Drought hazard assessment using GIS Comparison of groundwater runoff of three different hydrogeological units in the Western Carpathians determined by Kille's and hydrograph separation methods

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Abstract: The determination of groundwater runoff in watersheds with different geological structure from the hydrogeological unit division of the territory of Slovak republic point of view is presented in this article. Specifically, the study discusses the influence of geological conditions on the formation of groundwater runoff, as well as compares the results of determining groundwater runoff while using different methods. The study does not involve hydrogeological units built of rocks with high permeability as limestones, dolomites or permeable Quaternary sediments. The results showed that the average annual total runoff determined in the watersheds varied in the range of 6 L.s^{1}.km^{2} to 36 L.s^{-1}.km^{2}, depending on the hydrological unit. While in the Flysch zone hydrogeological unit it was the lowest from 6 L.s^{-1}.km^{2} to 25 L.s^{-1}.km^{2}, in the Inner Carpathian Paleogene hydrogeological unit the range was wider at 6 L.s^{-1}.km^{2} to 33 L.s^{1}.km^{2}. The average annual runoff calculated in the watersheds of the Crystalline rock hydrogeological unit ranged between 6 L.s^{-1}.km^{2} and 36 L.s^{-1}.km^{2}. The groundwater component of the total water runoff contributes the most in the watersheds of the Crystalline rock hydrogeological unit, as anticipated.

Keywords: Groundwater runoff, runoff components ratio, rock environment, hydrogeological units of the Slovak Republic.

1. INTRODUCTION

This article presents partial results of a larger study aimed at the determination of groundwater runoff in watersheds with different geological based on of the division of hydrogeological units delineated for the territory of Slovak Republic. The study complements the knowledge of ongoing research and hydrogeological studies in the field of assessing the quantity of surface and groundwater in nature. Specifically, the study discusses the influence of geological conditions on the formation of total and groundwater runoff, as well as compares the results of determining groundwater runoff while using different methods.

Many of the studies that evaluate groundwater runoff within the Slovak Republic have a partial (local) character. Among the extensive works dealing with the determination of groundwater runoff from various hydrogeological units in Slovakia are, for example, the works of Krásný et al. (1982), Kullman et al. (1997), Malík et al. (2005), Stojkovová (2007), Machlica et al. (2010), Malík et al. (2013), Bajtoš et al. (2016) and Dugovič & Malík (2021).

In this study, 43 watersheds were selected and evaluated. These watersheds represent three different hydrogeological units of the Western Carpathians. The runoff components and properties of all watersheds were assessed, specifically calculation of the total runoff, the groundwater runoff, as well as the mutual relationship of total runoff, groundwater runoff and nonevaporated part of precipitation totals, and finally the expression of the ratio of groundwater runoff to total runoff from the watersheds. The principle of obtaining the results was to work with smaller, representative observed watersheds in the environment of geographic information systems, as well as work with data on the surface flow from given watersheds in hydrogeological software, thus creating a basic picture of the differences in the formation of groundwater runoff based on the comparison of groundwater characteristics obtained by two different methods in three hydrogeological units in Slovakia.

2. METHODS

2.1. Selection and delineation of the evaluated watersheds

Several basic factors affecting the correctness and quality of the results described in this article were considered when selecting the evaluated watersheds. The main factor was the homogeneity of the rock environment in terms of the basic division of the hydrogeological units of the Western Carpathians Mts. Similarities in lithology and/or contrasting lithological properties of rocks outcropping on the area of watersheds were primarily considered in the process of appropriate watershed selection. Another condition for the selection was the size of the watershed. This factor is closely related to the homogeneity of the rock environment, as the larger the watershed, the more geologically diverse it can be. An area of up to a maximum of 100 square kilometres was selected for the investigated watersheds. Last but not least, the selection was influenced by the availability of data in a sufficient

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time span of surface flow observation. In the first round, 131 watersheds were selected. The selection subsequently underwent a closer analysis and, considering the given factors, was reduced to the final 42 watersheds (Fig. 1). The selected watersheds represent three hydrogeological units of the Western Carpathians: The Crystalline rocks hydrogeological unit (19 watersheds), The Flysch zone hydrogeological unit (16 watersheds) and The Inner Carpathian Paleogene hydrogeological unit (7 watersheds). Basic data on watersheds (Tabs. 1–3) are based on available information on surface water gauging stations on creeks from yearbooks of the Slovak Hydrometeorological Institute (hereafter SHMI). A database was created from the given data (Nejedlík et al., 2010).

The water divide lines for the watersheds were determined by the position of surface water gauging stations. Identified areas for each watershed were added to the database (Tab. 1). In this case, SHMI data on areas of the evaluated watersheds, presented in yearbooks, were not used. In the past, the original values were determined by planimetry on paper maps which were often intentionally deformed (for military-tactical reasons in the cold-war period in the second half of the 20th century), the current digital form of the relief data enables more accurate delineation of areas. Having in mind the geological background of the data, in this study the manual procedure of watershed delineation was preferred. For the needs of our study, the priority was to determine the watershed area as accurately as possible, however, we do not claim to definitively determine it accurately.

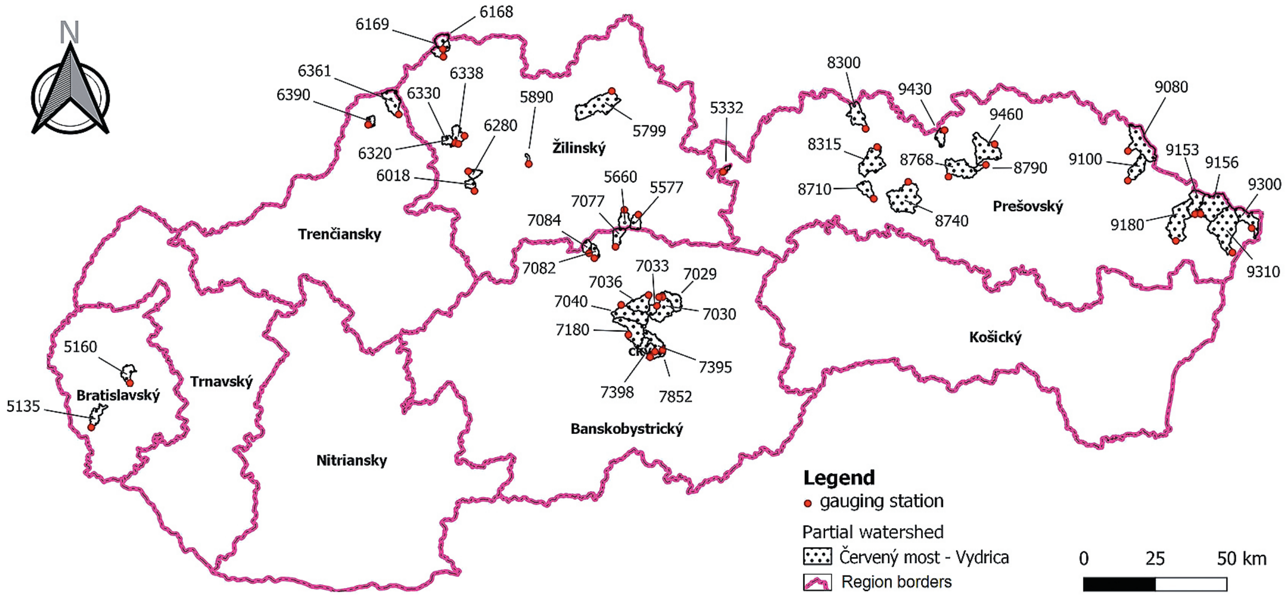

Fig. 1: Map of the evaluated watersheds in the territory of the Slovak Republic.

Tab. 1: Selected characteristics of the evaluated watersheds assigned to Crystalline rock hydrogeological unit.

ID	Catalogue number	Name of the gauging station	River/creek	Stationing [km]	Mean elevation [m a. s. l.]	MIN elevation [m a. s. l.]	MAX elevation [m a. s. l.]	Area [km^2]
2	5135	Červený most	Vydrica	3.30	350	176	476	21.38
3	5160	Pezinok	Blatina	8.75	482	239	748	18.96
4	5332	Tri studničky	Beliansky potok	15.20	1632	1132	2484	3.40
13	5577	Kožiarka	Zadná voda	1.20	1422	913	2014	15.79
14	5660	Horáreň Hluché	Palúdžanka	10.20	1376	827	1959	19.72
22	6018	Valča	Valčiansky potok	7.90	852	551	1230	10.04
38	6280	Kunerad	Bystrička	8.00	1009	614	1472	11.44
51	7029	Čierny Balog	Šaling	0.90	849	582	1210	25.21
52	7030	Čierny Balog	Čierny Hron	15.50	853	564	1338	66.17
53	7033	Čierny Balog	Brôtovo	3.30	846	633	1061	9.47
54	7036	Čierny Balog	Vydrovo	1.10	782	547	1068	34.08
55	7040	Hrončok	Kamenistý potok	11.40	915	649	1333	47.60
57	7077	Jasenie	Lomnistá	4.90	1368	743	1981	18.79
58	7082	Pohronský Bukovec	Bukovec	4.60	1038	557	1600	10.19
59	7084	Brusno	Sopotnica	7.60	1308	790	1754	11.73
60	7180	Hriňová-nad VN	Slatina	50.80	848	568	1343	52.92
61	7395	Ipeľský potok	Ipeľ	200.10	836	422	1111	26.63
62	7398	Málinec-nad VN	Ipeľ	197.60	803	349	1111	53.14
78	7852	Ďubákovo	Kokavka	11.50	882	775	994	2.84

Tab. 2: Selected characteristics of the evaluated watersheds assigned to Flysch zone hydrogeological unit.

ID	Catalogue number	Name of the gauging station	River/creek	Stationing [km]	Mean elevation [m a. s. l.]	MIN elevation [m a. s. l.]	MAX elevation [m a. s. l.]	Area [km^2]
16	5799	Lokca	Hruštínka	0.90	858	621	1393	78.67
26	6168	Klokočov-Klin	Predmieranka	8.00	783	551	1061	15.99
27	6169	Klokočov	Predmieranka	5.00	722	510	1061	35.18
46	6361	Papradno	Papradnianka	13.80	735	427	1071	36.53
47	6390	Vydrná	Petrinovec	2.20	596	381	892	8.49
102	8768	Ľutina	Ľutinka	5.10	775	423	1096	50.02
103	8790	Hertník	Pastovník	4.80	784	496	1049	5.48
110	9080	Medzilaborce	Vydranka	0.54	556	316	844	64.73
111	9100	Čabiny	Olšava	0.65	446	250	781	30.93
112	9153	Starina	Stružnica	0.10	577	341	1010	33.30
113	9156	Starina	Cirocha nad VN	43.40	618	345	1172	66.57
114	9180	Snina	Pčolinka	1.00	384	214	790	71.11
118	9300	Nová Sedlica	Zbojský potok	12.40	675	382	1191	35.20
119	9310	Ulič	Ulička	2.50	573	243	1188	96.57
122	9430	Lenartov	Večný potok	4.50	742	474	1056	14.88
124	9460	Kľušov	Šibská voda	4.30	472	286	1015	59.91

Tab. 3: Selected characteristics of the evaluated watersheds assigned to Inner Carpathian Paleogene hydrogeological unit.

ID	Catalogue number	Name of the gauging station	River/creek	Stationing [km]	Mean elevation [m a. s. l.]	MIN elevation [m a. s. l.]	MAX elevation [m a. s. l.]	Area [km^2]
19	5890	Turany	Čiernik	0.50	564	411	829	2.69
42	6320	Lietava-obec	Lietava	3.75	529	402	820	11.47
43	6330	Lietava-majer	Lietava	2.70	521	392	820	13.57
44	6338	Bánová	Bitarovský potok	1.03	416	352	634	18.59
85	8300	Hniezdne	Kamienka	0.70	716	531	1013	34.46
86	8315	Jakubany	Jakubianka	8.00	941	609	1285	54.16
100	8710	Nižné Repaše	Torysa	123.90	1003	765	1238	21.07

2.2. Processing of the total water runoff, surface and groundwater runoff components

For this research, data of average daily flows from surface water gauging stations were processed. Surface runoff data for the 42 monitored watersheds were provided by the SHMI as a part of the "Integrated System for the Simulation of Runoff Processes" (ISSOP), in which they were used by the staff of the State Geological Institute of Dionýz Štúr (hereafter SGIDS) in the past period (Bajtoš et al., 2016). The time series include different stream flow monitoring data for the period 1961 to 2012. Although the data for many watersheds in this range concern different time periods – which could possibly influence the resulting estimated groundwater runoff values – the evaluated time series are as long as possible for the use of statistical methods of determining groundwater runoff (10 years). If only overlapping time series were used, it would not be possible to cover as many watersheds and the scope of this study would be considerably smaller. From the data, the average yearly values of the total runoff Q_c in m^3.s^1 for the monitored period available for individual watersheds were determined (Tabs. 4–6).

For the purpose of determining groundwater runoff values from surface flow data two modules from the HydroOffice 2015 software package were used; namely the "Kille 3.1" and the "BFI+ 3.0" modules (Gregor & Fendek, 2012; Gregor, 2010).

The Kille 3.1 module is used to calculate the value of the long-term average groundwater runoff from a watershed. At least a 10-years long period of daily flow observations is required. The program is based on the classic methodology of statistical determination of groundwater runoff according to Kille (1970), which was specifically applied by Fendeková & Fendek (1999). The average values of groundwater runoff Q_{pd} in m^3.s^{-1} for individual watersheds are given in Tabs. 4–6.

The BFI+ 3.0 module separates the baseflow (assumed to represent the groundwater runoff) from the total watershed runoff based on a hydrograph separation method – the Local Minimum method – with the value of the time step length N = 20. The use of this specific time step length was adopted from the results of Stojkovová & Fendeková (2010) who compared the best fit of various time steps with other separation methods results. This value is determined from local hydrological and meteorological conditions. The resulting value of the average baseflow (groundwater) runoff Q_{pd} in m^3.s^1 (Tabs. 4–6) was determined from the daily values of the base (groundwater) runoff calculated by the module. Tabs. 4-6 also presents BFI index which represents the contribution of groundwater runoff to total watershed runoff (Q_{pd} / Q_c [BFI+ 3.0] in per cents).

Specific groundwater runoff Q_{pz} in L.s^1.km^{-2} from the values of the groundwater runoff determined by the Kille's and Local Minimum methods (Tabs. 4–6). Average yearly groundwater contribution to watershed runoff was determined in percent as follows: Q_{pd} (Kille) /Q_c; Q_{pd} (Local Minimum) /Q_c (Tabs. 4–6).

3. RESULTS AND DISCUSSION

3.1. Crystalline rock hydrogeological unit

Using the Kille's method, the average annual value of the groundwater runoff was determined in the range from 0.016 $m^3.s^1$ to 0.314 $m^3.s^1$. The Local Minimum method was also used to estimate the average annual base (groundwater) runoff in the monitored watersheds with values of 0.015 $m^3.s^1$ – 0.314 $m^3.s^1$. The lowest groundwater runoff (0.015 $m^3.s^1$ – 0.016 $m^3.s^1$) was determined by both Kille's and Local Minimum methods in the watershed of the Kokavka creek, which is the smallest among the monitored watersheds with an area of 2.9 km^2. The highest values of groundwater runoff were estimated in the Lomnistá creek watershed (0.314 $m^3.s^1$ for both methods), which represents one of the higher elevated mountainous watersheds with relatively steep relief (Tab. 1). The results of groundwater runoff determined by both methods were relatively similar. The values obtained by Kille's method were in most cases slightly higher (0.3% – 10.6%) or exactly the same as the results determined by the Local Minimum method.

Ranges of the average annual specific groundwater runoff obtained by the two methods were similar and varied approximately between, 2.6 $L.s^1.km^2$ to 16.7 $L.s^1.km^2$. Based on the values determined using the Local Minimum method, the range of values is 2.385 $l{\cdot}s^1{\cdot}km^2$ – 16.711 $l{\cdot}s^1{\cdot}km^2$ (Tab. 4).

The percentage of groundwater runoff in the total watershed runoff for the values determined by Kille's method varies between 30.1% (the Blatina creek) and 55.6% (the Lomnistá creek). Overall, the groundwater runoff makes up around a half of the total runoff in 5 of the evaluated watersheds while it is less than a half in the other 14 watersheds (Tab. 4). Values of the percentage of groundwater runoff in the total watershed runoff determined by the Local Minimum method are, in most cases, similar with relative differences from 0.3% to 10.6% (Tab. 4).

3.2 . Flysch zone hydrogeological unit

The average annual value of the groundwater runoff in this hydrogeological unit determined by the Kille's method ranged from 0.032 $m^3.s^1$ to 0.513 $m^3.s^1$. The Local Minimum method provided values of 0.034 $m^3.s^1$ – 0.514 $m^3.s^1$. The lowest groundwater runoff (0.032 $m^3.s^1$ – 0.040 $m^3.s^1$) was determined in the watersheds of the Petrinovec and Pastovník creeks by both methods, which are the two smallest watersheds in the Flysch zone hydrogeological unit with areas of 8.49 km^2 and 5.48 km^2, respectively. The highest values of groundwater runoff using both methods were estimated in the Hruštínka creek watershed (0.513 $m^3.s^1$ and 0.514 $m^3.s^1$), which represents one of the larger watersheds and is the most elevated one as well (Tab. 2). The values of groundwater runoff from the watersheds determined by Kille's method were in most cases slightly higher (by 0.44% to 12.54%), with the exception of 4 watersheds where the groundwater runoff determined by the Local Minimum method, was higher by 0.18% to 19.08%. (Tab. 5).

The average annual specific groundwater runoff, based on the values of the groundwater runoff determined by Kille's method

Tab. 4: Average yearly values of total runoff and groundwater runoff discharges in the evaluated watersheds in Crystalline rock hydrogeological unit.

ID	Catalogue number	Evaluated period	Q_c		Q_{pd} [$m^3.s^1$]		Q_{pz} [$L.s^{-1}.km^2$]		Q_{pd} / Q_c (%)		Q_{pd} / Q_c [BFI+ 3.0]
			[mm]	[$m^3.s^1$]	Kille	Local Minimum	Kille	Local Minimum	Kille	Local Minimum	
2	5135	1965– 012	193	0.131	0.056	0.051	2.638	2.385	43.1	38.9	0.61
3	5160	1962–2009	361	0.217	0.065	0.063	3.449	3.323	30.1	29.0	0.53
4	5332	1975 - 1991	621	0.067	0.027	0.027	8.000	7.941	40.6	40.3	0.58
13	5577	1972–2003	1132	0.567	0.229	0.234	14.490	14.820	40.4	41.3	0.63
14	5660	1970–2011	969	0.606	0.307	0.285	15.588	14.452	50.7	47.0	0.66
22	6018	1987–2012	474	0.151	0.074	0.071	7.390	7.072	49.1	47.0	0.64
38	6280	1981–2012	824	0.299	0.152	0.146	13.269	12.762	50.8	48.8	0.64
51	7029	1990–2012	310	0.248	0.105	0.101	4.173	4.006	42.4	40.7	0.61
52	7030	1995–2012	339	0.711	0.268	0.263	4.047	3.975	37.7	37.0	0.59
53	7033	1990–2003	290	0.087	0.036	0.036	3.801	3.801	41.4	41.4	0.62
54	7036	1969–2003	284	0.307	0.142	0.136	4.155	3.991	46.1	44.3	0.64
55	7040	1969–1979	445	0.671	0.284	0.280	5.966	5.882	42.3	41.7	0.62
57	7077	1969–2010	948	0.565	0.314	0.314	16.711	16.711	55.6	55.6	0.70
58	7082	1991–2009	603	0.195	0.099	0.109	9.755	10.697	51.0	55.9	0.72
59	7084	1980–2008	836	0.311	0.165	0.164	14.024	13.981	52.9	52.7	0.69
60	7180	1987–1997	369	0.619	0.274	0.270	5.178	5.102	44.3	43.6	0.62
61	7395	2001–2011	338	0.285	0.131	0.124	4.916	4.656	45.9	43.5	0.60
62	7398	2001–2011	311	0.524	0.230	0.222	4.323	4.178	43.8	42.4	0.60
78	7852	1979–1999	389	0.035	0.016	0.015	5.528	5.282	44.9	42.9	0.60

Explanations: ID – identification number of a watershed; Q_c – total average runoff from a watershed in $m^3.s^{-1}$, or in mm; Q_{pd} – groundwater (base) watershed runoff in $m^3.s^{-1}$; Q_{pz} – specific groundwater (basic) watershed runoff in $L.s^{-1}.km^{-2}$; Q_{pd} (Kille) / Q_c – percentage share of the groundwater (base) watershed runoff determined by Kille's method to the total watershed runoff; Q_{pd} (Local Minimum) / Q_c – percentage share of the groundwater (base) watershed runoff determined by the Local Minimum method to the total watershed runoff; Q_{pd} / Q_c [BFI+ 3.0] – share of the groundwater (base) watershed runoff to the total watershed runoff calculated by the BFI+ 3.0 module.

varies from 2.043 L.s^1.km^2 to 6.522 L.s^1.km^2. The values based on the Local Minimum method, the range of values is 1,983 L.s^1.km^2 – 7,299 L.s^1.km^2. The values for individual watersheds are shown in Tab. 5.

The percentage share of groundwater runoff in the total watershed runoff varies from 19,9% to 45,8% based on the groundwater runoff determined by Kille's method and from 18,6% to 51,3% based on the groundwater runoff determined by the Local Minimum method. The minimal contribution of groundwater runoff to the total runoff was calculated in the Vydranka creek watershed (18,6% – 19,9%), while the watershed with the highest contribution was the Pastovník creek watershed (45,8% – 51,3%). On average, the groundwater runoff makes up around 1/3 of the total runoff in the watersheds representing the Flysch zone hydrogeological unit with the specific values shown in the Tab. 4 depending on which values of the calculated groundwater runoff were used.

3.3. Inner Carpathian Paleogene hydrogeological unit

The average annual values of the groundwater runoff determined by the Kille's method vary from 0.036 m^3.s^1 to 0.179 m^3.s^1 – while the values determined by the Local Minimum method vary from 0.036 m^3.s^1 – 0.172 m^3.s^1. The lowest groundwater runoff value (0.036 m^3.s^1) was determined by both methods in the Lietava creek watershed, which is the second smallest among the monitored watersheds with an area of 11.47 km^2. The highest values of groundwater runoff using both methods were estimated in the Jakubianka creek watershed (0.172 m^3.s^1 – 0.179 m^3.s^1), which represents one of the larger and more elevated watersheds from this group (Tab. 3). The results of groundwater runoff determined by both methods for watersheds representing this hydrogeological unit were significantly similar.

The values of the average annual specific groundwater runoff, based on the values of the groundwater runoff determined by Kille's method range from 1.818 L.s^1.km^2 to 15.167 L.s^1.km^2, while those based on the Local Minimum method range from 1.673 L.s^1.km^2 to 14.870 L.s^1.km^2. Specific values for individual watersheds are shown in Tab. 6.

Groundwater runoff contribution to the total watershed runoff vary from 26.9% to 57.6%. The values of the groundwater contribution were slightly higher in almost every instance when the values of groundwater runoff determined by Kille's method were used. Minimal contribution of groundwater runoff in the total runoff was determined in the Kamienka creek watershed (26.9% – 28,3%), while the watershed with the highest contribution was the Lietava creek watershed (56.7% – 57.6%). The resulting range of groundwater contribution is shown in Tab. 6 based on groundwater runoff values of which method were used.

3.4. Overall comparison of evaluated hydrogeological units

The overall comparison of the runoff components ratios of the three hydrogeological units by means of averages and medians is shown in Tab. 7. Most of the watersheds in the Crystalline rock hydrogeological unit are relatively smaller in size, but they are usually in mountainous regions with higher altitude and rugged terrain with steeper slopes. This generally means that there are higher amounts of precipitation and that the precipitation and surface water move faster than in the more levelled terrain, which means less evaporation.

Watershed areas in the Flysch hydrogeological unit are relatively larger than in the Crystalline rock hydrogeological unit (Tab. 3), but their mean elevation is generally lower and have more levelled terrain with more soil cover.

Tab. 5: Average yearly values of total runoff and groundwater runoff discharges in the evaluated watersheds in Flysch zone hydrogeological unit.

ID	Catalogue number	Evaluated period	Q_c		Q_{pd} [m^3.s^{-1}]		Q_{pz} [.s^{-1}–km^2]		Q_{pd} / Q_c (%)		Q_{pd} / Q_c [BFI+ 3.0]
			[mm]	[m^3·s^{-1}]	Kille	Local Minimum	Kille	Local minimum	Kille	Local Minimum	
16	5799	1969 –2000	495	1.234	0.513	0.514	6.522	6.534	41.6	41.7	0.59
26	6168	1969–2012	676	0.343	0.097	0.094	6.041	5.879	28.2	27.4	0.53
27	6169	1981–2012	649	0.724	0.164	0.154	4.650	4.377	22.6	21.3	0.45
46	6361	1984–1997	519	0.601	0.144	0.140	3.953	3.832	24.0	23.3	0.51
47	6390	1971–2012	401	0.108	0.032	0.034	3.804	4.005	29.9	31.5	0.57
102	8768	1992–2011	338	0.536	0.192	0.183	3.828	3.659	35.7	34.1	0.56
103	8790	1969–1983	449	0.078	0.036	0.040	6.515	7.299	45.8	51.3	0.61
110	9080	2001–2010	546	1.121	0.224	0.209	3.454	3.229	19.9	18.6	0.50
111	9100	1973–1992	410	0.402	0.098	0.092	3.168	2.974	24.4	22.9	0.52
112	9153	2001–2011	512	0.541	0.137	0.136	4.102	4.084	25.2	25.1	0.50
113	9156	2001–2011	559	1.179	0.272	0.269	4.087	4.041	23.1	22.8	0.50
114	9180	2001–2010	267	0.601	0.145	0.141	2.043	1.983	24.2	23.5	0.49
118	9300	1972–1988	787	0.878	0.217	0.198	6.159	5.625	24.7	22.6	0.46
119	9310	2001–2011	542	1.660	0.334	0.320	3.459	3.314	20.1	19.3	0.48
122	9430	1982–1992	473	0.223	0.070	0.087	4.731	5.847	31.6	39.0	0.56
124	9460	1992–2010	179	0.340	0.146	0.130	2.442	2.170	43.0	38.2	0.59

Explanations: ID – identification number of a watershed; Q_c – total average runoff from a watershed in m^3.s^{-1}, or in mm; Q_{pd} – groundwater (base) watershed runoff in m^3.s^{-1}; Q_{pz} – specific groundwater (basic) watershed runoff in L.s^{-1}.km^{-2}; Q_{pd} (Kille) / Q_c – percentage share of the groundwater (base) watershed runoff determined by Kille's method to the total watershed runoff; Q_{pd} (Local Minimum) / Q_c – percentage share of the groundwater (base) watershed runoff determined by the Local Minimum method to the total watershed runoff; Q_{pd} / Q_c [BFI+ 3.0] – share of the groundwater (base) watershed runoff to the total watershed runoff calculated by the BFI+ 3.0 module.

Tab. 6: Average yearly values of total runoff and groundwater runoff discharges in the evaluated watersheds in Inner Carpathian Paleogene hydrogeological unit.

ID	Catalogue number	Evaluated period	Q_c		Q_{pd} [m^3.s^{-1}]		Q_{pz} [L.s^{-1}.km^2]		Q_{pd} / Q_c (%)		Q_{pd} / Q_c [BFI+ 3.0]
			[mm]	[m^3.s^{-1}]	Kille	Local Minimum	Kille	Local Minimum	Kille	Local Minimum	
19	5890	1968–1997	1043	0.089	0.041	0.040	15.167	14.870	45.8	44.9	0.62
42	6320	1970–2012	203	0.074	0.036	0.036	3.139	3.139	48.6	48.6	0.61
43	6330	1984–2002	365	0.157	0.091	0.089	6.669	6.559	57.6	56.7	0.69
44	6338	1984–1992	261	0.154	0.047	0.046	2.507	2.474	30.3	29.9	0.54
85	8300	1982–2012	377	0.412	0.116	0.111	3.378	3.221	28.3	26.9	0.53
86	8315	1985–1997	310	0.533	0.179	0.172	3.299	3.176	33.5	32.3	0.58
100	8710	1983–1993	513	0.343	0.132	0.122	6.255	5.790	38.4	35.6	0.57
101	8740	1961–2012	190	0.503	0.152	0.140	1.818	1.673	30.2	27.8	0.50

Explanations: ID – identification number of a watershed; Q_c – total average runoff from a watershed in m^3.s^{-1}, or in mm; Q_{pd} – groundwater (base) watershed runoff in m^3.s^{-1}; Q_{pz} – specific groundwater (basic) watershed runoff in L.s^{-1}.km^{-2}; Q_{pd} (Kille) / Q_c – percentage share of the groundwater (base) watershed runoff determined by Kille's method to the total watershed runoff; Q_{pd} (Local Minimum) / Q_c – percentage share of the groundwater (base) watershed runoff determined by the Local Minimum method to the total watershed runoff; Q_{pd} / Q_c [BFI+ 3.0] – share of the groundwater (base) watershed runoff to the total watershed runoff calculated by the BFI+ 3.0 module.

Areas and elevation of the watersheds in the Inner Carpathian Paleogene hydrogeological unit are similar to those in the Flysch zone hydrogeological unit. However, the average area of these watersheds is smaller (Tab. 3).

Given the abovementioned values, it can be therefore concluded that the physicalgeographical characteristics of watersheds, such as their location, altitude, nature of the relief and of course the area itself, had a significant influence on the determination of the runoff components ratios and values of the evaluated watersheds. However, the most important aspect of the formation of groundwater runoff and the ratio of groundwater runoff to total runoff discussed in this article is the influence of the rock environment. The two parameters that best describe the runoff components ratios of watersheds with different rock environment are the specific groundwater runoff and the ratio of groundwater runoff to the total watershed runoff (tab. 7).

Because of the differences in watershed areas, the best way to compare groundwater runoff in different hydrogeological units is to evaluate the average values of the specific groundwater runoff. This was the highest in the Crystalline rock hydrogeological unit, the average value of the specific groundwater runoff was the highest, at 7.758 L.s^1.km^2 or 7.632 L.s^1.km^2, depending on which method for determining the groundwater runoff was used (Tab. 7). The Flysch zone unit has the lowest specific groundwater runoff (4.310 L.s^1.km^2 or 4.303 L.s^1.km^2). The value in the Inner Carpathian Paleogene hydrogeological unit was slightly higher (5.279 L.s^1.km^2 or 5.113 L.s^1.km^2), depending on the method of the groundwater runoff determination (Tab. 7).

The value of the average percentage share of groundwater runoff to the total watershed runoff in the Crystalline rock hydrogeological unit was from 44% to 45%, depending on which method was used to calculate the groundwater runoff. For hydrogeological unit of the Flysch zone, this percentage share was 29% on average, by both methods. Lastly for the Inner Carpathian Paleogene hydrogeological unit the percentage share was from 38% to 39% on average, depending on the groundwater runoff determination method (Tab. 7).

The differences in values representing runoff components and ratios are quite modest. The comparison of hydrogeological units is therefore rather relative, as despite the significantly different geological structure, they are actually very similar from a hydrogeological point of view. While considering the above-mentioned statement, it is still possible, based on the described values, to assume a certain influence of different geological conditions of the three hydrogeological units on the runoff components ratios and runoff properties of the evaluated watersheds on the results of this study. However, the hydrogeological unit, or the geological conditions and the physical-geographical conditions definitely do not represent the only influencing factors in the formation of groundwater runoff and its share to the total runoff from the watershed. There are various other natural and artificial aspects, for example air humidity conditions, soil coverage, afforestation or the anthropogenic influence of the given territory and of course the meteorological conditions in the evaluated time periods, that have an effect on it.

4. CONCLUSIONS

In this study, 42 watersheds were selected and evaluated in terms of basic physicalgeographical characteristics as well as hydrological and hydrogeological parameters affecting the runoff ratios of the monitored watersheds. Data on the surface flows from the final profiles of the evaluated watersheds were processed. The average annual values of runoff parameters in each watershed were determined from the data. Subsequently, the results within the three hydrogeological units were compared. It is a relative comparison due to the different time periods and a variety of humidity conditions. The Kille 3.1 and BFI+ 3.0 modules from the HydroOffice 2015 software package were used to calculate the groundwater runoff values. The Local Minimum method was used to separate the basic (groundwater) runoff using the BFI model with a time step length value of N = 20.

The evaluated watersheds differ within the individual hydrogeological units in terms of their geomorphological conditions, such as area, and other characteristics. Therefore, to compare individual hydrogeological units, the specific values of runoff parameters - runoff values per square kilometres - were used.

The value of the average annual total watershed runoff determined in the Crystalline rock hydrogeological unit ranged

Tab. 7: Average and median values of the selected average yearly values of the runoff components ratio parameters for the whole hydrogeological unit.

Hydrogeological unit Average		Crystalline rock		Flysch zone		Inner Carpathian Paleogene	
		Median	**Average**	**Median**	**Average**	**Median**	
Area [km^2]		24.18	18.96	43.97	35.87	29.96	19.83
Mean elevation [m a. s. l.]		971	853	644	647	678	640
Qc	[mm]	528	389	488	504	408	338
	[L.s^{-1}.km^2]	17	12	15	16	13	11
Q_{pz} [L.s^{-1}.km^2]	Kille	7.758	5.528	4.310	4.020	5.279	3.339
	Local Minimum (20)	7.632	5.282	4.303	4.023	5.113	3.198
Q_{pz} / Q_c (%)	Kille	44.9	44.2	29.0	25.0	39.1	36.0
	Local Minimum (20)	43.9	42.3	28.9	24.3	37.8	33.9
Q_{pd} / Q_c [BFI+ 3.0]		0.63	0.62	0.53	0.52	0.58	0.58

Explanations: Q_c – total average runoff from a watershed in mm or in L.s^{-1}.km^2; Q_{pz} – specific groundwater (basic) watershed runoff in L.s^1.km^2; Q_{pz} (Kille) / Q_c – percentage share of the specific groundwater (base) watershed runoff determined by Kille's method to the total watershed runoff; Q_{pz} (Local Minimum) / Q_c – percentage share of the specific groundwater (base) watershed runoff determined by the Local Minimum method to the total watershed runoff; Q_{pd} / Q_c [BFI+ 3.0] – share of the groundwater (base) watershed runoff to the total watershed runoff calculated by the BFI+ 3.0 module.

between 6 L.s^1.km^2 and 36 L.s^1.km^2, while in the Flysch zone hydrogeological unit it ranged from 6 L.s^1.km^2 to 25 L.s^1.km^2, and in the Inner Carpathian Paleogene hydrogeological unit it was from 6 L.s^1.km^2 to 33 L.s^1.km^2.

Using the Kille's method, the average annual value of the specific groundwater runoff for the watersheds of the Crystalline rock hydrogeological unit was determined from 2.638 L.s^1.km^2 to 16.711 L.s^1.km^2. For watersheds in the Flysch zone hydrogeological unit, this value ranged from 2.043 L.s^1.km^2 to 6.522 L.s^1.km^2 and for the Inner Carpathian Paleogene hydrogeological unit watersheds it ranged from 1.818 L.s^1.km^2 to 15.167 L.s^1.km^2. The values of the average annual groundwater runoff calculated with the Local Minimum method were relatively similar, however in most cases lower for all three hydrogeological units, specifically around 1.6% to 3.8% lower.

The share by which the groundwater component contributes to the total water runoff from the watershed was determined the highest for the Crystalline rock hydrogeological unit (44% – 45% on average), with the median value of 42% – 44%, depending on the method of groundwater estimation used. This ratio was slightly lower for watersheds in the Inner Carpathian Paleogene hydrogeological unit, with the groundwater runoff share of 39% and 38% on average, when the Kille's method and the Local Minimum method were used, respectively. The median value of the share for this unit was 34% to 39%. The value of this ratio was the lowest for watersheds in the Flysch zone hydrogeological unit, with the average value of the groundwater share around 29% with both methods used and the median value of 24% – 25%. Therefore, the groundwater runoff contributed the most to the total runoff in the watersheds of the Crystalline rock hydrogeological unit, as anticipated. For this unit it was almost 1/2 of the total runoff on average. For the Flysch zone hydrogeological unit, the groundwater runoff represented approximately 1/4, 1/3 of the total runoff from the watersheds. Though the differences in the geological structure of these three hydrogeological units are considerable, the units are quite similar from hydrogeological point of view. The comparison is more on the relative basis as the differences are not that great. The reason for this is that along with the geological environment, many other factors influence the runoff conditions of a watershed.

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