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The Use of a Standardized Runoff Indicator for Hydrological Characterization of Selected Rivers of Poland and Slovakia

Katarzyna Kubiak-Wójcicka[1], Martina Zeleňáková[2], Pavol Purcz[2], Dorota Simovova[3]*

[1]Nicolaus Copernicus University in Toruń, Poland

[2]Technical University of Kosice, Slovakia

[3]Slovak Hydrometeorological Institute, Slovakia

[*]corresponding author's e-mail: kubiak@umk.pl

1. Introduction

Knowlede of the hydrologic regime of rivers comprises the basis for water resources assessment in river basins. For last several years, a number of studies on variability of river runoff under the influence of climate changes (Stahl et al. 2010) and anthropogenic changes have barchieen conducted (Lv et al. 2018). Determination of runoff change trends is remarkably important to strategic management of water resources (Húska et al. 2017). Therefore, numerous studies discuss the issue of uneven distribution throughout the year, in regional extent, caused by seasonality of climatic factors (Parajka et al. 2009). Such research was conducted by Kļaviņš et al. (2008) on the rivers of Latvia, Stonevičius et al. (2014) in Lithuania. The runoff studies on the area of Poland were conducted by Gutry-Korycka & Rotnicka (1998), Michalczyk & Głowacki (2008), Pociask-Karteczka (2011), Jokiel & Stanisławczyk (2012), Gądek & Tokarczuk (2015), Niedzielski & Miziński (2017), Wrzesiński & Sobkowiak (2018), Mostowik et al. (2019). The studies of Pekárová et al. (2006) revealed that the analysis of runoff of main European rivers throughout last 150 years did not indicate significant increasing or decreasing trend. Contrary results have been achieved in small river basins, where the runoff reacts quicker to the changes that take place in the basin, which causes significant changes to the runoff (Song et al. 2012). The assessment of river discharge reaction to precipitation depends on physiographic features of the catchment, among others they are geological structure, fall of the ground, plant cover (Banasik & Hejduk 2012, Osuch et al. 2015, Wałęga et al. 2016, Čanjevac & Orešić 2018, Dunca & Bădăluţă-Minda 2018). Van Loon & Laaha (2015) claim that over 30 factors may be distinguished in a catchment, which may have influence to the river runoff. Interactions between the mentioned factors vary temporally and spatially (Bažatová & Šimková 2015).

The aim of this paper is to investigate how the data collected from 2 selected basins with diverse physically-geographical parameters talks about the frequency of floods and droughts in the last three decades. Two basins have been selected for the case study: lake district basin in Poland (Gwda) and mostly the mountain basin in Slovakia (Laborec). The areas of Poland and Slovakia have been included by Spinoni et al. (2015) in common region of Europe – Eastern Europe. Based on the data regarding discharge and precipitation in the years 1981-2010, there have been analyzed long-term and seasonal trends of runoff changes. On the basis of average monthly precipitation and runoff, the appearance and duration of wet and dry periods as well as their intensity have been compared. The comparison of the results was possible thanks to application of standardized hydrological indices.

Standardized Runoff Index (SRI) was developed on the basis of the Standardized Precipitation Index (SPI) concept for hydrological drought characteristics (Nalbantis & Tsakiris 2009). It is a simple and efficient index of hydrological droughts assessment. It was applied to assessment of dry and wet period forecasts in various climate zones. The proposed approach bases on the assessment of water resources in various hydro-climatic conditions and on determination of various intensity classes of hydrological drought.

2. Study area

Two basins located in Central Europe, which reflect different climate and physio-georaphic conditions, have been selected for the analysis (Table 1). Hydrological characteristics of the rivers Gwda and Laborec have been presented in the Table 2. The River Gwda, located in northern part of Poland, is a 4th order tributary, which flows into the River Noteć. Total length of the river is 139.95 km. Gwda's basin is a lake district basin, built of sands and fluvioglacial gravels, with numerous endorheic depressions and large share of lakes and forests. Forest area (afforestation index) comprises 30% of total area, while lakes area (lake density index) is 2.5% (Kubiak-Wójcicka & Kornaś 2015). Arable area accounts for 44.4 % of the Gwda River basin. The basin represents the agricultural-forest type. The River Laborec is a tributary of Bodrog. It is mostly a mountain river. Its length is 135.5 km. The basin's surface area is 4522 km^2 and is characterized by large river network density (1.01 $km \cdot km^{-2}$). The most important tributaries of Laborec include rivers Uh and Cirocha. The basin is asymmetric, left-side tributaries prevail over the rightside ones. In the basin of River Laborec there are located artificial water reservoirs, which have influence on the discharge of the River Laborec.

Table 1. Physio-geographical parameters of basins of the Rivers Gwda and Laborec

Characteristics	Gwda River	Laborec River
Basin area (km^2)	4947.27	4522.70
Average altitude (m a.s.l.)	128.1	657.5
Forest cover (%)	30	40
Denivelation (m)	160.5	580
River network density (km·km^{-2})	0.31	1.01

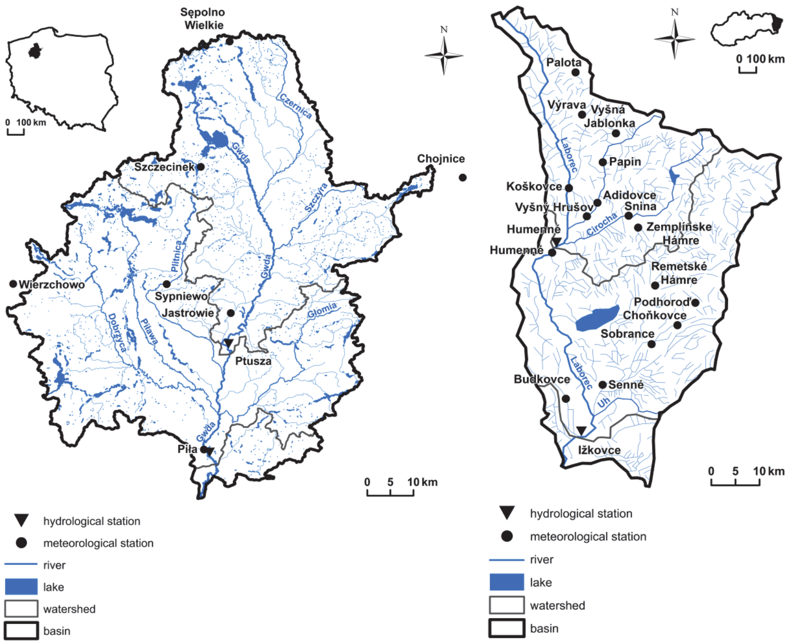


Fig. 1. Study area

Table 2. Hydrological characteristics of the Rivers Gwda and Laborec

River	Gauging station	Basin area in km^2 (% of total area)	Precipitation 1981-2010 (mm)	Average discharge 1981-2010 (m^3·s^{-1})
Gwda	Ptusza	2042.00 (41.3%)	659	11.91
Gwda	Piła	4713.11 (95.3%)	634	27.80
Laborec	Humenne	1321.63 (29.2%)	816	12.74
Laborec	Izkovce	4350.86 (96.2%)	799	51.55

3. Materials and methods

In order to characterize the runoff regime, the data pertaining to discharge and precipitation in basins of Gwda and Laborec was used. On the basis of daily values,there have been calculated the average monthly and average annual values in multiyear period of 1980-2010. The data comes from Institute of Meteorology and Water Management – National Research Institute (data pertaining to Gwda's basin) and from Slovak Hydrometeorological Institute (SHMI) (data pertaining to Laborec's basin).

The runoff in River Gwda basin was analyzed on the basis of the discharge at gauging stations in Piła and Ptusza, and in the River Laborec basin – Izkovce and Humenne. Average monthly and annual precipitation consist of averaged precipitation recorded on several meteorological stations located in particular catchments. The precipitation data for the River Gwda basin come from 7 precipitation stations closing the water gauging station in Piła, while the Ptusza gauging station encloses 5 meteorological stations. In the Laborec river basin there were 16 meteorological stations, while in the Humenne profile there were 10 stations. Location of the stations have been presented on Fig. 1.

The analysis has been focused on the trends of average annual and monthly runoff and on occurrence of dry and wet periods. The 30-year measurement period assumed for the analysis is considered as reliable for creation of a credible characteristics of volume, regime and variability of the runoff (Ljubenkov & Cindrić Kalin 2016). The assumption of the beginning of study at the 1980s is important because that decade is considered a turning point in development of hydro-climatic variables (Blahušiaková & Matoušková, 2015).

Because the basins under analysis are similar in their surface area but different in physio-geographical conditions, the runoff variability has been analyzed with use of the standardized meteorological indices – SPI (Standardized Precipitation Index) (Mc Kee et al. 1993), which are SRI (Standardized Runoff Index) (Shukla & Wood 2008, Lorenzo-Lacruz et al. 2013, Kubiak-Wójcicka &

Bąk 2018). As a normalizing function, a 2-parameter logarithmic function was adopted (Vicente-Serrano et al. 2012). The calculation details have been presented in the work by Bąk & Kubiak-Wójcicka (2017). In order to calculate the SRI values in various time scales (*n* months), it is necessary to use accumulation of discharges for each month and for *n* months. Five different time series have been analyzed: 1, 3, 6, 9 and 12 months. Based on the achieved SRI values, classification of drought intensity has been carried out (Table 3). The main advantage of the SRI index is the fact that it allows for estimation of beginning and end of a drought as well as its intensity. Hydrological drought beginning is assumed when the SRI is less than -1.0 while wet periods – when the SRI > 1.0. The range between -1.0 and 1.0 has been defined as regular.

Table 3. The classification scale for SRI values
(McKee et al. 1993, Bąk & Kubiak-Wójcicka 2017)

SRI value	Category
SRI≥2.0	Extremely wet
2.0>SRI≥1.5	Severely wet
1.5>SRI≥1.0	Moderately wet
1.0>SRI>-1.0	Normal
-1.0≥SRI>-1.5	Moderately dry
-1.5≥SRI>-2.0	Severely dry
SRI≤-2.0	Extremely dry

To understand present and future water resources sustainability and developments, it is necessary to consider the existence of a trend in hydro-meteorological variables. The most common for trend analysis is non-parametric Mann-Kendall (MK) statistical test. The Mann-Kendall test follows statistics based on standard normal distribution (Z), using Eq. (1) (Mann 1945, Kendall 1975).

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if} \quad S < 0 \end{cases} \tag{1}$$

in which,

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{2}$$

where x_j and x_k are data values at times *j* and *k* (*j* > *k*) respectively.

$$\mathrm{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \tag{3}$$

$$\mathrm{Var}(S) = [n(n-1)(2n+5) - \sum_{i=1}^{m} g_i(g_i - 1)(2g_i + 5)]/18 \tag{4}$$

where:
n – the number of data points,
m – the number of tied groups
(a set of g_i of sample data having the same value).

The null hypothesis H0 (no trend) is accepted if $Z<Z_{\alpha/2}$ and rejected (hypothesis H1) if $Z>Z_{\alpha/2}$ where α is the significance level and $Z_{\alpha/2}$ the standard normal distribution for $\alpha/2$. The applications carried out considered α=0.05 and $Z_{\alpha/2}$=1.645. The trend magnitude in time series is expressed by Sen's method (Sen 1968):

$$\beta = \mathrm{Median}\left((x_j - x_k)/(j - k)\right) \tag{5}$$

where:
x_j, x_k – data values at times *j* and *k* ($j > k$) respectively.

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series. Both the MK test and Sen's method require time series to be serially independent, which can be accomplished using the pre-whitening technique. In this paper, the authors used a trend-free pre-whitening method before applying the MK test to detect significant trends (Khaliq et al. 2009).

4. Results and discussion

4.1. Annual precipitation and discharge in the years 1981-2010

Annual precipitation in the Laborec river basin reach on the average approximately 800 mm in the years 1981-2010. In the basin area, the precipitation ranges from 560 to 1020 mm. Maximum precipitation has been recorded in 2010, when it reached approximately 1113 mm. The lowest precipitation has been recorded in 1986 (620 mm). Due to the location of Gwda river basin in a lake district and in a so called rain shadow, annual precipitation is lower when compared to the precipitation in the Laborec river basin by approximately 180 mm. In the Gwda basin area, the precipitation ranges from 550 to 730 mm. The highest values of precipitation have been recorded in 2010 (821.7 mm) and 2007 (808.3 mm), and the lowest – in 1982 (377.4 mm). The amount of precipitation translates into annual average discharge. In the estuarial section of Gwda river in Piła the discharge value on the average was 27.8 $m^3 \cdot s^{-1}$ (specific runoff 5.9 $dm^3 \cdot s^{-1} \cdot km^{-2}$), while for the river Laborec in Izkovce it was 51.55 $m^3 \cdot s^{-1}$ (specific runoff 11.4 $dm^3 \cdot s^{-1} \cdot km^{-2}$).

The trend course analysis reveals statistically significant increase of annual precipitation sum on all the analyzed meteorological stations in the analyzed multi-year period. The results achieved in the Laborec river basin coincide with studies carried out on the area of whole Slovakia (Labudová et al. 2015, Zeleňáková et al. 2017). However, precipitation increase does not imply annual discharge increase on all gauging stations. Only in the river Laborec, weak upturn trend of discharge in gauging station Izkovce, while in gauging station Humenne the trend was upturn but statistically insignificant (less than 0.05). In the Gwda river basin, despite the upturn trend of precipitation, a downturn trend of discharge has been recorded. It was especially noticeable in Piła gauging station, where a statistically significant downturn discharge trend was recorded (Fig. 2-3).

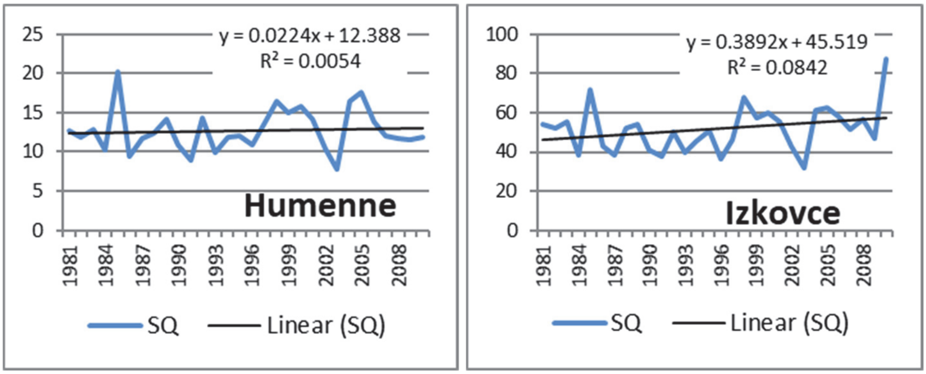
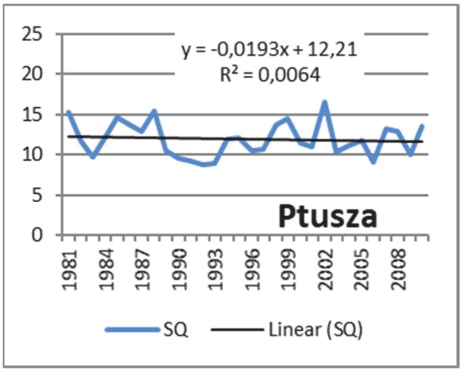


Fig. 2. Average annual discharge (SQ in $m^3 \cdot s^{-1}$) of Laborec at gauging station Humenne and Izkovce in the years 1981-2010

Despite different precipitation and discharge distribution throughout a year, their seasonal distributions in both basins are similar (Table 4). The largest average monthly precipitation occurred in July while largest average monthly discharges were recorded in March and April. In the Gwda river basin, the precipitation in summer months predominated and consisted about 58% of the annual precipitation, while river discharge was higher in winter months and also consisted approximately 58% of the annual discharge. The situation is similar in the Laborec river basin. In the summer months, the precipitation consisted of 60-62% of annual precipitation, while the discharge in winter months was significantly higher than in the case of River Gwda and consisted 64-67% of annual discharge.

The studies of Štefunková et al. (2013) indicated that in long-term periods, average runoff will be decreasing in summer months and increasing trend will appear in winter and early spring periods. It results from air temperature increase and shifting snow thawing from spring to winter months.



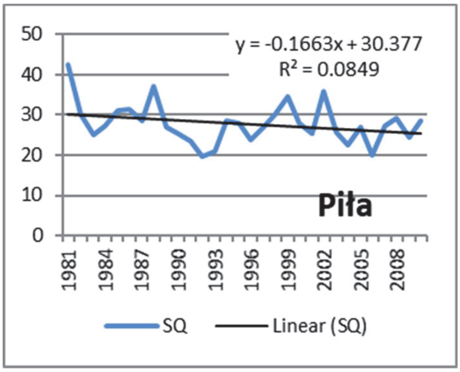


Fig. 3. Average annual discharge (SQ in $m^3 s^{-1}$) of Gwda at gauging station Ptusza and Piła in the years 1981-2010

4.2. Seasonal distribution of precipitation and discharge in the years 1981-2010

Table 4. Precipitation and discharge in the years 1981-2010

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
River Gwda, gauge Ptusza												
P (mm)	49.7	37.3	48.5	37.1	57.2	72.7	**75.4**	72.8	58.1	47.3	50.7	55.5
Qmean(m^3s^{-1})	13.55	14.85	**16.39**	15.00	13.06	11.22	9.71	8.89	9.04	8.91	10.35	11.97
Qmax (m^3s^{-1})	21.38	27.76	**28.31**	20.85	18.91	17.59	14.81	14.43	15.33	13.08	19.14	18.44
Qmin (m^3s^{-1})	9.13	8.92	9.45	**9.50**	7.72	6.81	6.02	5.77	6.01	4.93	6.52	8.14
River Gwda, gauge Piła												
P (mm)	48.2	36.0	47.2	35.0	58.1	67.8	**71.5**	70.1	56.2	43.6	47.7	52.3
Qmean(m^3s^{-1})	32.56	35.12	**38.12**	34.88	28.74	24.05	21.97	21.17	21.57	22.27	24.58	28.83
Qmax (m^3s^{-1})	49.50	63.10	**63.30**	48.80	41.30	39.30	35.90	33.40	34.10	31.20	44.80	40.50
Qmin (m^3s^{-1})	22.40	22.40	**25.20**	21.80	16.50	12.30	11.00	11.00	11.60	12.20	14.30	19.50
River Laborec, gauge Humenne												
P (mm)	46.9	45.1	46.5	56.2	83.2	94.1	**107.2**	83.9	79.8	58.2	56.1	58.7
Qmean(m^3s^{-1})	12.09	14.90	**30.78**	22.17	14.72	9.47	10.35	5.34	5.80	6.57	10.28	13.80
Qmax (m^3s^{-1})	24.77	38.79	**63.17**	59.56	51.06	35.53	33.93	15.52	18.58	19.99	31.20	37.53
Qmin (m^3s^{-1})	1.35	2.75	**11.00**	5.53	3.83	2.66	1.74	1.14	1.61	1.41	1.84	1.21
River Laborec, gauge Izkovce												
P (mm)	49.0	45.5	45.7	55.3	81.3	89.2	**98.3**	79.8	75.7	58.6	58.3	62.1
Qmean(m^3s^{-1})	49.44	55.43	**98.10**	90.75	56.54	39.32	36.69	29.58	29.45	33.28	45.08	54.95
Qmax (m^3s^{-1})	106.88	146.77	185.72	**230.05**	178.98	169.57	82.40	66.54	48.93	90.26	123.04	169.13
Qmin (m^3s^{-1})	8.50	19.84	**26.88**	26.06	13.73	16.88	14.98	13.66	11.98	18.49	10.06	7.08

The course of average monthly discharges of Gwda and Laborec is balanced over a year with maximum occurring usually in March or April and minimum in Spetember or October. The years, in which the highest and the lowest annual average discharge values were recorded, the seasonal distribution changed. In case of the River Laborec, the most wet year was 2010, which had 2 high river flows – in June and December – caused by heavy precipitation (Fig.

4). The lowest annual discharge was recorded in 2003, in which a single maximum, related to spring thaw, occurred in April. The highest discharges of the analyzed period in River Gwda basin took place in 1981 and the lowest – in 1992. In wet year 1981, 2 high river flows were recorded: in March and November, while in 1992 just one – in April (Fig. 5).

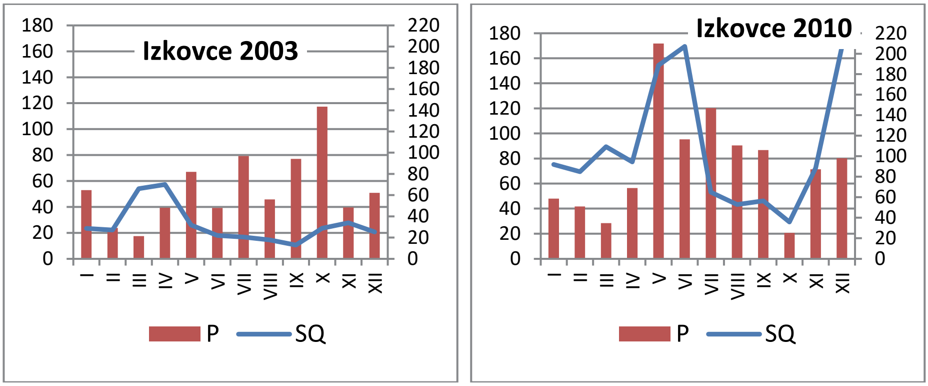


Fig. 4. The course of average monthly discharge (SQ in $m^3 s^{-1}$) of River Laborec at gauging station Izkovce in dry year 2003 and wet year 2010 against precipitation (P in mm)

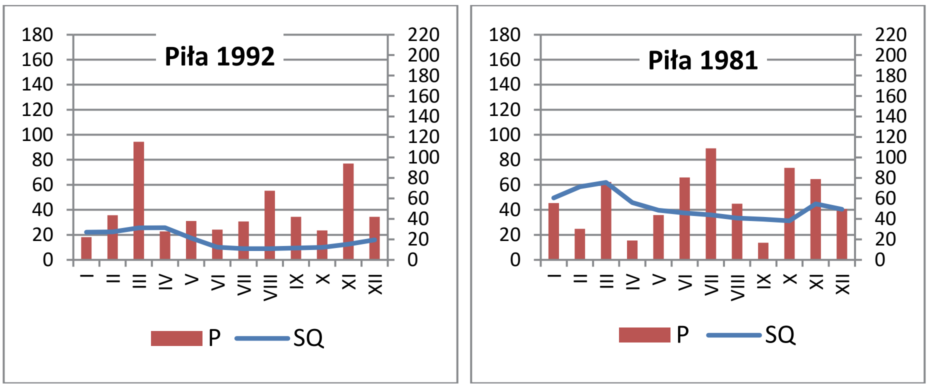


Fig. 5. The course of average monthly discharge (SQ in $m^3 s^{-1}$) of River Gwda at gauging station Piła in dry year 1992 and wet year 1981 against precipitation (P in mm)

4.3. Standardized Runoff Index (SRI) utilization in hydrological analyses

The analysis of course and occurrence of wet and dry periods in the basins being discussed is possible with use of the Standardized Runoff Index. The course of the SRI's values in particular months has been presented in various time scales on 2 gauging stations. The highest amplitude of the SRI value has been achieved in the case of 1-month interval and at gauging station Izkovce it was 6.35, Piła – 5.31. Based on the SRI values there can be identified periods of occurrence of wet and dry months.

The frequency of dry and wet periods' occurrence in the basin of River Laborec is significantly higher than in the case of River Gwda. It results from higher susceptibility of the basin to course of precipitation. River Gwda basin is much more hydrologically inert and does not react that suddenly to precipitation volume. The SRI index has been presented on the basis of the following parameters: number of months (duration of drought/wetness in months) and maximum intensity, in Tables 5-6.

Table 5. Parameters of the SRI in various time scales for River Gwda at gauging station Ptusza and Piła

	SRI-1	SRI-3	SRI-6	SRI-9	SRI-12
Ptusza					
Number of wet months (SRI>1.0)	62	64	62	66	76
Number of dry months (SRI<-1.0)	62	61	74	75	65
Index maximum value	2.44 (II 2002)	2.25 (IV 2002)	2.05 (VII 2002)	2.05 (III 1981)	1.93 (XII 2002)
Index minimum value	-2.68 (V 1993)	-2.36 (VI 1993)	-2.11 (VIII 1993)	-1.99 (VI 1993)	-2.11 (VI 1993)
Piła					
Number of wet months (SRI>1.0)	57	58	56	64	67
Number of dry months (SRI<-1.0)	62	55	51	47	45
Index maximum value	2.57 (II 2002)	2.31 (II 1981)	2.24 (IV 1981)	2.40 (IX 1981)	2.55 (XI 1981)
Index minimum value	-2.74 (VII 1992)	-2.73 (VII 1992)	-2.60 (XI 1992)	-2.28 (I 1993)	-2.34 (V 1993)

Table 6. Parameters of the SRI in various time scales for River Laborec at gauging station Humenne and Izkovce

	SRI-1	SRI-3	SRI-6	SRI-9	SRI-12
Humenne					
Number of wet months (SRI>1.0)	64	59	57	47	54
Number of dry months (SRI<-1.0)	61	63	59	59	59
Index maximum value	2.54 (VI 2010)	2.16 (VII 2010)	2.32 (X 2010)	2.32 (XII 2010)	2.35 (III 1981)
Index minimum value	-3.05 (XII 1986)	-3.41 (I 1987)	-3.16 (I 1987)	-3.00 (IV 1984)	-2.80 (V 1984)
Izkovce					
Number of wet months (SRI>1.0)	59	62	57	56	56
Number of dry months (SRI<-1.0)	44	53	56	61	63
Index maximum value	3.48 (VI 2010)	2.63 (X 1998)	2.53 (X 2010)	2.64 (XII2010)	2.48 (XII2010)
Index minimum value	-2.87 (I 1987)	-3.34 (I 1987)	-2.76 (II 1987)	-2.65 (V 1984)	-2.44 (V 1984)

Maximum value of the SRI index recorded at gauging station Ptusza is lower than that recorded at the station Piła. That may be caused by water retention in the basins located by the hydropower plants. In case of River Laborec, maximum values of the SRI index are higher at the station Izkovce than Humenne. Possible cause is River Uh estuary which is located close to the gauging station Izkovce. Hydrological droughts are more gentle at gauging station Izkovce than at gauging station Humenne. The delay is approximately 1 month. During the wet periods, drought intensity is also higher at gauging station Izkovce than at Humenne. Duration of dry periods extends and the number of wet months stabilizes. Frequency of dry and wet periods' occurrence is higher in case of the mountain river than the lake district one. The lowest SRI values for River Gwda were recoded in 1992, which is related to the one of the lowest precipitation throughout the analyzed period (481 mm) and low precipitation in the preceeding year 1991 (553 mm). The highest values of the SRI for River Laborec were in 2010, in which annual precipitation sum in the basin was the highest over the analyzed period and its value was 1113 mm. The lowest SRI values were recorded in 1987 – annual precipitation sums were 771 mm – and it was preceeded by the year 1986 with the lowest recorded precipitation sum of 620 mm. The share of particular drought classes in River Laborec and River Gwda basins varies. Noteworthy is higher frequency of extremely wet months (SRI >=2.0) and extremely dry months in the basin of River Laborec. Moreover, there are the years in which in the River Laborec basin the extremely wet and extremely dry periods occur simultaneously at the same year, e.g. 2007. Normal years (-1.0<SRI<1.0) in the estuarial parts of both rivers comprise approximately 67-71% of the analyzed period.

Table 7. Monthly trend analysis of discharge in the years 1981-2010

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
River Gwda, gauge Ptusza												
Z	-0.1779	0.0593	0.2075	0.2965	-0.1779	-0.4447	-0.9191	0.2372	0.0296	0.2075	0.1779	0.3558
β	-0.0193	0.0078	0.0110	0.0193	-0.0072	-0.0181	-0.0316	0.0127	0.0007	0.0065	0.0177	0.0186
River Gwda, gauge Piła												
Z	-0.6226	0.7412	0.0889	0.0593	-0.0889	-0.7116	-1.5121	**-2.2533**	**-1.7493**	-1.3935	-1.4528	-1.4824
β	-0.0683	0.0696	0.0037	0.0044	-0.0210	-0.0894	-0.1398	**-0.2501**	**-0.1733**	-0.1204	-0.1432	-0.1324
River Laborec, gauge Humenne												
Z	1.3342	0.7709	-1.0081	0.2286	-0.3261	-0.1186	0.6523	0.7412	-0.2668	-0.8302	-0.2668	-0.4744
β	0.1383	0.1307	-0.3098	0.0168	-0.0319	-0.0186	0.0421	0.0590	-0.0140	-0.0393	-0.0169	-0.0702
River Laborec, gauge Izkovce												
Z	1.1613	0.6774	0.0968	-0.5565	-0.7258	-1.0645	-1.4758	-0.0000	-1.3548	-1.3065	0.9194	-0.2419
β	0.3064	0.2908	0.0409	-0.4087	-0.3070	-0.2455	-0.2011	-0.0032	-0.2067	-0.1927	0.2277	-0.1024

*bold values in grey mean significant trend

Tables 7 and 8 summarize the results from the trend analysis based on the Mann-Kendall non-parametric statistical test for a critical probability level of 5% coupled with the Sen approach applied to the discharge datasets. The results of trend analysis show mainly decreasing trends of discharges in evaluated gauges. Significant decreasing trends were proved in Ptusza station at River Gwda in Poland and in Izkovce station at River Laborec in Slovakia. These decreasing trends are obvious mainly in summer months (August and September). The obtained values are usually not statistically significant.

Table 8. Trend analysis of discharge in summer and winter months

Station	winter (I-III, X-XII)	summer (IV-IX)	year (I-XII)
River Gwda, gauge Ptusza			
Z	0.4216	-0.8299	-0.3899
β	0.0018	-0.0032	-0.0006
River Gwda, gauge Piła			
Z	-1.3449	**-2.0938**	**-2.3404**
β	-0.0113	**-0.0214**	**-0.0081**
River Laborec, gauge Humenne			
Z	0.4257	-0.0728	0.2845
β	0.0042	-0.0005	0.0008
River Laborec, gauge Izkovce			
Z	0.6366	**-2.2039**	-1.0156
β	0.0174	**-0.0393**	-0.0080

*bold values in grey mean significant trend

5. Conclusions

The periods of drought and flood occurrence overlap with other authors' studies for the analyzed basins. The slow rise in air temperature had been lasting since the mid-nineteenth century. At the turn of the 1980s and 1990s, an intensive increase in air temperature and reduction of precipitation started, which contributed to the formation of droughts (Żmudzka 2009). Those droughts were reflected not only in Poland but also throughout Central and Eastern Europe (Kliment & Matoušková 2008, Spinoni et al. 2015, Somorowska 2016). In the basin of River Laborec, droughts were occurring much more often than in the River Gwda basin at the same time. The strongest droughts in the River Laborec basin occurred in 1987 in shorter cumulation periods (SRI-1, 3 and 6) and in 1984 in longer cumulation periods (SRI-9 and 12). What is worth of mentioning, is an intense hydrological drought in 2003, which occurred in both short (SRI-1) and in long (SRI-12) cumulation period. That drought was also recorded by Fendeková et al. (2018) in other Slovak river basins. In the River Gwda basin, the strongest droughts occurred in 1992 (SRI-1, 3, and 6) and in 1993 (SRI-9 and 12). Year 2010 in most of the area of Europe, was an extremely wet year. Large precipitation which took place in May and June resulted in floods in both Poland and Slovakia (Bissolli et al. 2011, Kundzewicz 2012). In 2010 in the Gwda River basin, the precipitation was one of the largest in the analyzed multi-year period. However, it did not result in an increased river discharge (Kubiak-Wójcicka & Kornaś, 2015).

The study of influence of selected river basin parameters on river runoff has been conducted in 2 river basins in the area of Poland and Slovakia. The influence, in the analyzed river basins, depends on precipitation. The index method (SRI) that was applied, allowed for relatively simple identification and, at the same time, assessment of drought intensity in appropriate classes.

In order to assess runoff variability, there was used the SRI index (Standardized Runoff Index), which was calculated in several time scales, i.e. 1, 3, 6, 9 and 12 months. The analysis of drought duration and intensity with the SRI index in short time intervals revealed that hydrological droughts (SRI<-1.0) on River Gwda were longer and less intensive than in the case of River Laborec, in which hydrological droghts were shorter and more intensive. Duration of wet periods (SRI>1.0) was similar in case of both rivers, however, the phenomenon intensity was higher in the mountain river. The analysis of longer cumulation periods revealed that for River Gwda, wet periods extended while hydrological drought periods' duration decreased. In case of River Laborec, wet periods slightly shortened, while drought periods got significantly longer. The trend analysis of discharges proved significant decreasing trends, which can be a sign of drought hazard in the end of summer period.

Hydrological droughts in River Laborec basin occurred more frequently but were brief and more intensive than in case of River Gwda. River Laborec is characterized with higher sensitivity of water downflow than the basin of River Gwda, which is considerably inert to precipitation.

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Abstract

This study compares river discharge of two catchments in Central Europe. The catchments' areas are similar while their geological structure differs significantly. The River Laborec (Slovakia) is an example of a mountain river, draining hardly permeable land. The River Gwda (Poland) is a lowland river, draining mainly sandy formations. The study used average monthly flows in the period of 1980-2010 measured on water gauges Humenne and Izkovce on the river Laborec and water gauges Piła and Ptusza on the river Gwda.

The aim of the study is a review of hydrological drought course in two catchments that differ in their structure. The analysis was conducted on the basis of the SRI (Standardized Runoff Index), which was calculated in various time scales, i.e. 1, 3, 6, 9 and 12 months. It is a dimensionless index, which allows determination and comparison of dry and wet periods for rivers in various regions. The analysis of duration and intensity of the SRI in short time periods revealed that hydrological droughts on the river Gwda lasted longer and were less intense than in case of river Laborec. The duration of the wet periods (SRI > 1.0) was similar on both rivers, however the phenomenon intensity was higher on the mountain river. The analysis of longer accumulation periods revealed that on the river Gwda wet periods got longer, while hydrological drought periods were shortened. In case of the river Laborec, wet periods were slightly shortened, while drought periods have extended significantly.

Keywords:
discharge, hydrological drought, Standardized Runoff Index (SRI), Poland, Slovakia

Wykorzystanie znormalizowanego wskaźnika odpływu do charakterystyki hydrologicznej wybranych rzek Polski i Słowacji

Streszczenie

W niniejszym opracowaniu porównano odpływ rzeczny w 2 zlewniach centralnej Europy o podobnej powierzchni zlewni i zróżnicowanej budowie geologicznej. Rzeka Laborec (Słowacja) jest przykładem rzeki górskiej, odwadniającej tereny trudno przepuszczalne, natomiast rzeka Gwda (Polska) reprezentuje zlewnie pojezierną, zbudowaną głównie z utworów piaszczystych. W opracowaniu wykorzystano średnie miesięczne wartości przepływów w okresie 1980-2010 na posterunkach wodowskazowych Humenne i Izkovce na rzece Laborec oraz Piła i Ptusza na rzece Gwdzie.

Celem niniejszego opracowania jest ocena przebiegu suszy hydrologicznej w dwóch zlewniach o zróżnicowanej budowie. Analizę przeprowadzono w oparciu o wskaźnik SRI (Standardized Runoff Index), który obliczono w różnych skalach czasowych tj. 1, 3, 6, 9 i 12 miesięcy. Jest to bezwymiarowy wskaźnik, który umożliwia wyznaczenie i porównanie okresów suchych i mokrych dla rzek z różnych regionów. Analiza czasu trwania i intensywności wskaźnika SRI w krótkich skalach czasowych wykazała, że susze hydrologiczne (SRI < -1.0) na rzece Gwdzie trwały dłużej i charakteryzowały się mniejszą intensywnością niż w przypadku rzeki Laborec. Czas trwania okresów wilgotnych (SRI > 1.0) był podobny w obu rzekach, jednak większą intensywność zjawiska notowano w rzece górskiej. Analiza dłuższych okresów kumulowania wykazała, że dla Gwdy okresy wilgotne uległy wydłużeniu, natomiast skróceniu uległy okresy suszy hydrologicznej. W przypadku rzeki Laborec okresy wilgotne uległy niewielkiemu skróceniu, natomiast okresy suszy zdecydowanie uległy wydłużeniu.

Słowa kluczowe:
przepływ, susze hydrologiczne, Standaryzowany Wskaźnik Odpływu (SRI), Polska, Słowacja