Water resources in small flysch catchments in the Bieszczady Mountains

Karolina Mostowik

Jagiellonian University, Institute of Geography and Spatial Management, Gronostajowa St. 7, 30–387 Kraków, Poland

karolina.mostowik@doctoral.uj.edu.pl

Introduction

The Carpathian Mountains are substantial source of water for surrounding lowland areas. Despite the fact that the mountains are characterized by high precipitation supply, steep topography and low groundwater storage capacity of flysch bedrock determine fast surface runoff and poor groundwater resources in the Outer Carpathians. Hydrological studies in the Carpathians are frequently conducted in medium-sized catchments with little emphasis on variability among small (ca. 10 km^2) sub-catchments. In fact, water resources in small, adjacent catchments may substantially differ, as was proved for zero-order catchments feeding springs in the upper part of the Połonina Wetlińska Massif (the Bieszczady Mountains, Eastern Carpathians, Płaczkowska et al. 2018, Mostowik et al. 2021). Therefore, this study focuses on further recognition of water resources in small catchments across the Połonina Wetlińska Massif (**Fig. 1**, **Fig. 2**).

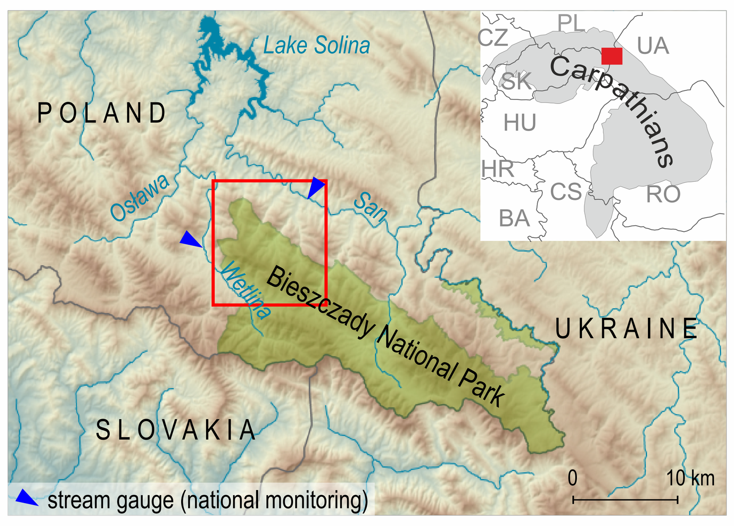


Fig. 1. Map of the study area (red rectangle – the Połonina Wetlińska Massif with surroundings)

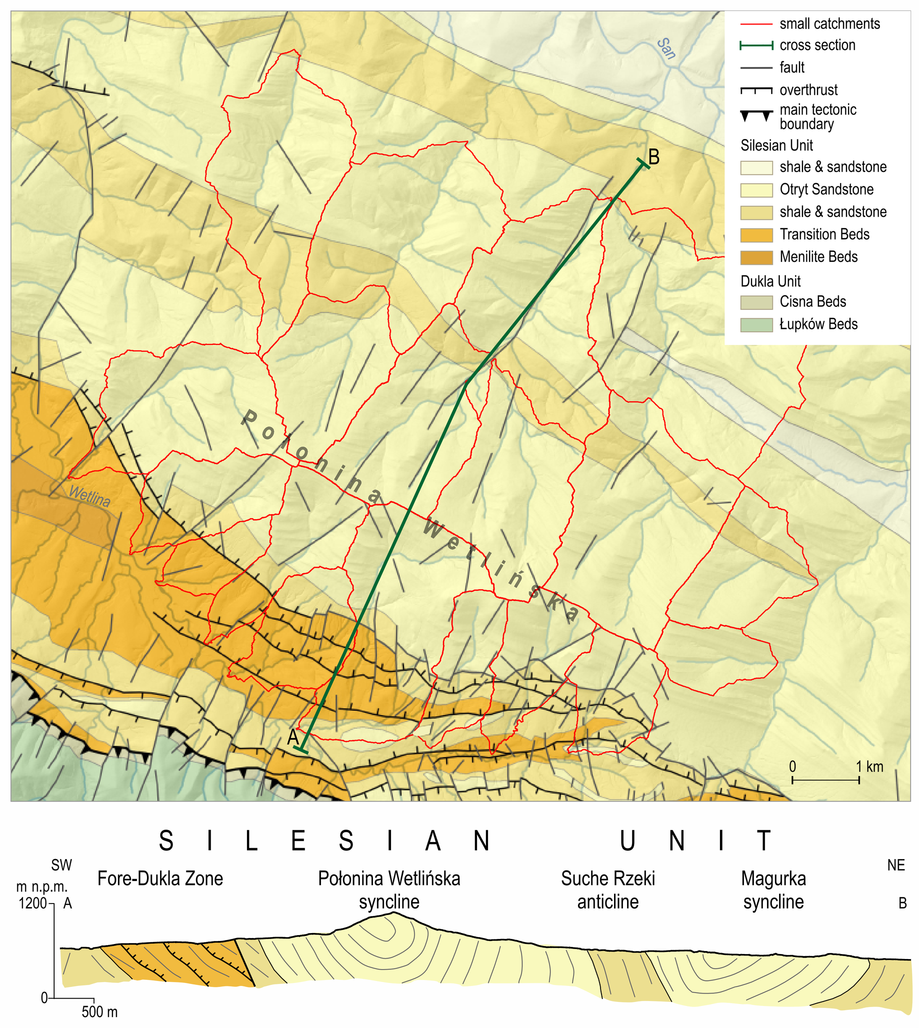


Fig. 2. The Połonina Wetlińska Massif with its geological and tectonic background (based on the Detailed Geological Map of Poland 1:50000)

Research Objectives

- to investigate hydrological conditions in small catchments with reference to catchments' characteristics
- to compare hydrological conditions in small catchments with medium-sized catchments of the San and Wetlina rivers (national monitoring network)

Data & Methods

The dataset used in this study covers hydrological years 2018–2019 and contains daily river flow from 7 own gauging sites in small catchments and from 2 gauging sites in medium-sized catchments supervised by the Institute of Meteorology and Water Management. The daily flow data was used to describe hydrological conditions in selected catchments, as well as to separate baseflow with Eckhardt's digital filter based on parameters obtained as proposed by Collischonn and Fan (2013). Additionally, baseflow in 19 small catchments across the Połonina Wetlińska Massif was measured during six campaigns in 2018 and 2019, when river flow was low and might have been identified as the effect of groundwater recharge only. Characteristics of 19 studied small catchments including their lithology, land use, slope, area, length, width, perimeter, mean, minimum and maximum elevation, elongation ratio and drainage density were defined in this study. In the next step the Spearman's rank correlation coefficient between baseflow in the studied catchments and the catchment characteristics was calculated.

Collishonn W., Fan F.M., 2013. Defining parameters for Eckhardt's digital baseflow filter. *Hydrol. Process.* 27, 2614–2622

Results

1. Precipitation supply in the first investigated hydrological year (2018) was approximately average and was characterized by wet winter season, whereas the second year (2019) was clearly dry, especially in summer and autumn (**Fig. 3**). Fast streamflow response to rainfall events or snowmelt periods was typical for all analysed catchments and daily flows among rivers were highly correlated.
2. Streamflow referred to a catchment area (specific runoff) has revealed high spatial variability, with the highest values noted for the catchment No. 7, located on the northern slope of the Połonina Wetlińska (**Fig. 3**, **Fig. 4**). Average specific runoff in small catchments varied from 24 to 54 dm^3·s^{-1}·km^{-2} in 2018, and from 17 to 33 dm^3·s^{-1}·km^{-2} in 2019, whereas in medium-sized catchments it was 34 and 25 dm^3·s^{-1}·km^{-2} (Wetlina River), and 16 and 24 dm^3·s^{-1}·km^{-2} (San River), respectively (**Fig. 4**).

Fig. 3. Specific runoff in selected catchments

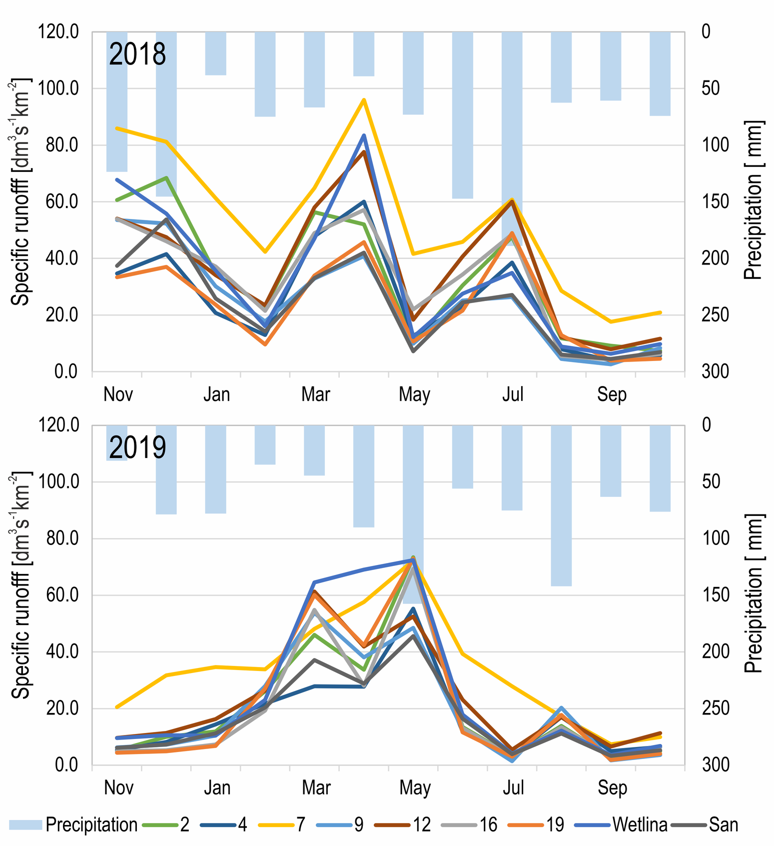
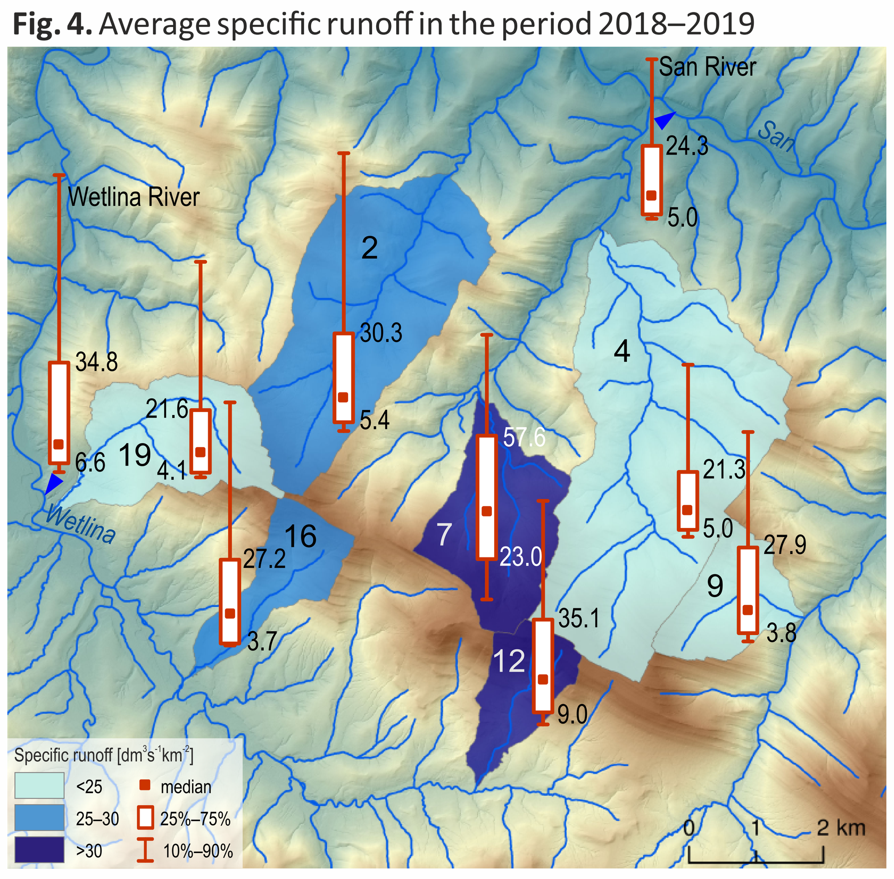


Fig. 4. Average specific runoff in the period 2018–2019



3. Baseflow during selected dry periods ranged from 0.2 to over 30 dm^3·s^{-1}·km^{-2} in the studied catchments (**Table 1**), clearly showing unexpectedly large spatial differences in groundwater storage capacity. The highest baseflow was identified in catchments no. 7, 12, and 13, whereas the lowest was typical for catchments no. 10, 15, 17, and 18 (**Fig. 5**, **Table 1**).
4. Surprisingly, almost none of the catchment characteristics indicated evident correlation with baseflow during any studied period. Baseflow was significantly correlated only with maximum catchment elevation (r_{Aug18}=0.5 to r_{Sep19}=0.7) and with the ratio of the Transition Beds (r=-0.5 in Jul 2018, Aug 2019, and Sep 2019), where shale dominates over sandstone. However, this formation covers only 5% of the study area and cannot be considered as main factor affecting baseflow in the whole region.
5. Average baseflow in the period 2018–2019 was the lowest in the San catchment (9.4 dm^3·s^{-1}·km^{-2}), whereas the highest equaled 36.1 dm^3·s^{-1}·km^{-2} in the catchment no. 7 (**Fig. 6**). The average baseflow index ranged from 42% in the catchment no. 19 to 82% in the catchment no. 7 (**Fig. 7**). That confirms large differences in groundwater storage capacity across the Połonina Wetlińska Massif reported in the analysis of baseflow during selected dry periods.

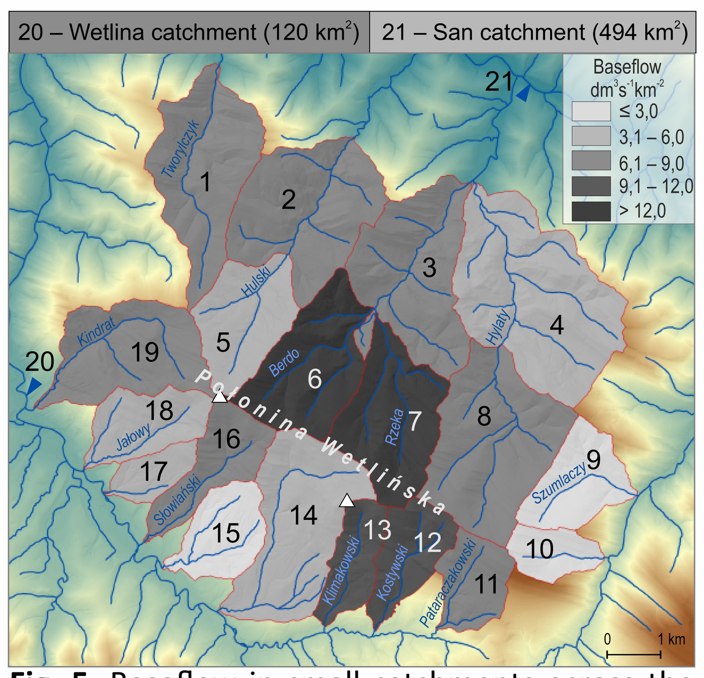


Fig. 5. Baseflow in small catchments across the Połonina Wetlińska Massif during dry period, August 13-14, 2018

Table 1. Baseflow in selected catchments during six dry periods in 2018 and 2019 (red – the lowest vaule, green – the highest value during a campaign)

No.	River	Baseflow [dm^3·s^{-1}·km^{-2}]					
		Jul '18	Aug '18	Sep '18	Jul '19	Aug '19	Sep '19
1	Tworylczyk	14.8	7.2	4.0	6.0	3.0	1.7
2	Lower Hulski	18.7	7.5	4.0	4.6	2.9	2.8
3	Lower Rzeka	22.5	6.6	6.4	8.9	4.9	3.2
4	Lower Hylaty	17.3	5.2	3.2	4.0	2.1	1.9
5	Upper Hulski	12.8	5.8	3.0	4.0	1.8	2.5
6	Berdo	23.3	13.3	4.3	11.8	5.1	3.5
7	Upper Rzeka	33.2	21.4	10.1	14.8	8.7	7.3
8	Upper Hylaty	21.1	6.5	2.8	5.8	1.9	2.3
9	Szumlaczy	17.4	2.1	2.0	4.8	2.1	1.1
10	Tributary near quarry	14.8	2.9	2.2	3.8	0.5	0.5
11	Pataraczakowski	19.3	7.0	3.4	6.6	5.0	2.2
12	Kostywski	34.3	9.4	6.7	13.8	5.7	3.7
13	Klimakowski	30.7	9.9	7.8	11.5	3.8	5.1
14	Pański Zwór	12.8	4.2	4.8	4.6	1.8	1.7
15	Łomianykowski	8.8	2.8	3.4	1.4	0.3	0.2
16	Słowiański	17.3	7.1	4.0	4.0	2.0	1.5
17	Tributary in Smerek	12.2	5.0	5.3	3.0	1.5	0.4
18	Jałowy	13.6	4.0	4.4	2.0	0.6	0.2
19	Kindrat	15.1	7.3	4.2	5.0	1.9	1.7
	San	14.0	5.2	4.7	4.1	3.3	3.2
	Wetlina	12.9	7.3	6.6	4.5	3.3	2.9

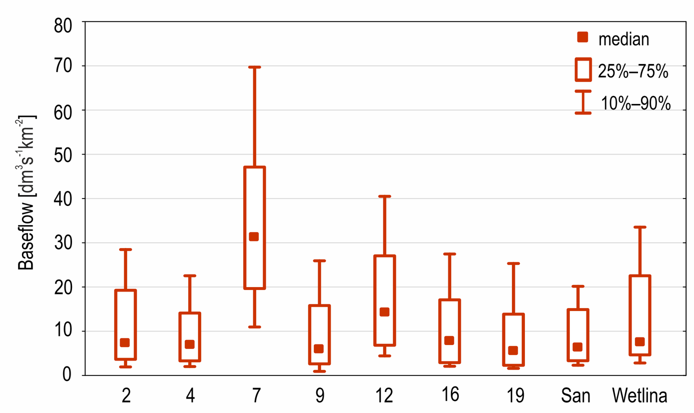


Fig. 6. Baseflow characteristics in selected catchments in the period 2018–2019

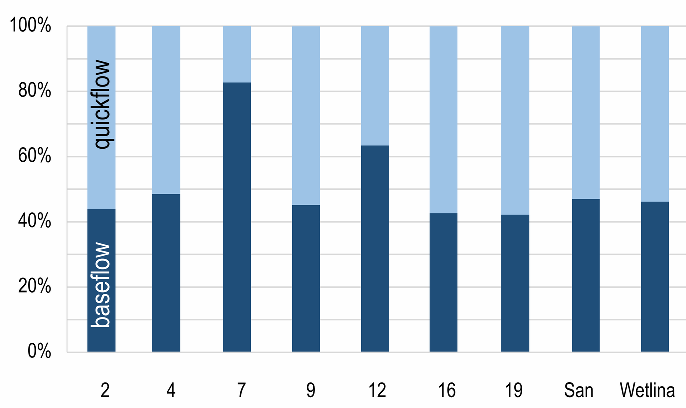


Fig. 7. Baseflow and quickflow components of streamflow in the period 2018–2019

Conclusions

In the flysch part of the Carpathians, similarities in small catchments' lithology, climatic conditions, land use and morphometry do not imply similarities in groundwater resources, and, in consequences, in total catchment runoff. In the study area, dominated by sandstone formations, the local bedrock structures appeared to be crucial for total water resources. The occurrence of joints and faults of different origin promotes the enlargement of groundwater storage capacity. Furthermore, the monoclinal, northern and steep dip of rock layers facilitates the extension of the recharge area due to an inflow of infiltrating water from the opposite (southern) site of the ridge (**Fig. 2**). Finally, gravitational slope deformations modify the conditions of subsurface water flow on the slope and may locally increase the retention capacity of the shallow active zone, with a particular increase in infiltration in the area of occurrence of ridge-top trenches. To conclude, high spatial variability of water resources across a small mountain range with flysch bedrock should be taken into consideration in local water management strategies and natural retention programmes.

Further reading:
Płaczkowska E., Siwek J., Maciejczyk K., Mostowik K., Murawska M., Rzonca B., 2018. Groundwater capacity of a flysch-type aquifer feeding springs in the Outer Eastern Carpathians (Poland). Hydrology Research, 49(6): 1946-1959. doi: 10.2166/nh.2018.200
Mostowik K., Krzyczman D., Płaczkowska E., Rzonca B., Siwek J., Wacławczyk P., 2021. Spring recharge and groundwater flow patterns in flysch aquifer in the Połonina Wetlińska Massif in the Carpathian Mountains. Journal of Mountain Science, 18(4): 819-833. doi: 10.1007/s11629-020-6524-2

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