SEASONALITY OF SUMMER FLOODS IN SLOVAKIA

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Abstract: The timing and regularity of flood events can be used as a measure of similarity in the hydrological response of a catchment. Seasonality measures of floods are often used as indicators in pooling processes for regional flood frequency analysis. The temporal variability of a flood occurrence is expressed by the mean day of flood occurrence (DQ) and the index of seasonal concentration (r). For the seasonality analysis of summer floods in these study 142 catchments from the whole territory of Slovakia were selected, with a minimum record length of 20 years and a maximum record length of 70 years respectively. The catchment areas varied around 100 km^2. The results of the study indicate regions with a high risk of summer floods and can be used as an aid to decision making concerning flood protection measures in Slovakia.
Key words: seasonality, annual maximum summer floods, small catchments

SEZONALITAETSANALYSE VON SOMMERHOCHWAESSERN

Zusammenfassung: Die Bestimmung der Sezonalitaet der Hochwaesser dient als ein Kennwert der Aehnlichkeit der Eizugsgebiete in der hydrologischen Reaktion auf die Hochwaesser. In dieser Studie wurden die Sezonalitaetscharakteristiken fuer 142 mittlere Einzugsgebiete aus der ganzen Slowakei mit der Flaeche um 100 km^2 und Beobachtungsreihen von 20 bis 70 Jahren bestimmt. Die Resulate der Analyse haben Regionen mit hohem Risikopotenzial der Hochwaesser bestimmt und koennen als Entscheidungsanalyse bei Hochwassermassnahmen dienen.
Schlüsselworte: Sezonalitaet, Sommerhochwaesser, kleine Einzugsgebiete

1. Seasonality measures

The timing and regularity of flood events can be used as a measure of similarity in the hydrological response of a catchment. Seasonality measures of maximum floods are often used as indicators in pooling processes for regional flood frequency analysis.

Directional statistics according to Burn (1997) form a useful basis for defining similarity measures derived from the timing of flood evants. Bayliss & Jones (1993) first applied seasonality measures for catchments in the UK. Approaches following their concept have been used in many studies, e.g., Zrinji & Burn (1995), Burn (1997), Burn, Zrinji & Kowalchuk (1997) to explain similarity (dissimilarity) measures of flood formation and as a parameter for the selection of homogenous pooling groups. The temporal and spatial bimodality of flood events in these studies was expressed by the mean date of flood occurrences (DQ) and their variability measure (index r). *The mean date of flood occurrence (DQ)* belongs among the most frequently used characteristics of seasonality measures. Following Bayliss & Jones (1993) it represents the fictive centre of the occurrence of Q_{max} within a year and the weighted value of all dates of Q_{max} occurrence. Every date of occurrence of annual peak discharges $Q_{max,I}$ is recalculated on the day of the occurrence (DQ_i) as the sum of all the previous days in the same year, including the day of the occurrence. The mean value of 28.25 days in February takes leap years into consideration, so the average year has 365.25 days. DQ_i values range from 1 (January 1) to 365.25 (December 31). The mean date of a Q_{max} occurrence (DQ) is determined as the simple arithmetic mean of the DQ_i values:

$$\overline{DQ} = \frac{\sum_{i=1}^{n} DQ_i}{n} \qquad DQ \in \langle 1;365,25 \rangle \tag{1}$$

The *index of the seasonal concentration (r) of the peak discharges* indicates the distribution of days of flood occurrence within a year. The first step of index r estimation involves the transformation of DQ_i values into an angle

$$\alpha_{DQ} = DQ_i \frac{2\pi}{365,25} \qquad \alpha_{DQ_i} \in \langle 0.98°; °360° \rangle \tag{2}$$

Directed angles α_{DQi} in an anti-clockwise direction in a circle representing a calendar year are depicted. The mean angle α_{DQ} is determined by the arithmetical means of the x- and y-coordinates of $\alpha_{DQi.}$

$$\bar{x} = \frac{1}{n}\sum \cos(\alpha_{DQ_i}) \qquad \bar{y} = \frac{1}{n}\sum \cos(\alpha_{DQ_i}) \tag{3}$$

The corresponding angle is

$$\alpha_{DQ} = \tan^{-1}\left(\frac{\bar{y}}{\bar{x}}\right) \tag{4}$$

This mean angle can then be re-transformed into a date via

$$\overline{DQ} = \alpha_{DQ} \frac{365,25}{2\pi} \tag{5}$$

In addition, a variability measure, index r, of the time of flood occurrences at a station can be defined as

$$\bar{r} = \sqrt{\bar{x}^2 + \bar{y}^2} \qquad r \in \langle 0;1 \rangle$$

(6)

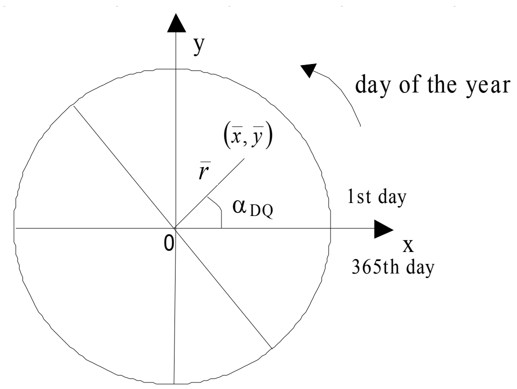


Figure 1. Index of the seasonal concentration (r) of summer floods

Index r values close to 1 indicate strong seasonal behavior, if r=1, all the peak discharges occur on the same day, whereas r values close to zero show the high variability of flood occurrences for the catchment.

Q_{max} occurrence mode (ModQ) is another characteristic of the expression of seasonality, where the month of the most frequent seasonality occurrence of Q_{max} can be identified. The value of ModQ is often used as an additional indicator.

In Merz et al. (1999), the seasonality of peak discharges and precipitation was analysed and the delineation of homogeneous regions for flood frequency estimation in Austrian catchments was performed. The fundamental idea and assumption was that seasonality is linked to flood-related processes. Equal or similar seasonality behaviors leads back to equal or similar flood-inducing mechanisms. The seasonality of annual maximum discharges and the annual maximum value of daily precipitation totals were expressed by the index of seasonal concentration r (applying the above-mentioned procedures). The seasonality of the mean monthly discharge and mean monthly precipitation totals was analysed using the *Pardé coefficient (Pk)*. For a given month *i* is

$$Pk_i = \frac{12}{n}\sum_{j=1}^{n}\left(\frac{Q_{ij}}{\sum_{i=1,12} Q_{ij}}\right) \qquad (7)$$

where Q_{ij} is the mean monthly discharge of month *i* in the year *j* and *n* is the length of the analyzed time series.

Pk values range from 1 (runoff and precipitation uniformly distributed during the year) to 12 (all the mean monthly values of discharge and precipitation occurred in the same month). In the graphic representation every stream-gauge is plotted as one vector (arrow) with the length of the vector proportional to Pk and the direction of the vector representing the month i_{max} when the maximum precipitation or discharge occurred.

Piock-Ellena, et al. (1998) followed the concept of the methodology of Merz et al. (1999). The authors comparised different indicators of the delineation of homogeneous pooling groups in Austria. To identify the homogeneous pooling groups, cluster analysis was used with following pooling characteristics:

- geographical coordinates of streamgauges,
- coefficient of variation (Cv) a coefficient of the skewness (Cs) of the samples,
- seasonality of occurrence of peak discharges expressed by the mean day of flood occurrence DQ_i and its variability measure – index r,
- the seasonality of mean monthly discharge expressed by the Pardé coefficient.

The authors explained that all the above-mentioned procedures for investigation of seasonality have significance in the regionalisation process. They are considered to be more objective and reliable methods than using some traditional or some subjective methods for pooling procedures.

The usefulness of a flood and precipitation seasonality analysis based on *the index of seasonal concentration (r)* and *the mean day of Q_{max} occurrence (DQ)* is also evident in Steinbrich, et al. (2002). Seasonality is assessed as an appropriate indicator in the regionalisation process. The precipitation and peak discharges seasonality investigation was used to determine the main flood-inducing mechanisms and thus identify particular homogeneous regions in the southwest of Germany.

The seasonality of annual peak discharges in Slovakia was analysed by Čunderlík (1999). Two hundred sixty-six catchments with different record length were investigated. Following seasonality characteristics have been tested: *the mean day of Q_{max} occurrence (DQ), the index of seasonal concentration (r) and the mode of Q_{max} occurrence (ModQ).* Each of these derived characteristics refer to a different aspect of Q_{max} seasonality; thus, a common assessment of their spatial variability had to be carried out. As pooling characteristics, the mean day of Q_{max} occurrence and the index of seasonal concentration of Q_{max} have been selected to derive homogenous pooling groups for regional flood frequency analysis.

2. Seasonality analysis of summer floods in Slovakia

For the seasonality analysis, 142 catchments from the whole territory of Slovakia were selected. They had a minimum record length of 20 years and a maximum record length of 70 years respectively. The catchment areas varied around 100 km^2. The annual maximum peak discharges were recorded from two separate seasons, the summer season with rainfall-induced discharges and the winter season with floods originating from rainfall and mixed events. The origin of each event was analysed separately. In this study the analysis concerning annual rainfall floods is presented.

The temporal variability of the floods was expressed by the mean day of the flood occurrence (DQ) and the index of seasonal concentration (r).

Figure 2 shows the classification of catchments into four categories according to the mean values of DQ. DQ values are expressed as a number represented by a calendar date. They range from 122 (May 2) to 214 (August 2), with a mean value of 184 (July 3).

From the analysis we can conclude that the month of the most summer flood occurrences is July (55.6% of all the catchments investigated), followed by June (41.8% of thecatchments). There are about 5.3% catchments with a mean day of summer flood occurrence in May, and only one catchment has a mean day of flood occurrence in August.

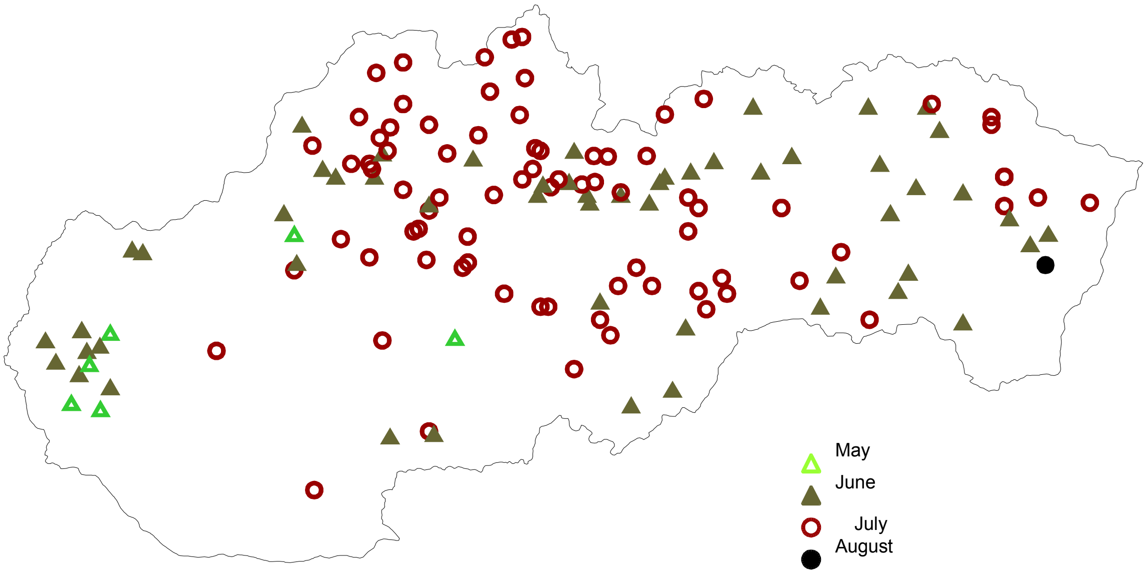


Figure 2. Categorization of catchments according to the mean day values of flood occurrence (DQ)

For catchments in the lowlands, basins and centrally-located catchments of Slovakia, the mean value of DQ is in June. According to the geomorphological classification, they represent a catchment belt of lowlands and hollows in the west and northwest up to the north of Slovakia (the Zahorska lowland, the Povazske Podolie, the Zilina Basin, The Turiec basin and the Podtatranska Basin). In the south there are small catchments of Slana river and Krupinica stream belonging to this category. Many catchments located in the central Slovakia (Beskydy Region, catchments of the Fatra Region, the Tatra Region, the Strazovske Mountains, the Tribec, the volcanic mountains of the Slovenske stredohorie Mts. and catchments of the Slovenske rudohorie Mts.) as well as several catchments of the Laborec Mountains, the Bukov Mountains and the Kosice Basin on the east have a mean day of flood occurrence in July.

Figure 3 shows a spatial interpretation of four categories of the index r. The values of r range within an interval of 0.13 and 0.82, with a mean value of 0.57. The high variability of summer flood occurrences ($r<0.40$) is visible in the catchments of the Vychodoslovenska Lowland, the Slanske Mountains in the east, and the Juhoslovenska Lowland in the south. On the other hand, the catchments of the Orava Region, the Kysuce Region and Javorniky in the northwest of Slovakia as well as the catchments of the Tatra Region on the north, the Spis Region and the Saris Uplands show relatively strong seasonal summer flood occurrences ($r>0.60$).

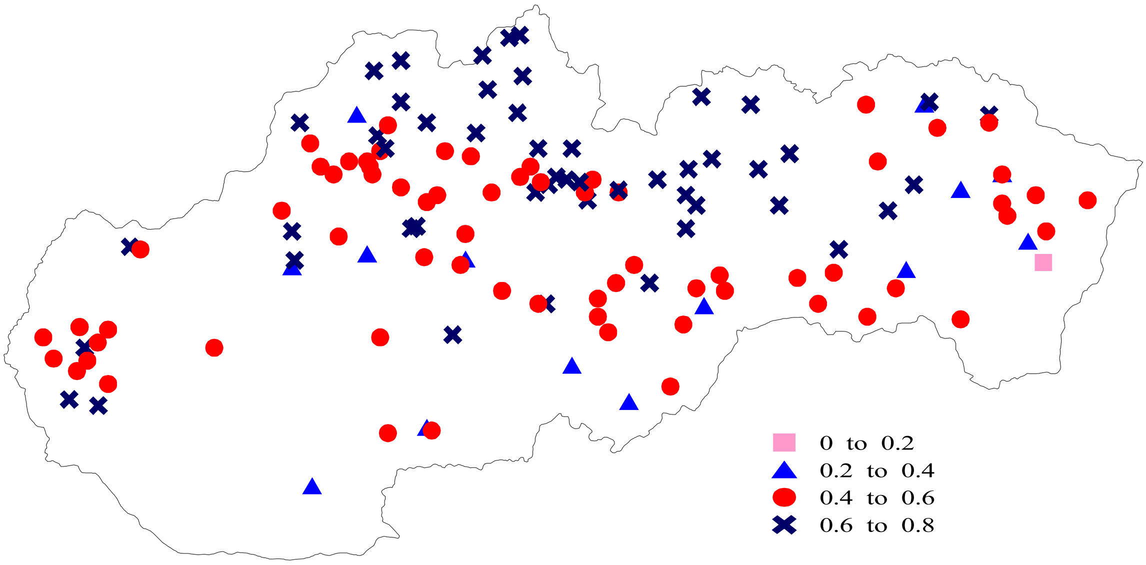
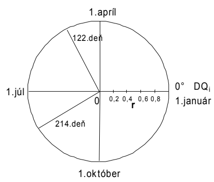


Figure 3. Categorisation of catchments according to the index r values.

Figure 4. Seasonality of Q_{max} expressed by a combination of the mean day of Q_{max} occurrence (DQ) and the index of seasonal concentration (r)

The seasonality of summer floods expressed by the combination of the mean day of flood



occurrence (DQ) and the index of seasonal concentration (r) is demonstrated in Figure 4. The vector length (arrow) is proportional to the index *r* value, and the direction of the vector represents the *DQ* value in α_{DQ} (from 0.98° to 360°) scale. The longest arrows indicate that the Q_{max} occurrence is concentrated in one month. The short arrows indicate a low concentration of Q_{max} occurrence in one month, i.e., the Q_{max} values are spread out over more than one month in the summer season.

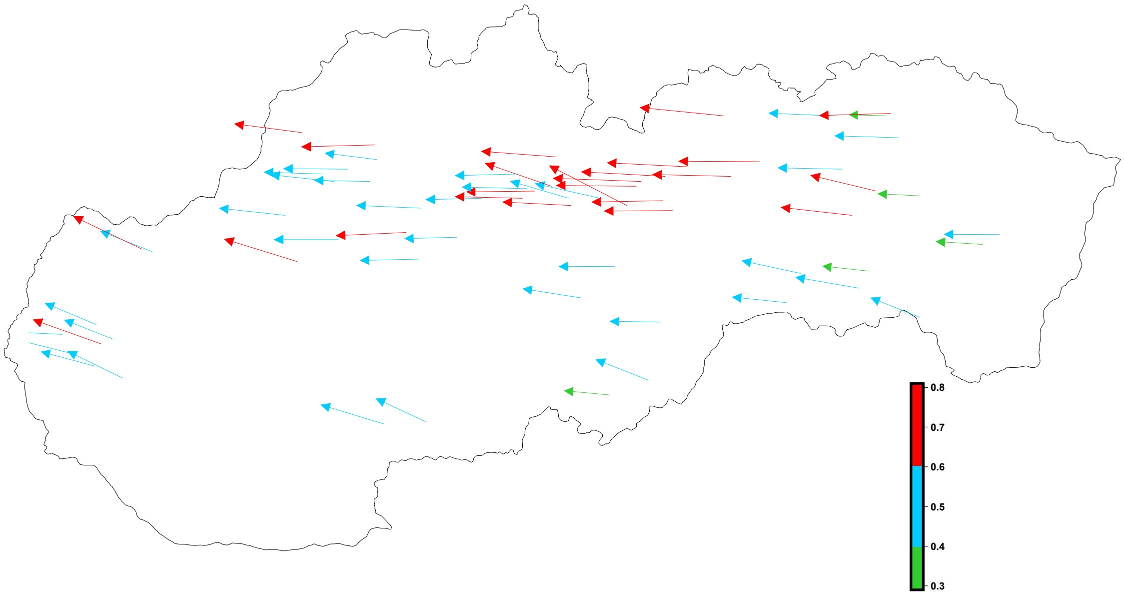


Figure 5. Seasonality of Q_{max} expressed by the mean day of Q_{max} occurrence (DQ) and the index of seasonal concentration (r) for the month of June

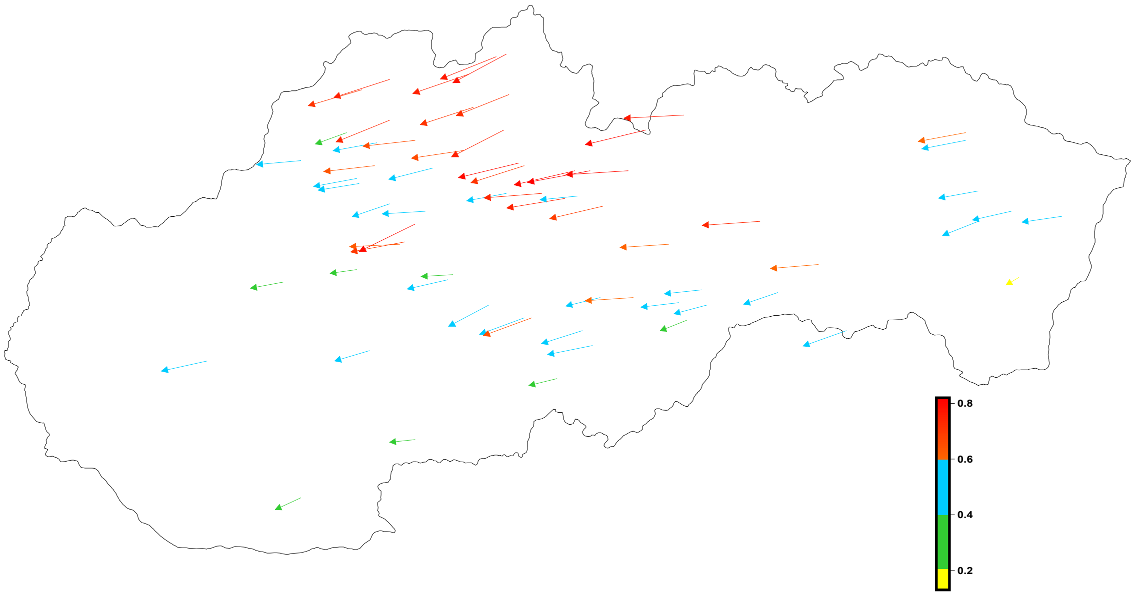


Figure 6. Seasonality of Q_{max} expressed by the mean day of Q_{max} occurrence (DQ) and the index of seasonal concentration (r) for the monthof July

3. Conclusions

According to the analysis of summer flood seasonality in the territory of Slovakia, we can conclude that a majority of the catchments show high potential for summer floods. These catchments are located mainly in the flysch region in the northern part of Slovakia, the Slovenske rudohorie and the Slovenske stredohorie Mts., the Tatra and the Fatra Region, the Spis Region, the Bukov Mountains and the Laborec Mountains. On the other hand, the catchments in the lowlands in the southern and eastern parts of Slovakia are not threatened by summer floods.

A comparison of the occurrence of summer floods in different months in the summer season presented in Figures 5 and 6 shows that the catchments of the western flysch region in the northern part of the country, catchments of the High Tatra Region, the Fatra Region, the Strazovske Mountains and the Slovenske rudohorie Mts. in central Slovakia are threatened by floods in July, whereas the catchments of the Low Tatra Region and the catchments of the west flysch region are mostly affected by summer floods in June. The results of the study indicated regions with a high risk of summer floods and can be used as an aid to decision making concerning flood protection measures.

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