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A COMPARISON OF HYDROLOGICAL DROUGHT CHARACTERISTICS DEFINED BY THE POT AND SPA METHODS IN THE DUNAJEC RIVER BASIN

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Summary

This paper addresses the problem of how drought definition by POT and SPA methods influences drought characteristics. Using the 1984-2013 daily flows at 24 selected gauging stations in the Dunajec river basin and assuming two threshold levels $Q_{70\%}$ and $Q_{95\%}$ and four minimum drought durations (5, 7, 10 and 14 days) as the pre-set criteria, it was shown that, when compared to the POT method, the application of the SPA method usually leads to less number of droughts and, consequently, of longer duration. The SPA method, differently from POT, reduces dramatically the number of inter-event times, which suggests that some adjacent POT droughts may be dependent and should be pooled.

Key words: low flow, hydrological drought, drought duration, drought deficit, inter-event time

INTRODUCTION

Hydrological drought is the consequence of long-term precipitation deficiency in a catchment or over a larger area and gradual depletion of water resources and reveals in a river channel as a period with low flows. Usually, a drought event is understood as a process of uninterrupted flow (or stage) of water at a given river cross-section below the arbitrarily set critical value (Ozga-Zielińska and Brzezinski 1997, Tallaksen and van Lanen 2004, Węglarczyk 2006, Smakhtin 2001, Pociask-Karteczka *et al*. 2003).

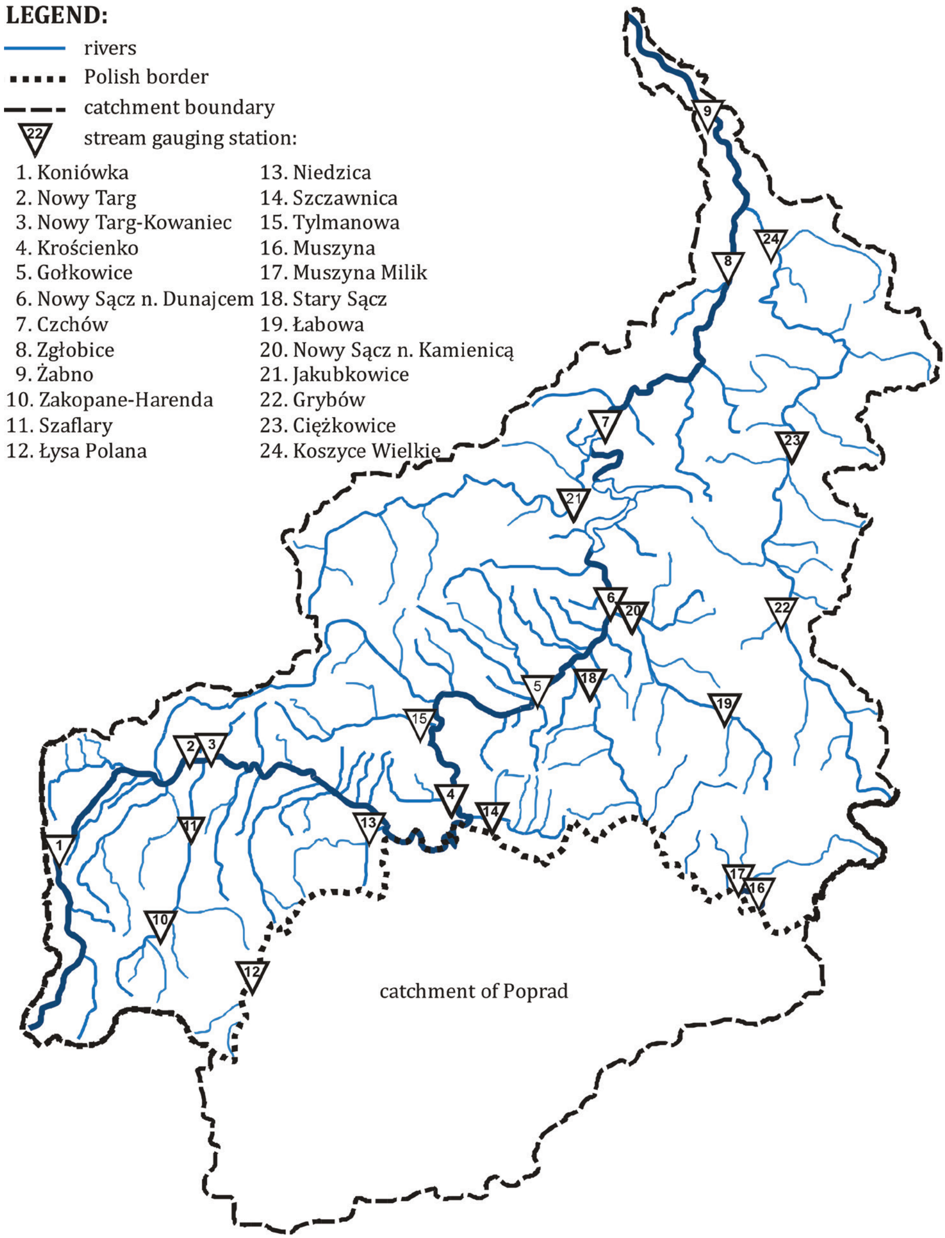


Figure 1. Study area: the Dunajec river catchment

There is no single definition of drought. In consequence, drought characteristics are dependent on the drought definition and their sense may vary. Even if drought is defined, a need arises to refine the definition as some of the adjacent drought events may seem not to be independent or the time between them is too short to justify the drought end. The aim of this paper is to compare the basic characteristics of drought, i.e., its duration, deficit and inter-event time between the adjacent droughts, calculated by two methods: POT (Peak Over Threshold) and SPA (Sequent Peak Algorithm) for different threshold flows and different minimum drought durations.

STUDY AREA AND DATA

The research was performed for the Dunajec river basin (Figure 1), which lies in the central-southern part of the Upper Vistula river basin. The Dunajec is a right tributary of the Vistula. A large part of its basin is typical for mountain and submountain catchment.

The highest source of the Dunajec is situated at the altitude of 1540 m above sea level in the Kocioł pod Wołowcem Valley in the Western Tatras. The Dunajec is formed from the combined waters of the Czarny Dunajec and Biały Dunajec rivers in the city of Nowy Targ, at the altitude of 577 m a.s.l.; and joins the Vistula river at the altitude of 174 m a.s.l. The length of the river is 274 km, the basin area is 6804 km^2, of which 4854.1 km^2 is in Poland, and the rest is in Slovakia. The average slope of the river channel exceeds 5.5‰ (more than 20‰ in the upper, 3.3‰ in the middle and 1‰ in the lower reach of the river).

For the research purposes, 24 gauging stations have been selected in the Dunajec basin. The arrangement of the gauges is shown in Figure 1; some basic characteristics of the catchments and flows are summarized in Table 1.

The uppermost gauging station is Łysa Polana (gauge no. 12 in Figure 1) on the Białka river. Above 700 m a.s.l. there are also located gauging stations of Zakopane-Harenda (gauge no. 10) on the Cicha Woda and Koniówka (gauge no. 1) on the Dunajec. The lowest gauging stations, below 200 m a.s.l., are: Żabno (gauge no. 9) and Zgłobice (gauge no. 8) on the Dunajec, and Koszyce Wielkie (gauge no. 24) on the Biała.

The average annual precipitation determined for the years 1952-1981 in the Dunajec catchment is 932 mm.

As the most area of the Dunajec basin is of mountain character, the differences between the minimum and maximum flows are considerable. For example, at the Koniówka gauging station (gauge no. 1, 229.9 km from the river mouth), the minimum flow observed in the period from 1984 to 2013 is 0.43 m^3·s^{-1}, average – 4.2 m^3·s^{-1}, and the maximum – 182 m^3·s^{-1} (max/min ratio is 423). In gauging station Żabno (gauge no. 9), at the distance 17.4 km before the mouth, these values are: minimum – 1.9 $m^3 \cdot s^{-1}$, average – 88.6 $m^3 \cdot s^{-1}$ and maximum 2500 $m^3 \cdot s^{-1}$ (max/min ratio is 1315).

Table 1. Basic information concerning gauging stations in the Dunajec basin and values of guaranteed flows read from the flow duration curves in gauging stations in the Dunajec basin for hydrological years 1984-2013

No.	River	Gauging station	Catchment area[1] (km^2)	Km by MPHP[2] (km)	Gauge elevation[1] (m a.s.l.)	$Q_{70\%}$ ($m^3 \times s^{-1}$)	$Q_{95\%}$ ($m^3 \times s^{-1}$)
1	Dunajec	Koniówka	134.0	223.84	725.3	1.85	0.94
2	Dunajec	Nowy Targ	431.0	200.82	579.3	3.75	2.00
3	Dunajec	Nowy Targ-Kowaniec	680.0	199.56	547.3	6.60	3.53
4	Dunajec	Krościenko	1579.0	151.62	413.5	15.00	8.23
5	Dunajec	Gołkowice	2045.0	121.09	312.9	17.70	10.00
6	Dunajec	Nowy Sącz	4341.0	108.27	275.7	30.60	17.00
7	Dunajec	Czchów	5316.0	69.1	275.7	29.60	17.60
8	Dunajec	Zgłobice	5647.0	38.62	190.7	32.81	19.20
9	Dunajec	Żabno	6732.0	17.32	173.4	37.70	21.60
10	Cicha Woda	Zakopane-Harenda	58.4	21.23	763.1	1.07	0.57
11	Biały Dunajec	Szaflary	210.0	7.23	636.5	2.54	1.36
12	Białka	Łysa Polana	63.1	30.57	965.6	1.02	0.51
13	Niedziczanka	Niedzica	136.0	1.29	495.5	0.68	0.27
14	Grajcarek	Szczawnica	75.7	2.97	452.9	0.51	0.26
15	Ochotnica	Tylmanowa	111.0	0.97	394.3	0.73	0.40
16	Poprad	Muszyna	1514.0	55.14	446.3	8.00	4.50
17	Poprad	Muszyna-Milik	1695.0	52.3	440.4	9.00	5.23
18	Poprad	Stary Sącz	2065.0	2.74	297.3	11.10	6.40
19	Kamienica	Łabowa	67.2	19.72	446.2	0.34	0.17
20	Kamienica	Nowy Sącz	239.0	0.99	279.0	1.10	0.56
21	Łososina	Jakubkowice	341.0	7.01	248.3	1.39	0.58
22	Biała	Grybów	209.0	74.14	319.7	0.62	0.24
23	Biała	Ciężkowice	525.0	47.74	238.6	1.57	0.70
24	Biała	Koszyce Wielkie	869.0	6.54	190.7	3.15	1.39

[1]Source: Rozporządzenie (2014) and Wodowskazy (1972)
[2]MPHP – Map of Hydrological Division of Poland, Source: Rozporządzenie (2014)

Two flow values: $Q_{70\%}$ and $Q_{95\%}$ (Table 1), taken from flow duration curves have been assumed as the threshold levels, as commonly used in the literature (Tomaszewski 2012, Hisdal, Tallaksen 2002, Stahl 2001, Fleig 2004). Flow duration curves were based on historical series of daily flows for 30 hydrological years (10958 daily flows) covering the period from 1.11.1983 to 31.10.2013.

METHODS OF IDENTIFICATION OF DROUGHT AND ITS PARAMETERS

In Figure 2 a sample from a series of drought events is shown with their characteristics. A drought event is defined here as a period of time when the flow does not exceed the assumed threshold value Q_g, which is usually a constant and most often equal to the quantile Q_p of order p read from the flow duration curve. The value of the probability of exceedance, p, depends on the author, and is typically equal to 70, 80, 90 or 95% (Zelenhasic and Salvai 1987, Hisdal and Tallaksen 2000, Smakhtin 2001, van Loon and van Lanen 2011, Stahl 2001) . A drought event begins at the starting time, t_p,, i.e., the first moment (e.g., the first day) when the flow goes below the threshold level Q_g, its duration is $t_n = t_k - t_p + 1$, where t_k is the drought event end, i.e., the last moment (e.g., the last day) of the uninterrupted series of (daily) flows below the threshold level Q_g. Drought event deficit V_n is the total volume of flow during time t_n, and the inter-event time between adjacent drought events is t_z.

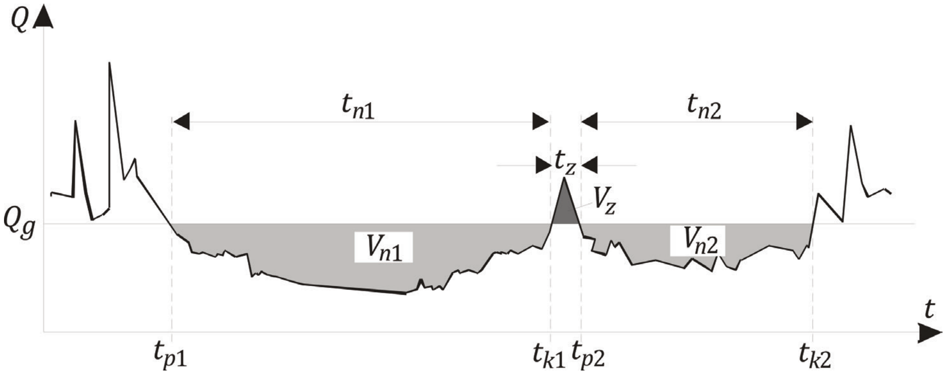


Figure 2. Basic parameters of a series of drought events

Not each drought event is of practical importance. It is obvious that, e.g., a 1-day drought is not a drought at all. To eliminate such minor drought events an additional condition may be introduced: the minimum drought duration, t_{min}. In the literature different values of t_{min} ranging from 5 to 14 days are assumed (Kostuch 2004, Tomaszewski 2012, Tallaksen and van Lanen 2004, Jakubowski 2011).

In this paper four values of t_{min}: 5, 7, 10 and 14 days were assumed.

Most often droughts are defined by one of the two methods: POT and SPA (Fleig 2004, Jakubowski 2011, Hisdal and Tallaksen 2000). The drought starting time is defined identically in both methods as a moment when discharge goes below the threshold level Q_g . The end of drought in the POT method occurs when the flow in the river begins to exceed the threshold level Q_g (van Lanen *et al*. 2008, Tallaksen and van Lanen 2004, Tokarczyk 2013).

Dependent drought events can be pooled with help of two inter-event criterions: IET and IEV (Fleig, 2004). According to the inter-event time criterion IET, two drought events are dependent when the inter-event duration is shorter than the assumed critical duration. Using the inter-event volume criterion IEV, successive droughts are pooled when the ratio of the inter-event flow surplus to drought deficit of preceding drought event is less than a certain adopted value. Some authors used a combination of the inter-event criteria. The duration of pooled droughts, is the sum of durations of these droughts and inter-event time.

In this article drought events are not pooled.

The SPA method is based on the flow mass curve and it was created in order to estimate the volume of a designed water storage reservoir. The currently used form of the SPA algorithm was introduced by Vogel and Stedinger (1987). This method is used by many authors, including T. Tallaksen and van Lanen (2004), Fleig (2004) and Jakubowski (2011). According to this method, the end of drought is defined as the moment at which the resulting deficit of water is compensated by the flows higher than the threshold flow Q_g. The day with the maximum deficit defines both the time of drought duration t_n and its deficit V_n.

RESULTS AND DISCUSSION

Droughts were determined by the POT and SPA methods, for two values of threshold flow Q_g ($Q_{70\%}$, $Q_{95\%}$) and 4 minimum drought durations t_{min} (5, 7, 10 and 14 days).

By increasing of the threshold level Q_g, some droughts combine together, and also new ones are observed, thereby the number of droughts increases and their duration and deficit decrease.

NUMBER OF DROUGHTS

In Figure 3 the number of POT and SPA droughts is shown as the relative difference ΔL_n defined by the following formula:

$$\Delta L_n = \frac{L_{SPA} - L_{POT}}{L_{POT}} \tag{1}$$

where $L_{(.)}$ denotes the number of droughts defined by the indexed method.

Figure 3 shows that ΔL_n is always negative for $Q_{70\%}$, and almost always negative for $Q_{95\%}$, which is the consequence of the fact that the number of SPA droughts is almost always less than that calculated by the POT method. The value of ΔL_n increases (in absolute values) with t_{min} reaching as much as 60% for t_{min} equal to 14 days. A change of Q_g from $Q_{70\%}$ to $Q_{95\%}$ results in an upwards shift of the upper limit of ΔL_n values: from about – 0.1 to more than +0.2.

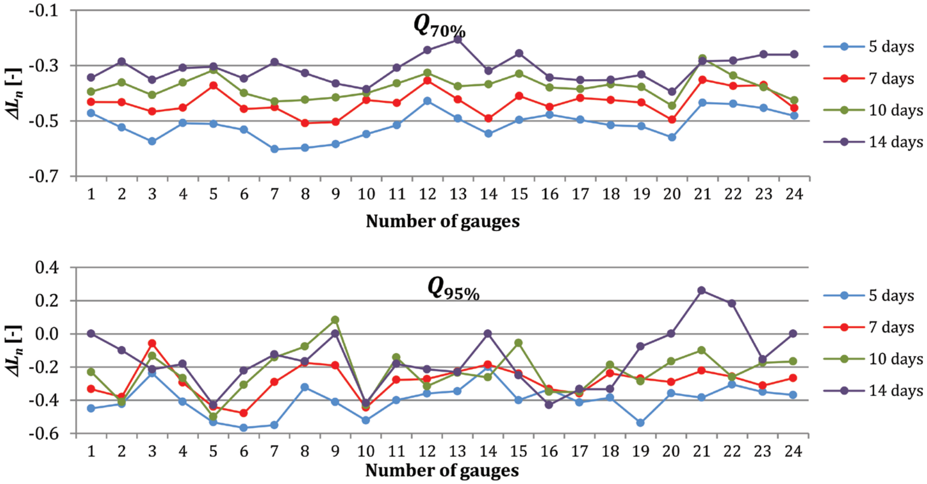


Figure 3. Relative difference ΔL_n in the number of droughts in the Dunajec basin calculated by the SPA and POT methods for t_{min} = 5, 7, 10, 14 days and the two threshold flows.

DROUGHT DURATION

SPA droughts are on average longer than those of POT (Figure 4). The difference in average durations is the result of merging droughts separated by a few days with flow greater than the given threshold level. For example, the average time of drought duration determined by the POT method for $Q_{70\%}$ and t_{min} = 5 days does not exceed 46 days, while of that calculated using the SPA method reaches 80 days. The difference is more pronounced for the greater threshold value.

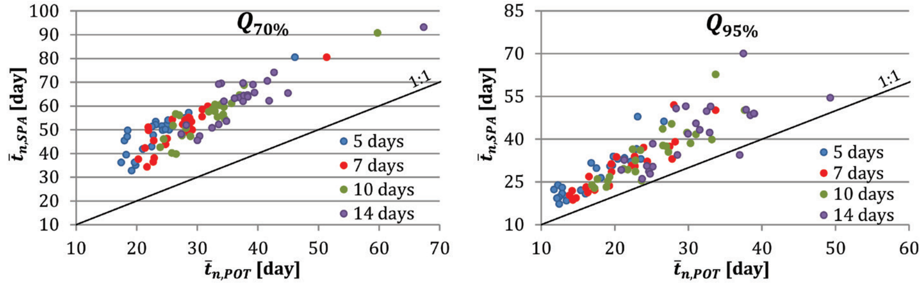


Figure 4. Average drought durations in the catchment of the Dunajec calculated by the POT and SPA for t_{min} = 5, 7, 10, 14 days and the two assumed threshold flows.

Figure 5 illustrates for two gauging stations how the value of t_{min} reduces the 30-year sum of drought durations, Σt_n, expressed as the percentage of the total time T = 10958 days (30 years). Maximum possible value of Σt_n/T is 30% for $Q_g = Q_{70\%}$ and 5% for $Q_g = Q_{95\%}$. For gauge 1, this reduction is rather small and little decreases with increasing value of t_{min}; for gauge 9 this reduction is larger and its dependence on t_{min} is more clear especially for SPA droughts. In general, in all examined cross-sections the SPA approach is less sensitive to the changes of t_{min} than the POT method.

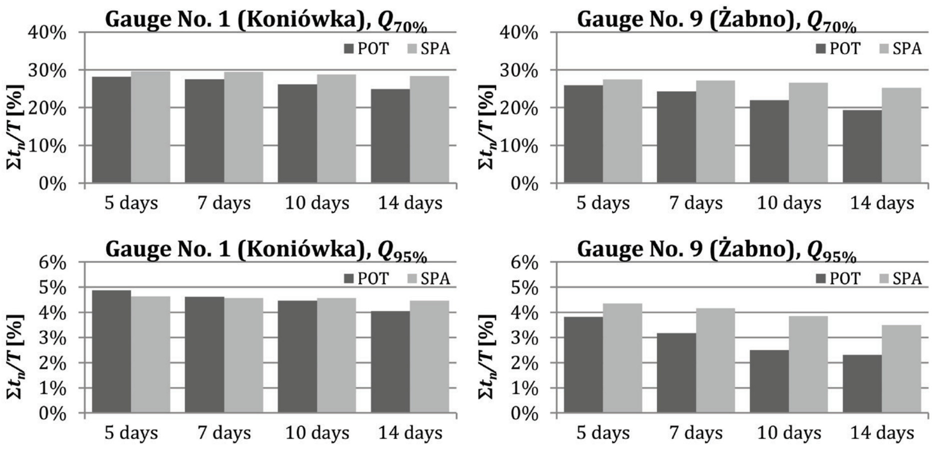


Figure 5. The relative total drought duration $\Sigma t_n/T$ in gauging station no. 1 and 9 on the Dunajec calculated by POT and SPA for t_{min} = 5, 7, 10, 14 days and $Q_g = Q_{70\%}$, $Q_{70\%}$ (*T* is the number of days in a 30-year period)

The question how the value of t_{min} reduces the 30-year sum of drought durations, Σt_n, is again illustrated in Figure 6, this time for all gauging stations, shown as an SPA and POT total drought duration percentage $\Sigma t_n/\Sigma t_g$ of the maximum possible total drought duration Σt_g with flows below the threshold ($\Sigma t_g = 30\% \times 10958$ for $Q_g = Q_{70\%}$ and $\Sigma t_g = 5\% \times 10958$ for $Q_g = Q_{95\%}$). The reduction for POT and SPA increases with increasing values of t_{min} independently of the value of Q_g. However, it is greater for $Q_{95\%}$ and $t_{min} = 14$ days. For $Q_{95\%}$ and t_{min} shorter than 14 days, the amount of reduction is similar for both methods, while for $Q_{70\%}$ this similarity is rarer and the SPA total drought duration is closer to the maximum possible value.

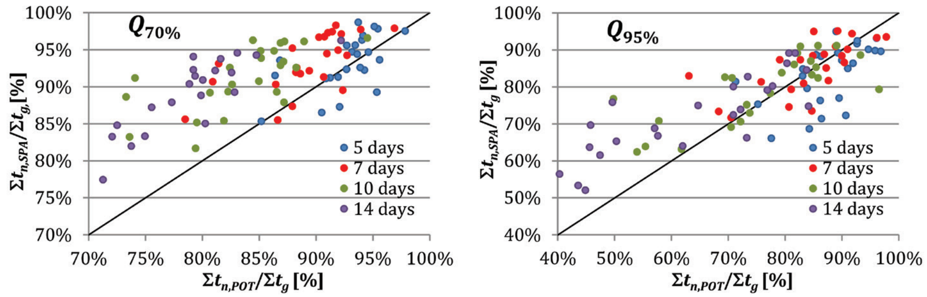


Figure 6. The ratio of actual to maximum total drought duration in the Dunajec catchment calculated by the SPA and POT methods.

DROUGHT DEFICIT

The total drought specific deficits (i.e., deficit divided by catchment area) calculated by the POT method are greater than those obtained of the SPA method. Figure 7 shows how this deficits change depending on Q_g and t_{min}.

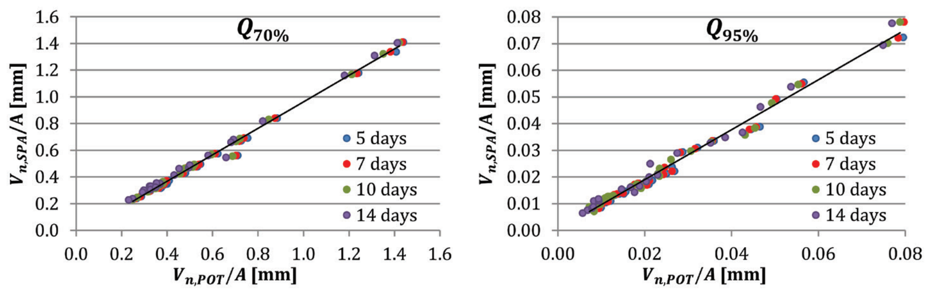


Figure 7. The total specific drought deficits according methods POT and SPA for adopted t_{min} and Q_g values.

INTER-EVENT TIME

The specificity of the SPA method suggests that, differently from the POT method, some shorter inter-event times t_z will be eliminated. To study this, the number of inter-event times t_z for $t_z = 1, 2, \ldots, 14$ days only, and for the adopted values of t_{min} and Q_g were calculated by the POT and SPA methods. In Figures 8 and 9 distribution of inter-event times t_z for SPA and POT is compared for 5 selected gauging stations in the Dunajec catchment.

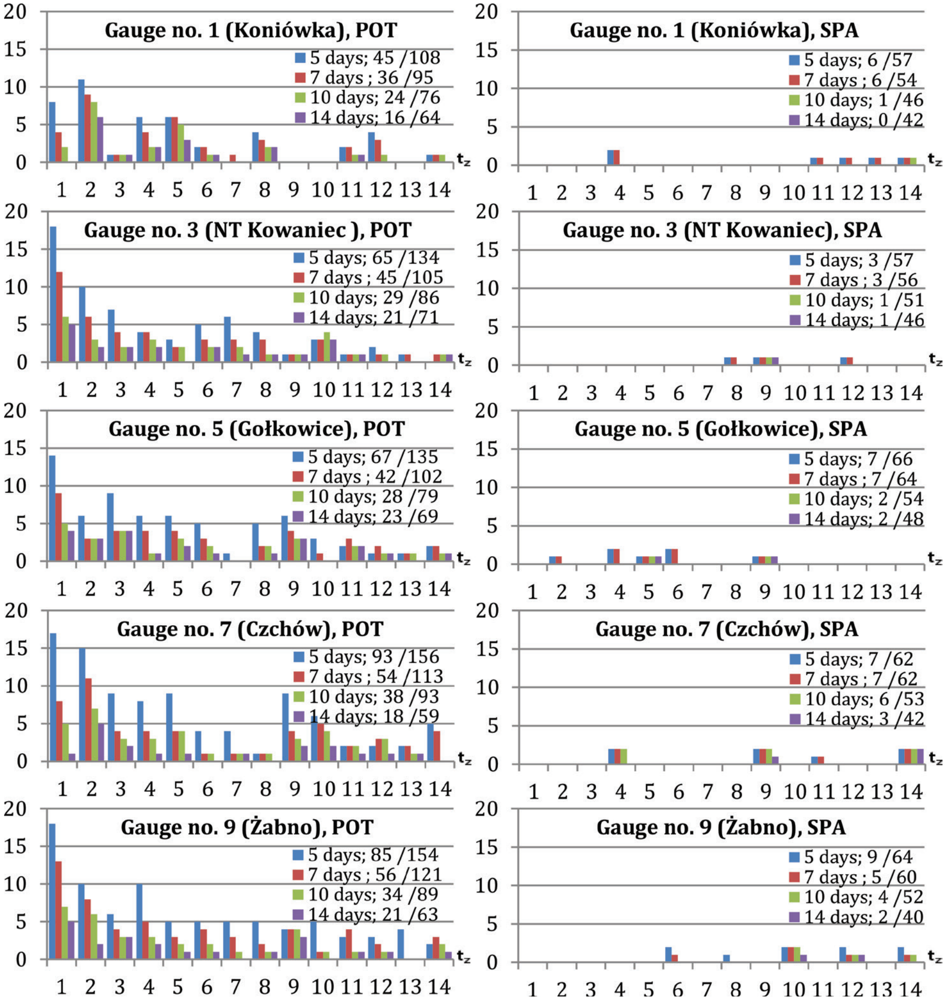


Figure 8. Distribution of inter-event times t_z (in days) for SPA and POT for 5 gauging stations on the Dunajec. The numbers after t_{min} denote the number of $t_z 14 \leq$ days and the total number of t_z.

Figures 8 and 9 show dramatic reduction of short inter-event times for SPA, independently of t_{min} and Q_g. This finding is observed in all gauging stations.

Figure 10 summarizes this difference in the distribution of inter-event times by comparing the areal average number of inter-event times (i.e. calculated using all the 24 gauging stations for t_{min} = 7 days). For all shown t_z's POT number of t_z is greater than the that for the SPA method.

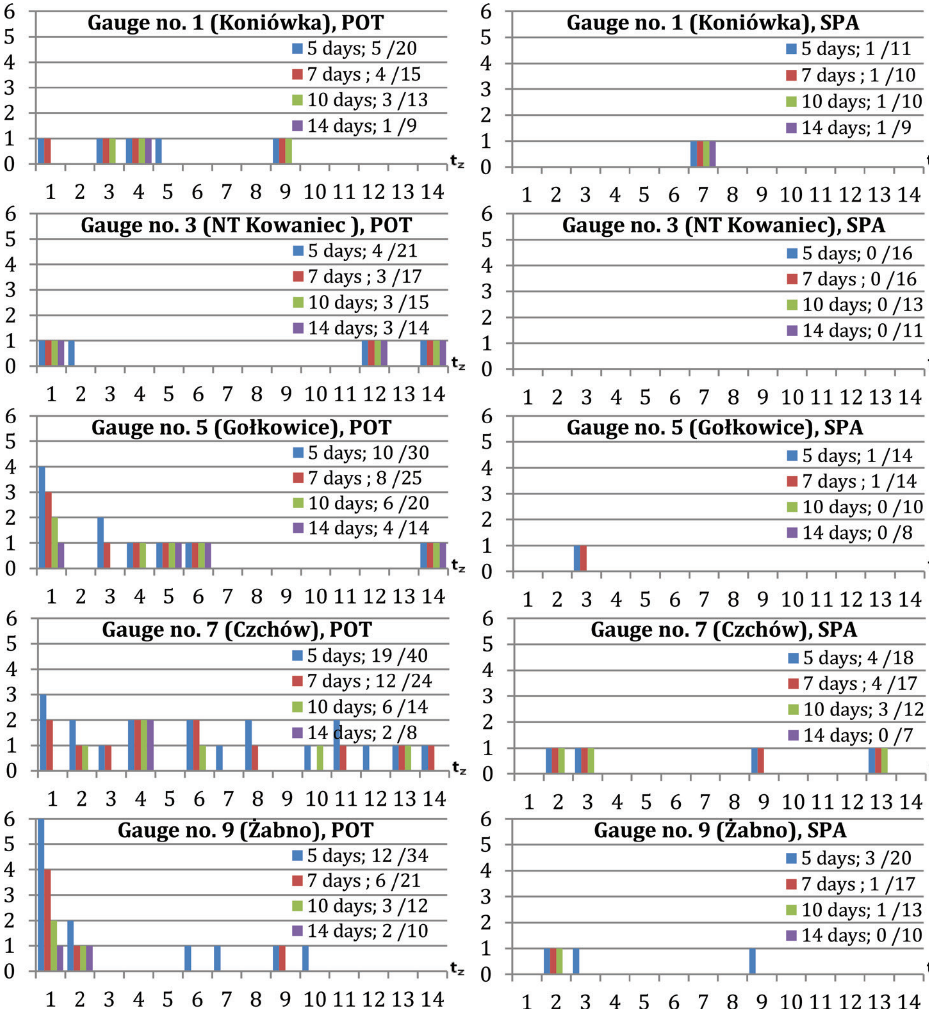
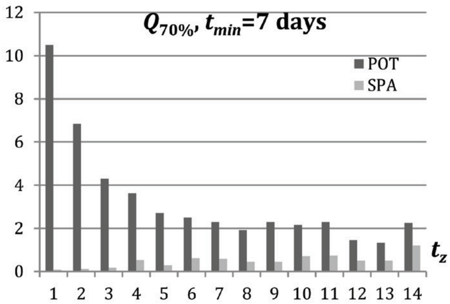


Figure 9. Distribution of inter-event times t_z (in days) for SPA and POT, for 5 gauging stations on the Dunajec. The numbers after t_{min} denote the number of $t_z \leq 14$ days and the total number of t_z.



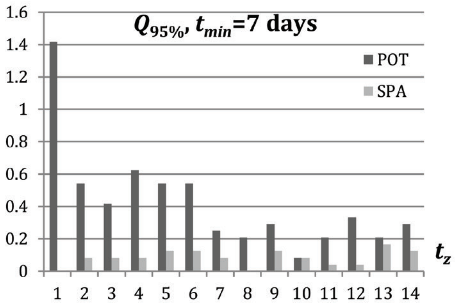


Figure 10. Area average distribution of inter-event times t_z (in days) for SPA and POT, for t_{min} = 7 days (all gauging stations in the Dunajec catchment included).

FINAL REMARKS AND CONCLUSIONS

This paper presents a comparison of drought characteristics at 24 gauging stations in the Dunajec basin defined by two methods: POT and SPA, based on daily flows from the 1984-2013 period, for threshold levels $Q_{70\%}$ and $Q_{95\%}$ and 4 minimum drought duration t_{min} (5, 7, 10 and 14 days). The number of droughts defined by the SPA method is less then that calculated by the POT method and the SPA drought duration is longer. SPA almost eliminates very short (a few-day) time between adjacent droughts. Since the POT method generates many short inter-event times, this might indicate that some droughts should be treated as interdependent and as such should be pooled.

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