and Russia induced an increase in food prices. In spring 2011, Western Europe faced severe water scarcity and low water levels. In 2003 and 2006, droughts in Europe caused crop failure, problems in navigation, restrictions in industrial water use, and loss of life due to a heat wave (Van Loon, 2015). This list of recent droughts is not complete, but indicates the recurring and worldwide nature of droughts. Droughts can occur in every climate, although its characteristics can vary significantly between regions. Drought is not a recent phenomenon. Actually, some of the most devastating drought events occurred in the previous century, like 1976 drought in Europe, the 1930s Dust Bowl in the USA and the 1920s food crisis in Russia and China. In the period 1900–2010, worldwide two billion people were affected and more than 10 million people died due to the impacts of drought (Van Loon, 2015).

Recent research projects such as DROUGHT-R&SPI (Internet 2), WATCH (Internet 3), ARIDE (Internet 4), DMCSEE (Internet 5), have significantly increased scientific understanding of the drought phenomenon, its causing mechanisms, impacts, and

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changes in time and space. One of the most important scientific developments is the growing view that droughts cannot simply be characterized by a lack of rainfall, but for describing the complexity of drought the knowledge of hydrological processes is also needed. Hydrological droughts can cover extensive areas and can last for months to years, with devastating impacts on the ecological system and many economic sectors, like: domestic and industrial water supply, irrigation, hydropower, navigation and recreation (Tallaksen, Van Lanen, 2004).

First step in analysis of droughts is drought definition. Many different definitions of drought can be found in papers of Dracup et al., (1980), Beran and Rodier (1985), Wilhite and Glantz (1985), Tallaksen and Van Lanen (2004), Mishra and Singh (2010). It is important to stress out, that because droughts have impacts on different sectors of society, there is a need for different definitions of them. Also, there are several classifications of droughts, and the most widespread is according to disciplines that study them. In this paper term hydrological drought is related to the hydrological droughts of surface waters, i.e. to the deficits of discharge in rivers. Threshold level method was used for selection of hydrological drought events on stations, so that hydrological drought is defined by two variables $X = f(D, T)$, where D – drought deficit, T – drought duration. Drought defined in this way provides more information for hydrological engineers, than one value of annual minimal discharge.

Since droughts have regional character, they cover large areas and can last for very long period, it is important to study them in regional context. The characteristics of regional drought can be analyzed by spatial distribution of selected droughts on hydrological stations (at-site droughts). This approach was used in this paper for analysis of hydrological droughts in Južna Morava basin.

Analysis of hydrological droughts in this paper is limited to the selection of hydrological droughts on stations, and to the spatial analysis of its characteristics: drought deficits and durations. This represents the first, but very important step, in full analysis of hydrological drought characteristics, which includes frequency analysis of derived time series of deficits and durations of droughts, i.e. the identification of theoretical distribution function and calculation of exceedance probabilities of hydrological droughts.

Background and study area

Analysis of hydrological droughts by threshold level method is done only for a few hydrological stations in Serbia: Sava – Sremska Mitrovica, Tisa – Senta, Danube – Bezdan and Danube – Bogojevo in papers of Zelenhasić and Salvai (1987), Salvai et al. (1990), Zelenhasić (2002). In Radić and Mihailović (2006) different method for deriving constant and varying threshold, as well as their influence on number, volume and duration of droughts for station Ljubičevski Most on Velike Morava river for the 1951 – 2003 period is presented.

Basin of Južna Morava is chosen as one of the largest river basins in Serbia, which according to climatological studies, together with basin of Velike Morava, is most exposed to the droughts. Also, it could be stated that its rivers represent hydrological regime of rivers in Serbia, south of Sava and Danube (excluding Drina and Lim) with low flow in summer-autumn period (August, September), so analysis of hydrological droughts is mostly related to the warm season. That's why the calculation was done for calendar years (1 January – 31 December). Also, this basin was chosen because its hydrological regime is much less under artificial changes than regime of Danube, Tisa and Drina. The 1960 – 2014 period was chosen because as long as possible time series is needed for further calculations of distribution function of drought deficits and durations, and to include recent droughts in analysis. Also, the largest possible number of hydrological stations (15) that have daily discharge data in this period was chosen to better represent spatial distribution of droughts. The natural regime of rivers or minimal anthropogenic influence was taken in account in the selection process of stations.

Basin of Južna Morava with area of 15592 km^2 is situated in south and southeast Serbia. One of its parts (6.8%), upper basin of Nišava river is on the territory of Bulgaria. Južna Morava is one of the average water abundant rivers of Serbia because its mean annual specific runoff is 5.9 $l/s/km^2$ which is very close to Serbia's average 5.4 $l/s/km^2$. The basin is intersected by gorges, wider valleys, mountain ranges and other forms of relief in which many tributaries of the Južna Morava, such as Nišava, Toplica, Jablanica and Vlasina have deeply carved their beds.

Precipitation regime and air temperature influence within year water flow variations. During winter on the large part of Južna Morava basin snow cover interchangeably accumulates and melts, and in conditions of increased temperatures at this time of year rainfall occurs, especially in the lower regions. In spring high waters develop due to rain and snowmelt in mountains. In summer-autumn period low flow occur due to lack of precipitation and increased evapotranspiration. These processes influence the distribution of runoff within year, so the rivers in Južna Morava basin mostly belong to pluvio-nival type of water regime, with maximum discharges in March and April, and minimum in August and September (figure 1).

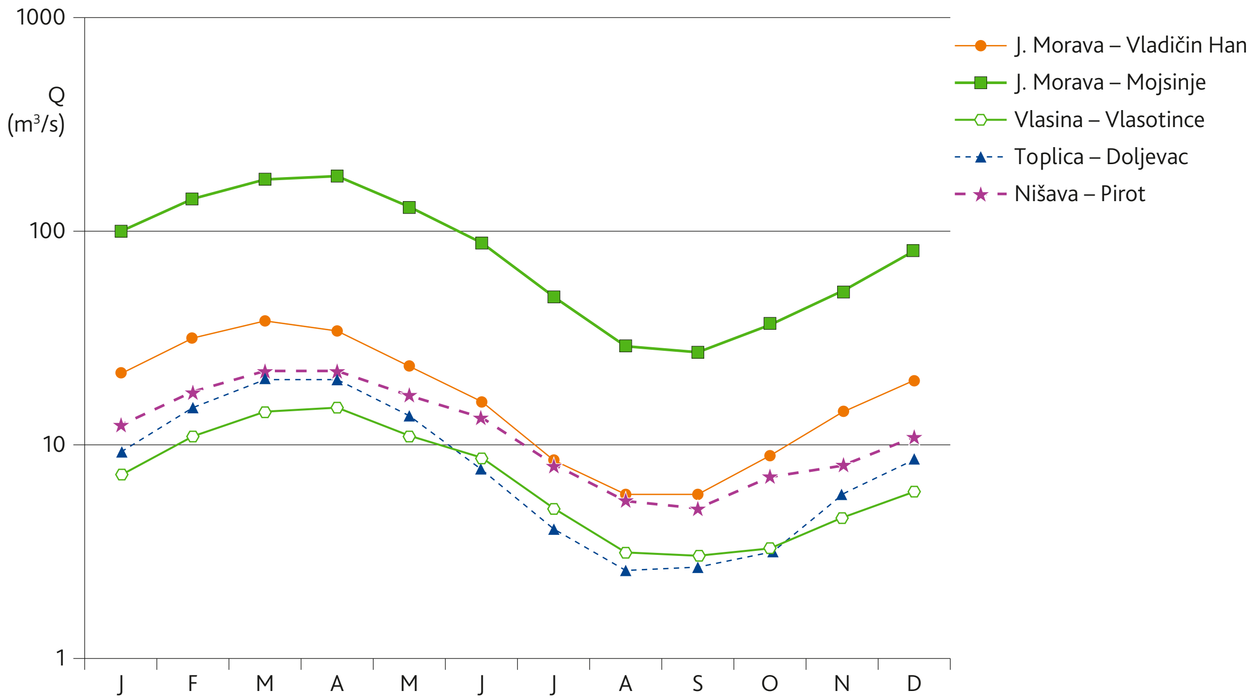

Figure 1. Comparative view of mean monthly discharges on representative stations for the period 1960-2014

Methods

Definition of droughts by threshold level method

Threshold level ("truncation level") method is discussed in details in Tallaksen et al. (1997) and Zelenhasić and Salvai (1987). The intensive use of this method is after year 1987, i.e. after publication of Zelenhasić and Salvai paper, which were first to used this method on daily discharge data. Further modifications of this method are related mainly to the way that threshold is selected, interdependent droughts are pooled together, that very small drought are removed. Manual on low-flow estimation and prediction of World Meteorological Organizaton (WMO, 2008) also recommends threshold level method for selection of hydrological droughts.

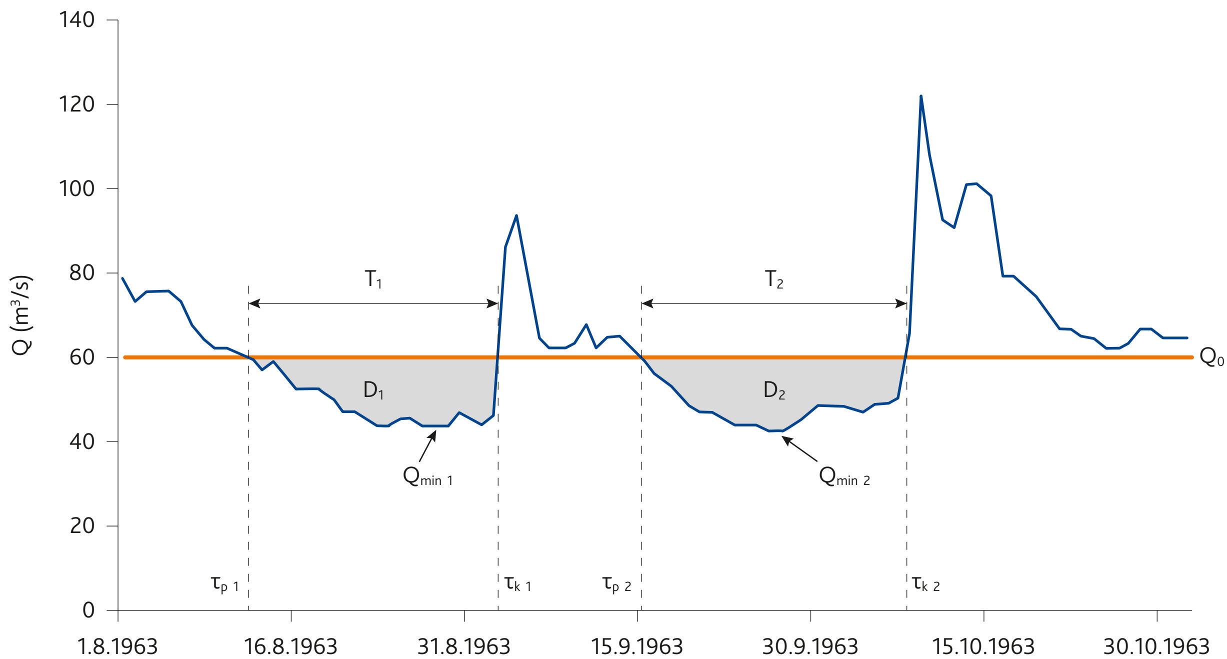

Figure 2. Definition of hydrological drought characteristics

The example of selecting hydrological droughts by threshold method is presented in figure 2. On the observed daily hydrograph value of selected in advance threshold (Q_o) is applied. Drought begins when discharge falls under threshold ($Q(t) < Q_o$) and drought ends when discharge returns above it ($Q(t) \geq Q_o$). This is how the time of beginning (τ_p) and end of a drought (τ_k) are defined. Two most important characteristics of drought are duration (T) and deficit (D) (figure 2). Duration (T) is the consecutive number of days when the discharge is under threshold value. Deficit volume (D) (term severity or total deficit is also often used in literature) presents cumulative deficit of discharges (D (t)) for given drought duration and it is calculated with formulas (1) and (2).

$$Di = \sum_{\tau_p}^{\tau_k} D(t) \qquad (1)$$

where D_i is deficit (volume) of drought i (in m³), a $D(t)$ is discharge deficit in time t and is equal:

$$D(t) = \begin{cases} Q_0 - Q(t), & Q(t) < Q_0 \\ 0, & Q(t) \geq Q_0 \end{cases} \qquad (2)$$

The choice of threshold is very sensitive matter. The decision about height and type of threshold depends on purpose of drought study. Also, threshold could be in advance defined value, like specific inflow to the reservoir, or defined by user – water supply, navigation, hydropower, etc. It is possible to use some of the low flow characteristics, like percentage of mean flow, or percentile from the flow duration curve. Most often for threshold level the percentile from flow duration curve is used, for example Q_{95}, i.e. the discharge that is exceeded for 95% of time during observation period. For perennial rivers in mid latitudes Q_{70} and Q_{90} are used as threshold levels. Threshold level that is very low could result in too many zero-drought years and the number of selected droughts is too small for frequency analysis. On the other hand, threshold that is relatively high would select drought that lasts more than a year (multi-year droughts).

Figure 3. Hydrological drought on stations in basin of Južna Morava (Photo: M. Urošev)
A) Južna Morava – Korvingrad, 02.09.2015., 19.00, $Q(t)=7.49$ m³/s < $Q_{90}=10.3$ m³/s
B) Južna Morava – Mojsinje, 06.09.2015., 09.40, $Q(t)=15.0$ m³/s < $Q_{90}=18.5$ m³/s
C) Jablanica – Pečenjevce, 02.09.2015., 16.45, $Q(t)=0.108$ m³/s < $Q_{90}=0.240$ m³/s
D) Vlasina – Vlasotince, 02.09.2015., 13.00, $Q(t)=1.78$ m³/s < $Q_{90}=1.95$ m³/s

Threshold Q_{95} was first applied, because usually the goal of drought analysis is to calculate return periods of large droughts, i.e. the most extreme ones. For example, this low threshold level has derived only 32 droughts for station Mojsinje on Južna Morava river, which is an outlet of whole basin, and in 36 out of 55 years (1960 – 2014) no droughts were recorded. Similar results are gained for other stations in basin of Južna Morava. This small number of droughts can't give reliable estimation of distribution parameters that are necessary for frequency analysis of extreme droughts. Threshold defined by percentile Q_{90} (18.5 m^3/s) have singled out greater number of droughts in relation to Q_{95} (15.3 m^3/s). For station Mojsinje 43 droughts were singled out in the 1960 – 2014, and droughts were recorded in 31 year, which enables sufficient number of data for reliable estimation of drought with little exceedance probabilities, i.e. large return periods. That's why the threshold Q_{90} was selected for drought definition, because generated time series are long enough, and the threshold is low enough to ensure that discharges included in analysis belong to lower extreme part of hydrograph. In figure 3 one can see how hydrological droughts look on stations in basin of Južna Morava ($Q(t) < Q_{90}$) recorded at the beginning of September 2015 at field survey.

Threshold could be fixed or variable, i.e. seasonal, monthly, daily (figure 4). Fixed threshold uses one constant value over whole time series. Variable threshold is applied in order to determine deviations from "normal" during season of high and low flow. However, periods with relatively small discharges during high flow season, or for example due to delayed onset of snowmelt, usually are not considered a drought. Therefore, drought defined by variable monthly or daily threshold should be called streamflow anomalies, and only droughts defined by fixed threshold should be called droughts (Hisdal, Tallaksen, 2000).

The use of daily data for definitions of droughts within year leads to two significant problems: dependence of droughts and minor droughts. During prolonged dry period discharge often exceeds threshold for short period of time, so the one drought is separated in the number of droughts. To avoid this problem, which can influence extreme value modeling, procedure for pooling these droughts should be introduced to gain independent time series of droughts. Tallaksen et al. (1997) described and analyzed three different procedures for pooling mutually dependent droughts: moving average (MA), sequent peak algorithm (SPA), the inter-event time and volume criterion (IC). They concluded that MA and SPA procedures give satisfactory results in pooling of mutually dependent droughts and elimination a number of minor droughts. MA procedure is applied on time series before selection of droughts. In this

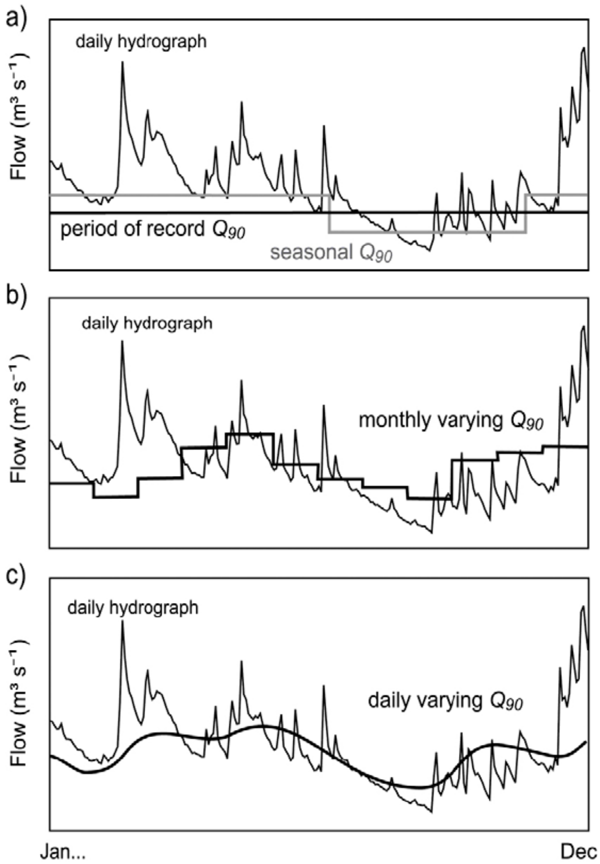

Figure 4. Different types of threshold levels: a) fixed threshold, b) variable monthly, c) variable daily (Hisdal et al., 2004)

case time series are smoothed and little peaks above threshold are removed. The use of 10 days averaging interval is recommended (Hisdal, Tallaksen, 2000). In this paper central moving average with 11 days interval (MA(11)) was used in order to preserve real dates when drought occurred. Although MA(11) filter removes great number of minor droughts and pools together mutually dependent droughts, some of this events remains. The solution for this problem implies introduction of additional criterions. First criterion is independence of droughts, i.e. the time between neighboring droughts needs to be greater than five days $t_c > 5$, because of filter applied MA(11) (five days before and five days after). If this criterion is not fulfilled neighboring droughts are pooled into one drought. Fleig et al. (2006), by analyzing droughts in basins around the world, concluded that best combination for removing minor drought is minimal duration of drought $t_{min} > 2$ days and minimal deficit $(D_0) = 0.005 \cdot D_{max}$, where D_{max} is maximal observed deficit.

Synchronicity of drought occurrence

For overview of large scale droughts in basin of Južna Morava it is recommended to use method which enables comparison of discharges on all stations and seasons. One of these methods is regional drought index (RDI), which represent regional drought in relation to time and location. This method is modification of regional deficiency index, which is developed by Stahl (2001), and applied on big part of Europe by Hannaford et al. (2011) and regional drought area index (RDAI), which is introduced by Fleig et al. (2011).

Drought index (DI) compares daily discharges $Q(t)$ with threshold value Q_o, in this case Q_{90}, so if they are smaller than threshold, the value 1 (drought) is assigned to them, and if they are bigger then threshold 0 (no drought) is assigned, i.e:

$$\begin{cases} DI(t)=1, & Q(t)<Q_{90} \\ DI(t)=0, & Q(t)\geq Q_{90} \end{cases} \tag{3}$$

For every station times series of DI are calculated, which constitutes of binary series of zero and one, which points out whatever river is in a state of drought or not. In this way 15 binary series each with 20089 daily data were gained.

In the basin of Južna Morava regional drought index (RDI) is calculated as average DI value of all stations in basin, i.e:

$$RDI(t)=\frac{1}{n}\cdot\sum_{i=1}^{n}DI_i(t) \tag{4}$$

where n is number of stations with daily DI value. Therefore, RDI time series represent the part of the region which is under drought on that day. Since RDI averages binary time series it values can vary from 0 to 1, where 0 means that none of the basins, or stations is in drought, while 1 signify that entire region, entire Južna Morava basin, is under drought conditions.

Results and discussion

Flow duration curve for all 15 stations, from which values of threshold level Q_{90} are taken, are presented in figure 5. For easier comparison of flow duration curves of various basins discharges on y-axis are defined as ratio of daily and mean annual discharge. In general shapes of the curves on all stations are very similar, except for Visočica – Braćevci, where slope of the curve is very steep, especially in its lower part > Q_{50} (figure 5b). This means that main runoff conditions do not differ substantially in entire basin. If we look at shapes of flow duration curves on sub-basins we can see that in low flow period > Q_{75} the smallest variations of discharges are on stations on Nišava and Vlasina river, than on Južna Morava at Mojsinje (figure 5a), and the biggest are on left tributaries of Južna Morava, as well as on Visočica (figure 5b). This order is directly dependent on the amount of rainfall, altitude, proportion of forest cover, as well as in reverse dependence on the impact of human activities on the water. On curves rivers with the highest percentage of flow equal to zero can easily be spotted (the so-called river "sušice") Visočica - Braćevci, Jablanica - Pečenjevce, Pusta reka - Pukovac.

Values of selected threshold Q_{90} and their specific values (q_{90}), normalized by basin area, are presented in table 1. Spatial distribution of q90 is similar to distribution of annual specific runoff, it's smallest in left tributaries of middle part of river Južna Morava (Jablanica, Pusta reka), and biggest in mountain areas (Vlasina, Nišava). The exception is the Visočica in Braćevci because its regime is disturbed by anthropogenic influence. Its source area in Bulgaria is transected by canals and together with waters from river Nišava are transferred on other slope of mountain Stara Planina in the basin of Brzija river, right tributary of river Ogošte, which latter as a right tributary flows into Danube. According to Ocokoljić (1987) on average 0.58 m^3/s of water was transferred from Visočica basin in the 1954 – 1970 period, which in relation to mean annual discharge of Visočica at Braćevci (1.67 m^3/s) is 35%.

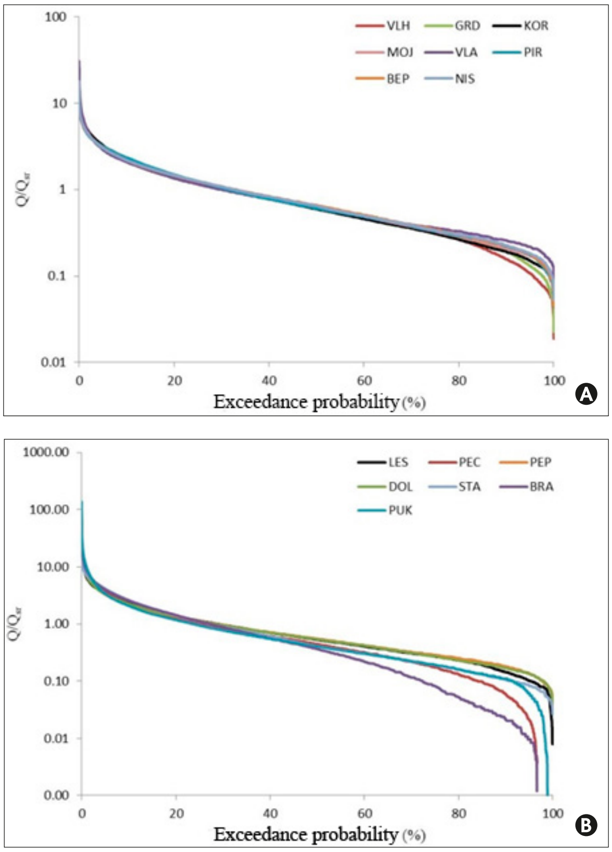

Figure 5. Flow duration curves for 1960-2014 period: A) stations on Južna Morava and Nišava, B) stations on tributaries of Južna Morava and Nišava (abbreviations on figure 5 match the same ones in table 1)

Table 1. Values of selected threshold Q_{90}

River	Station	Abbreviation of station	F (km²)	Q_{90} (m³/s)	q_{90} (l/s/km²)
Južna Morava	Vladičin Han	VLH	3052	2.90	0.95
Južna Morava	Grdelica	GRD	3782	4.68	1.24
Južna Morava	Korvingrad	KOR	9396	10.3	1.10
Južna Morava	Mojsinje	MOJ	15390	18.5	1.20
Vlasina	Vlasotince	VLA	879	1.95	**2.22**
Veternica	Leskovac	LES	500	0.54	1.08
Jablanica	Pečenjevce	PEC	891	0.24	***0.27***
Pusta reka	Pukovac	PUK	561	0.18	***0.32***
Toplica	Pepeljevac	PEP	986	1.22	1.24
Toplica	Doljevac	DOL	2052	1.60	0.78
Nišava	Pirot	PIR	1745	2.72	1.56
Nišava	Bela Palanka	BEP	3087	4.94	1.60
Nišava	Niš	NIS	3870	6.32	**1.63**
Temska	Staničenje	STA	818	0.78	0.95
Visočica	Braćevci	BRA	227	0.04	***0.16***

Main characteristics of hydrological droughts for each station are presented in table 2. The intensity of drought, *I* represents ratio of drought deficit and drought duration, so its spatial distribution is very similar to distribution of deficits, i.e. it depends on the size of basin area.

Analyzing data from table 2 it can be seen that mean drought duration in Južna Morava basin is 38 days. The longest mean duration is 53 days on Visočica at Braćevci, then on Vlasina at Vlasotince (49), and shortest 28 and 31 day on upstream stations on Južna Morava river, Vladičin Han and Grdelica.

The histogram of mean drought durations on stations in Južna Morava basin is presented in figure 6. Mean number of droughts in the basin for observation period 1960 – 2014 was 44.7 or 0.81 drought in one year. It can be seen on histogram that drought with duration from 31 to 40 days are dominant, with mean

Table 2. Main characteristics of hydrological droughts in Južna Morava basin for the 1960 – 2014 period for selected threshold Q_{90}

River	Station	Number of droughts	$D_{av.}$ ($\cdot 10^6$ m³)	$T_{av.}$ (days)	$Q_{av.}$ of drought (m³/s)	*I* of drought ($\cdot 10^6$m³/day)
Južna Morava	Vladičin Han	**51**	2.13	***28***	2.19	0.075
Južna Morava	Grdelica	**51**	3.74	***31***	3.58	0.119
Južna Morava	Korvingrad	41	8.42	40	8.37	0.210
Južna Morava	Mojsinje	43	12.46	39	15.59	0.316
Vlasina	Vlasotince	***39***	1.58	**49**	1.69	0.033
Veternica	Leskovac	47	0.48	36	0.42	0.014
Jablanica	Pečenjevce	46	0.50	40	0.13	0.012
Pusta reka	Pukovac	45	0.29	39	0.11	0.007
Toplica	Pepeljevac	46	1.09	39	0.95	0.028
Toplica	Doljevac	46	1.31	39	1.30	0.033
Nišava	Pirot	36	2.44	37	2.17	0.065
Nišava	Bela Palanka	49	3.29	34	4.13	0.098
Nišava	Niš	49	3.73	32	5.20	0.118
Temska	Staničenje	49	0.53	33	0.65	0.016
Visočica	Braćevci	***33***	0.10	**53**	0.02	0.002
	Average value	44.7	2.81	37.9	3.10	0.076

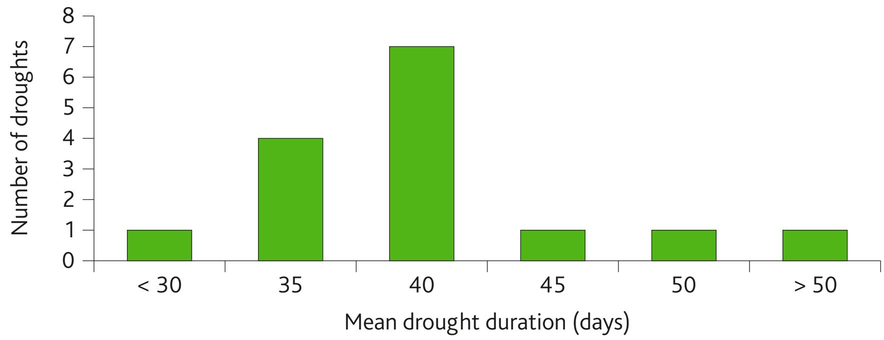

Figure 6. Histogram of mean drought durations in Južna Morava basin

duration 37.9 days. Distribution of mean drought duration is skewed Cs=0.97, because frequency of relatively shorter droughts (< 35 days) is bigger than frequency of longer droughts (> 40 days).

If comparison is made between number of droughts and mean duration (table 2) it can be seen that they are in inverse relationship (r = - 0.85), i.e with increased number of droughts its durations decreases. Thus, largest number of droughts 51 was recorded on most upstream stations on Južna Morava, Vladičin Han and Grdelica, as well as their smallest mean duration 28 and 31 respectively; while on the other side on nearby station Vlasotince on river Vlasina 39 droughts were registered in the same period with mean duration of 49 days.

Deficits are in direct relationship with basin area (r = 0.990) or mean annual discharge (r = 0.993) (figure 7), so the maximum mean deficit is at outlet station, Južna Morava at Mojsinje ($12.46 \cdot 10^6$ m^3).

In order to compare drought deficits standardization (normalization) of deficits is necessary. It can be done by dividing by basin area or mean discharge for observation period. In this paper deficit is standardized by mean annual discharge, i.e.:

$$D_S = \frac{D}{Q_{av}} \tag{5}$$

where D_s is standardized drought deficit expressed in days. The physical interpretation of standardized deficit is the number of days with mean annual discharge required to reduce the deficit volume to zero. It is always smaller than real drought duration.

Mean standardized deficits for the 1960 – 2014 period are given in table 3. Mean standardized deficit in entire Južna Morava basin is 1.6 days, with maximum in Vlasina basin (2.4 days) and Nišava at Pirot (2.3 days). In general, values of standardized deficits are in accordance with spatial distribution of drought duration, with some exceptions, like lower values of standardized deficits on Visočica and Temska rivers, in relation to drought durations on these stations.

Daily values of RDI for the 1960 – 2014 period are presented in figure 8. In figure 8 seasons when largest drought occur, according to area covered, can be clearly singled out, as well as the annual variations in the observation period. In Južna Morava basin hy-

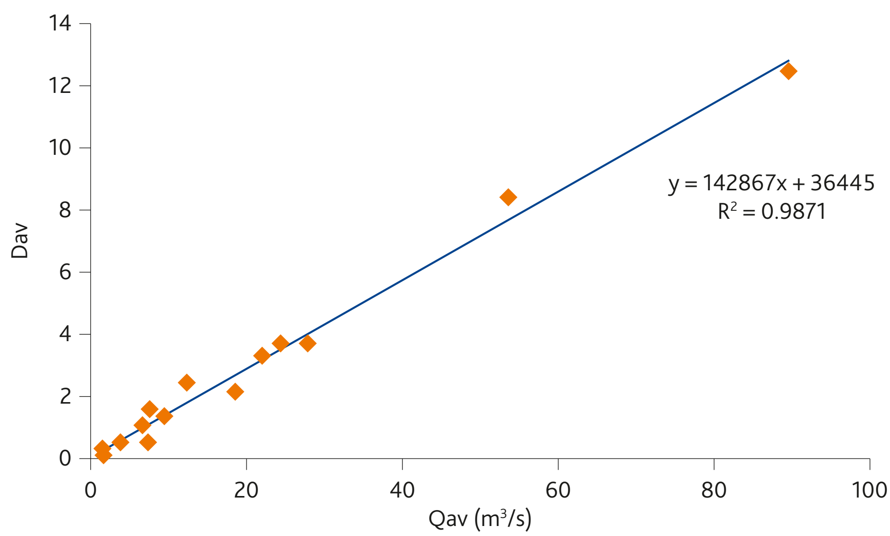

Figure 7. Relationship between mean drought deficit and mean annual discharge in Južna Morava basin

Table 3. Mean standardized drought deficits in Južna Morava basin

River	Station	$\overline{D}$ ($\cdot 10^6$ m³)	Q_{av} (m³/s)	$\overline{D_s}$ (days)
Južna Morava	Vladičin Han	2.13	18.6	1.3
Južna Morava	Grdelica	3.74	24.5	1.8
Južna Morava	Korvingrad	8.42	53.7	1.8
Južna Morava	Mojsinje	12.46	89.6	1.6
Vlasina	Vlasotince	1.58	7.56	**2.4**
Veternica	Leskovac	0.48	3.77	1.5
Jablanica	Pečenjevce	0.50	4.03	1.4
Pusta reka	Pukovac	0.29	1.62	2.1
Toplica	Pepeljevac	1.09	6.73	1.9
Toplica	Doljevac	1.31	9.42	1.6
Nišava	Pirot	2.44	12.3	**2.3**
Nišava	Bela Palanka	3.29	22.0	1.7
Nišava	Niš	3.73	27.9	1.5
Temska	Staničenje	0.53	7.41	***0.8***
Visočica	Braćevci	0.10	1.67	***0.7***
Average value		2.81	19.4	1.6

drological droughts are occurring from July till November, and most frequently in August and September, when they also cover the largest areas (> 60% of basin area). At the end of research period (2001, and 2012 – 2014) longer drought duration can be noticed, so droughts from summer-autumn period are prolonged into winter period, and in January of above mentioned years droughts covered around 50% of basin area. Days when droughts occurred on more than 80% of stations in basin are marked with bright blue color in figure 8. These are also the largest regional droughts in basin in the 1960 – 2014 period. Maximum RDI value of 1.0 is recorded in 24.9.1987, than in 17.9.1992 and 18.9.1992, as well as from 12.9.1994. until 15.9.1994. Beside these, largest droughts according to RDI values were in year 1968, 1985, 1990, 1993, 2000 and 2012. Also, in figure 8 the cyclicality in formation of drought years can be noticed, so the drought years in Južna Morava basin are grouped in the periods 1961 – 1965., 1984 – 1988., 1990 – 1994 and 2011 – 2013.

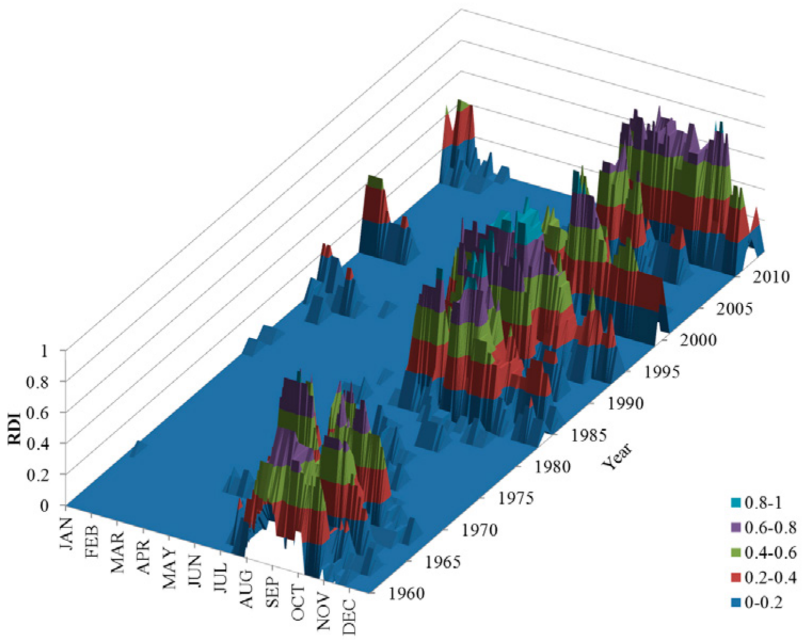

Figure 8. RDI values for Južna Morava basin in the 1960 – 2014 period

Conclusion

In this paper advantage of hydrological drought analysis with two variables (deficit and duration) over more common analysis with single value, for example with annual minimal discharge, is presented. Threshold level method was applied on 15 stations in Južna Morava basin for the 1960 – 2014 period, which represents the biggest sample on which it was applied in Serbia, whether it refers to analysis of low or high waters. This procedure can be applied for analysis of high waters, i.e. floods, only instead of volumes under threshold level, volume of high water above Q_{10} or Q_5 are selected.

For definition of droughts value of Q_{90} was selected as threshold level, because goal of analyses was spatial and temporal characteristics of extreme (large) droughts in Južna Morava basin. The research of relationship between deficits and duration of droughts and basin's physical-geographical characteristics was not a topic of this paper, but surely deserves more attention in further research. These relationships can contribute to more reliable determination of the mean deficit or duration, which are essential for further regional statistical analysis, i.e. for estimation of deficit of different return periods on ungauged basins. From literature review it can be seen that additional quantification of basin characteristics that are important for low flows (parameters of geology, soil, vegetation) is necessary.

Hydrological drought is complex phenomenon in terms of its causing factors and impacts on ecosystems and society. Therefore, it is important to better understand mechanisms of its onset, development and termination. Also, it is very important to have a good quantification of hydrological droughts, i.e. the results should have more applicability in water management. This paper focused on physical processes related to drought, while societal aspects were not considered. Anthropogenic effects are, however, sometimes hard to neglect because they can significantly affect observed hydrometeorological variables directly (decreases of water availability by e.g., abstractions from surface water or groundwater) or indirectly (changes in the hydrometeorological system, leading to a decrease in water availability, for example, changes in land use). Analyses of the relation between the physical causes and dimensions of drought and its impacts are possible, as well as human influences as additional driver of drought. One step further is bridging the gap between science, management and policy-makers, so that accumulated research experience could be implemented in field. This paper should contribute to better understanding of the professional public with the problems related to hydrological drought, and time series of drought deficits and durations derived in this paper are ready for further frequency analysis of these characteristics.

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