INFLUENCE OF HYDROLOGICAL DROUGHT ON SURFACE WATER AND GROUNDWATER QUANTITATIVE AND QUALITATIVE PARAMETERS IN THE TORYSA RIVER CATCHMENT, EASTERN SLOVAKIA

WPŁYW SUSZY HYDROLOGICZNEJ NA PARAMETRY ILOŚCIOWE I JAKOŚCIOWE WÓD POWIERZCHNIOWYCH I PODZIEMNYCH W ZLEWNI TORYSY, WSCHODNIA SŁOWACJA

MIRIAM FENDEKOVÁ[1], RENÁTA FĽAKOVA[1], VALÉRIA SLIVOVÁ[2], ZLATICA ŽENIŠOVÁ[1], PETER ŠKODA[2], BEÁTA DEMETEROVÁ[2], MARIÁN FENDEK[1], JÁN GAVURNÍK[2], PETER NÉMETHY[1], DAVID KRČMÁŘ[1]

Abstract. Surface water and groundwater quantitative and qualitative parameters depend on many factors, among which the climatic conditions and human influence play an important role. Hydrological drought affects first the surface water and with a certain time-lag also the groundwater. Human influence affects both the quantitative and qualitative properties. Hydrological drought in surface water and groundwater in the area of the upper Torysa River catchment was derived using the threshold level method for streamflow and baseflow values. Baseflow values were calculated using the local minimum method. In the end, number of surface water and groundwater drought periods was compared stressing the length of the drought period and time shift between the starting dates. Changes in chemical composition of surface and groundwater during drought periods were studied and analysed.

Key words: hydrological drought, changes in water quantity and quality, baseflow of river.

Abstrakt. Parametry ilościowe i jakościowe wód powierzchniowych i podziemnych zależą od wielu czynników, spośród których ważną rolę odgrywają warunki klimatyczne i działalność człowieka. Susza meteorologiczna początkowo oddziaływuje na wody powierzchniowe, a po pewnym czasie również na wody podziemne. Działalność człowieka wpływa zarówno na jakościowe, jak i ilościowe cechy wód. Susza hydrologiczna w wodach powierzchniowych i podziemnych w zlewni górnej Torysy została określona metodą poziomu progowego dla przepływu bazowego i przepływu całkowitego. Wartości przepływu bazowego obliczono metodą lokalnych minimów. Ostatecznie, liczba okresów suszy dla wód powierzchniowych i podziemnych została wyznaczona przez kompresję okresów suszy w ruchomych interwałach czasowych. Przeprowadzone analizy i prace studialne wykazały zmiany składu chemicznego wód w okresach suszy.

Slowa kluczowe: susza hydrologiczna, zmiany jakościowe i ilościowe wód, przepływ bazowy rzeki.

INTRODUCTION

Changes in hydrological balance elements were documented in the last 25 years in the majority of the Slovak catchments (Szolgay *et al*., 1997; Pekárová and Szolgay, ed., 2005). The most serious affecting was documented for discharge values on surface streams and for spring's yield in the southern, eastern and southeastern part of Slovakia, because of the air temperature and consequently potential evapotranspiration increase. In these areas, the yearly amount of

[1] Department of Hydrogeology, Faculty of Natural Sciences, Comenius University, Pavilon G, Mlynska dolina, 842 15 Bratislava, Slovakia
[2] Slovak Hydrometeorological Institute, Jeséniova 17, Bratislava, Slovakia

precipitation is quite low; reaching from 500 mm up to 700 mm. The situation could be quite complicated in areas, which, because of hydrogeological conditions, are not able to store and release sufficient amounts of groundwater to be used for water supply. Combination of the climatic and hydrogeological factors with groundwater abstraction can make the situation even worse (Patschová *et al*., 2001). One of the areas, suffering by the lack of water, is the area of the Eastern Slovakia. Geologically it is built of Tertiary sediments (Paleogene flysch sediments, Neogene volcanic and Neogene sedimentary rocks with prevailing of soft grained materials) covered by not very thick layers of Quaternary alluvial sediments, reaching in the upper and middle parts of the streams from 5 up to 15 m. In these areas, there are wells drilled into the alluvial deposits to solve the problem with drinking water supply. When groundwater sources are insufficient, the surface water reservoirs are built and operated. Therefore it is necessary to devote more attention to surface and groundwater drought evaluation.

The latest research in the Department of Hydrogeology is oriented on drought occurrence study, especially on groundwater drought study within the APVV -0335-06 project. Methods of surface and groundwater drought evaluation were proposed by Slivova (2008) and by Fendekova (in van Lanen *et al*., 2008).

The aim of the study was to propose the methods for surface and groundwater drought evaluation and apply it on the study area in the upper Torysa River basin, taking into account the differences in groundwater drought occurrence studying the spatial distribution of drought.

METHODS AND DATA

The proposed procedure of surface and groundwater drought evaluation consists in several steps. As the first one, occurrence of meteorological drought, expressed by different index methods is evaluated. The second step includes assessment of streamflow discharges, consisting in a basic statistical evaluation, time series analysis. The special attention is devoted to assessment of periods with low flows occurrence. In the third step, baseflow is separated from the streamflow values using different methods in order to be able to analyze the groundwater drought. At the same time, groundwater levels in meters above the sea level (m a.s.l.) are analyzed in the same way as streamflow discharges. The next step enables to define the surface and groundwater drought occurrence. In the end, changes in chemical composition and physical parameters of surface and groundwater during the drought periods are described.

Method of the rain factor according to Lang, assessment of the humidity of year (Majercakova *et al*., 2007) and the Standard Precipitation Index – SPI (McKee *et al*., 1993) are proposed to be used for meteorological drought occurrence assessment.

The occurrence of the drought periods in discharges is proposed to be studied using the parameters of the flow duration curve (FDC). It displays for all observed discharge values the percentage of time or number of days during which the equal or higher discharge values are observed. The FDC are constructed for each year of the evaluated period and then the master curve (average FDC) is constructed. Selected $Q_{x\%}$ or Q_{Mday} values could be further used as values indicating the occurrence of drought in discharges in the threshold level method. The threshold level is a limit value under which the drought occurs. The value of $Q_{90\%}$ which is approximately equal to Q_{330} is recommended to be used as a threshold level value for surface and groundwater drought assessment (Tallaksen and van Lanen, ed., 2004). The same procedure could be applied on baseflow values and groundwater levels indicating occurrence of groundwater drought.

The baseflow or groundwater runoff value is very important input value in the process of groundwater usable amounts estimation. Groundwaters are almost exclusively reserved for drinking water supply in Slovakia (Water act No. 364/2004). Groundwater outflow value changes with the change in basic climatic parameters (air temperature, precipitation amount, evapotranspiration). The local minimum method (Institute of Hydrology, 1980), revised by Morawietz (in Tallaksen and van Lanen, ed., 2004) was used for the baseflow separation. Baseflow values in a daily step were obtained using BFI model (5-days blocks moving averages) applied on the daily discharge time series.

Surface and groundwater droughts were proposed to be classified using the length of the drought period (see Table 1) during which the discharge, baseflow or groundwater level values are lower than the threshold level value.

Tabular and graphical assessment of drought duration and severity complemented the quantitative assessment of surface and groundwater drought. In the end, drought occurrence periods were evaluated on the base of chemical composition and physical properties of groundwater.

As the input data, discharges in two gauging profiles NiŽne Repaše and Brezovica nad Torysou were used.

Table 1

Drought classification

Klasyfikacja suszy

Length of the drought period in days	Drought classification
>100	Extreme drought (ED)
51–100	Large drought (LD)
10–50	Drought (D)

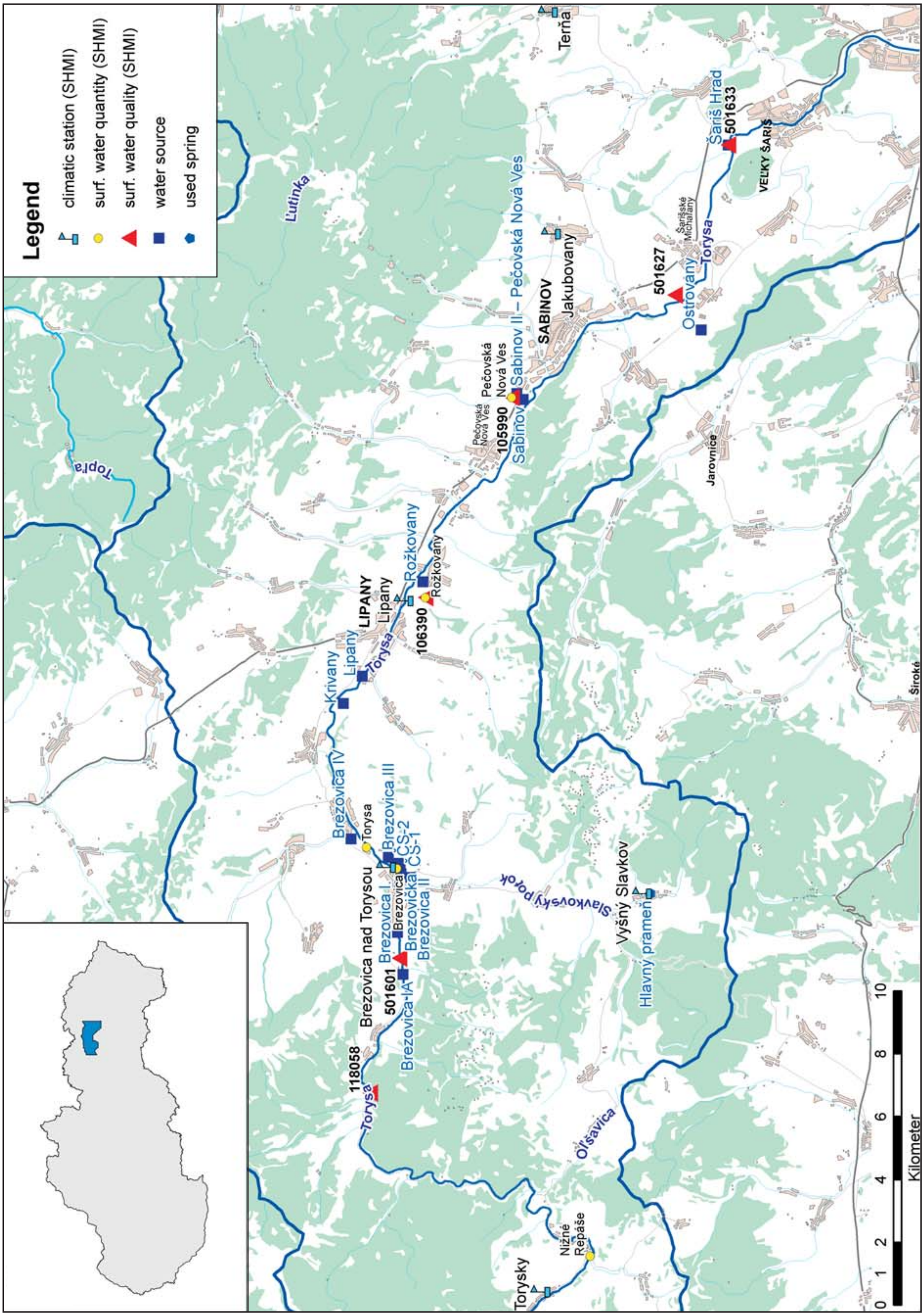

Fig. 1. Location of monitoring sites and water intakes

Lokalizacja punktów monitoringu i ujęć wód

The data comprises of the daily discharges for the period 1961–2006. Two precipitation stations data were also used, precipitation station in Torysky (813 m a.s.l.) and Brezovica (443 m a.s.l.). The air temperatures, used for meteorological drought evaluation were taken from the nearest climatic station in Sabinov – Jakubovany. Data from 14 groundwater monitoring wells were at the disposal, they were located in the alluvial plain of the Torysa River, downstream of the Brezovica gauging profile.

Water for drinking water supply for the Prešov county is abstracted from one surface water intake – direct abstraction from the Torysa River (former village BlaŽov), from spring (Hlavny spring in the Vyšný Slavkov) and from 16 well fields located in the alluvial deposits of the Torysa River and its tributary Slavkovský brook. The situation of monitoring objects is given on Figure 1.

Surface and groundwater quality was interpreted from the analyses of the Eastern Slovakian Waterworks, Slovak Hydrometeorological Institute network of surface and groundwater quality and from the own analyses of the Department of Hydrogeology.

THE STUDY AREA

The studied area is located in the Eastern Slovakia in Levočské vrchy Mts. From the climatic point of view, the area belongs to the mild climate with the average yearly air temperature of 7.7°C (long-term average of 1931–1980). The amount of precipitation ranges from 663 mm in Brezovica station (443 m a.s.l.) to 731 mm in Torysky station (813 m a.s.l.), which is the hightest located precipitation station in the catchment.

The main stream of the studied area is Torysa River. The upper part of the catchment (up to the profile of NiŽné Repaše) is a non-affected part of the catchment, downstream part from former BlaŽov village up to Brezovica is an affected part, mostly by groundwater abstraction in 8 water intakes and in seven more well fields downstream the Brezovica village.

According to the list of groundwater bodies (Kullman *et al*., 2005) the study area belongs to two of them. The first one is the groundwater body of the Pre-Quaternary rocks, labeled as SK2004900F – fissure groundwater of the Podtatranska group and flysch belt of the Hornad River basin area. The dominant rocks building the groundwater body are altering layers of sandstones and claystones of the Paleogene age. The second groundwater body is labeled as SK1001200P – porous groundwater of Quaternary alluvial sediments of the Hornad River basin. They are built by gravels, sandy gravels, sands and prolluvial sediments of the river plains and terraces. According to Kullman *et al*. (2006) is the studied area – upper part of the Torysa River basin (being a tributary of the Hornad River) in a potential risk of not reaching the good quantitative stage of groundwater bodies until 2015. One of the reasons is groundwater abstraction in many groundwater intakes along the Torysa River and its tributary Slavkovsky potok brook.

RESULTS AND DISCUSSION

Values of selected Q_{Mdays} for some profiles are put in Table 2. As it can be seen from the table, Q_{330} (which is approximately equal to $Q_{90\%}$) reaches the value ranging from 0.038 m^3/s^{-1} to 0.630 m^3/s^{-1} in the downstream part of the study area. These values were chosen as surface water drought threshold limits.

The results of groundwater level assessment showed, that the length of the drought periods is different in different monitoring wells. The most severe droughts occurred in summer-autumn periods and in winter periods. The longest drought periods lasted from summer to winter periods. Taking into account the $Q_{90\%}$ value as the threshold value for

Table 2

Q_{Mdays} values in selected profiles on Torysa River

Wartości Q_{Mdays} w wybranych profilach Torysy

Station number	Q_{Mdays} [m^3/s]							
	M = 30	M = 90	M = 180	M = 270	M = 330	M = 355	M = 364	$Q_{a1961–2000}$
1. Torysa – NiŽné Repáše	0.700	0.311	0.145	0.072	**0.038**	0.022	0.011	0.269
2. Torysa – over BlaŽov	2.211	0.982	0.457	0.228	**0.119**	0.070	0.036	0.850
3. Torysa – Brezovica	4.285	1.904	0.885	0.442	**0.231**	0.137	0.070	1.648
4. Torysa – Sabinov	8.848	4.230	1.935	0.987	**0.630**	0.462	0.279	3.423

Table 3

Groundwater drought (GWD) date, length and classification using the baseflow value

Okres i długość trwania suszy hydrogeologicznej (GWD) oraz jej klasyfikacja

Date of GWD occurrence	No. of dry days	Drought classification	Date of GWD occurrence	No. of dry days	Drought classification
28.8.61–25.10.61	59	LD	1.2.91–10.2.91	10	D
12.12.63–17.2.64	68	LD	31.8.92–7.10.92	38	D
3.7.68–24.7.68	22	D	7.1.93–21.1.93	15	D
31.12.72–11.2.73	43	D	24.2.93–14.3.93	19	D
2.11.73–28.12.73	57	LD	9.6.93–16.12.93	191	ED
27.12.77–15.2.78	51	LD	26.7.94–28.10.94	95	LD
9.7.83–10.9.83	64	LD	20.12.95–16.3.96	88	LD
9.7.83–10.9.83	37	D	7.1.97–22.2.97	47	D
23.1.84–5.2.84	14	D	2.2.99–27.2.99	26	D
18.8.86–25.3.87	220	ED	16.10.00–26.12.00	72	LD
2.9.87–30.11.87	90	LD	2.12.01–23.1.02	53	LD
1.11.88–21.2.89	113	ED	23.2.03–7.3.03	13	D
1.11.89–14.11.89	14	D	8.7.03–11.3.04	248	ED

Table 4

Groundwater parameters (mg/l)

Parametry wód podziemnych (mg/l)

Parameter	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	TDS
Periods with drought occurrence (n = 6)									
Average	9.01	4.75	102.04	23.98	10.44	50.03	17.63	315.65	542.61
Minimum	6.77	1.11	78.16	19.46	7.34	45.5	12.2	34.8	262.87
Maximum	12.5	7	123	26.73	13.11	55.23	25.4	529	770.44
Median	8.07	5.20	106.5	24.4	9.12	47.85	18.11	337.83	576.43
Periods without drought occurrence (n = 20)									
Average	8.57	3.94	89.52	24.36	11.74	59.39	21.49	315.39	540.12
Minimum	5.8	0.54	27.86	7.9	4.9	42.3	5.66	85.36	230.27
Maximum	25.17	6.11	136.27	69.25	26	122.96	66.6	463.8	735.64
Median	7.33	4.37	86.31	23.7	11.08	55.46	18.81	331.60	581.97

the groundwater drought, in all monitoring objects only the 1986/1987 and 1993/1994 droughts were commonly estimated.

When comparing the $Q_{90\%}$ baseflow values in the profile no. 3 Torysa–Brezovica, the threshold level was 0.200 and the groundwater drought periods lasted from 13 to 248 days, as it can be seen in Table 3. All together 26 periods of drought, among them 2 longer multiyear droughts occurred, with the longest duration of 248 days from July 2003 to March 2004. Two of the droughts were classified as extreme droughts.

The estimated groundwater drought threshold level for baseflow at Brezovica profile was applied in groundwater chemical composition assessment using the analyses of groundwater in periods with and without drought (Ženišová *et al*., 2008). The results are in Table 4. As it can be seen from the table, there are changes in groundwater chemical composition visible in datasets within and out of the drought periods. The changes can be seen in the slight increase of the TDS, where the Ca^{2+} and HCO_3^- contents increased. However, it would need some more detailed study, having at the disposal more chemical analyses results.

CONCLUSION

The paper proposed method of assessment (quantification) of the hydrological drought and its possible application for estimation the impact of hydrological drought on surface water and groundwater quality and quantity.

Changes in surface and groundwater quantity and quality during the drought periods require more attention than it is paid to them at present. It is necessary not only to study this phenomenon, but also to propose the methods of its prediction and consequences mitigation measures. We hope to propose ways to do that in to coming period.

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