Space analysis groundwater runoff changes from selected Slovak catchments

MIRIAM FENDEKOVÁ

PRIF UK, Mlynská dolina, Pav. G, 842 15 Bratislava

Abstract. Results of the groundwater runoff study from selected catchments in Slovakia showed the different intensity of groundwater runoff changes as well as the different pattern of their time evolution during the period of 1931-1990. The relationships among estimated values of groundwater runoff and some physical-geographical characteristics were studied using statistical methods – regression analysis and factor analysis. The decrease of groundwater runoff values during the last decade, 1981-1990, is evident in almost all catchments and reaches from –7.3 % on Kriváňsky potok to -44.7 % on Starohorský potok compared to the reference period of 1931-1980. Only at the Kysuca and Ľubochnianka catchments was there a slight increase of groundwater runoff. No clear territorial relationship was found. The decrease of groundwater runoff characteristics was closely connected only with the individual catchment area.

Key words: catchment, hydrogeological conditions, time series, groundwater runoff, specific groundwater runoff

Introduction

The most important aquifers in Slovakia are Quaternary sediments in which 59.3 % of groundwater exploitable sources are stored. 41.0 % of the whole bulk is stored in Quaternary sediments of lowlands and 18.3 % in Quaternary sediments of river valleys. Important amounts of exploitable sources – 23.6 % are also stored in Mesozoic rocks, mainly in limestones and dolomites (Hanzel & Melioris, 1996). These highly important sources of drinking water supplies are qualitatively and quantitatively very vulnerable.

The qualitative vulnerability is conditioned mainly by the position of their occurrence – most of them are stored in the first uppermost horizon of groundwater, which is threatened by many kinds of human activities.

Alluvial deposits in river valleys are exposed to potential pollution sources, which follow from the high density of habitation, concentration of industry and agricultural activities. This pollution can come to the groundwater from the surface or from stream flows by infiltration of polluted surface water (Hyánková et al, 1991). Pollution sources in mountainous regions of carbonate rocks are connected with tourism, air pollution and agricultural activities (Hyánková et al., 1993).

The overexploitation of groundwater reserves in the catchment represents the main quantitative threat caused by human activities (Némethy, 1996). The next factor is the decrease of precipitation amounts, which can be observed with various intensity in Slovakia over last two decades, as documented by many Slovak researchers and summarised by Marečková et al. in Country study Slovakia (1997). Besides of distinct decrease of precipitation amounts in some parts of Slovakia, an increase of the air temperature and thus of evaporation over the whole country since 1987 (Lapin in Marečková et al., 1997) was demonstrated. These climatic events have also evoked a response in the surface runoff (Majerčáková, 1994; Majerčáková in Marečková et al., 1997) and in groundwater runoff (Kullman Jr. et al. in Marečková et al., 1997).

The first author, to study the space distribution of groundwater runoff throughout Slovakia was Kullman (1965). The most important regional assessment of the groundwater runoff was performed by Krásný et al. (1982) for the whole of former Czechoslovakia. It was based on the 10 – 12 years long data sets from 250 gauging station of the State Monitoring Network of river discharges. The method of base flow calculation introduced by Kille (1970) was used for the entire area. Results were compared with those obtained by other methods for selected gauging stations, representing different natural conditions (Krásný et al., 1982). The representativeness of results obtained by utilization of the Kille's method was demonstrated by Krásný et al. (1982). Krásný divided the whole region of former Czechoslovakia into 8 groups of areas, according to the value of specific groundwater runoff as follows:

I. areas with slight groundwater runoff less than 0.5 l/s km^2,

II. areas with very low groundwater runoff about 0.5 l/s km^2,

III. areas with low groundwater runoff 1.0–2.0 l/s km^2,

IV. areas with medium groundwater runoff 2.0–3.0 l/s km^2,

V. areas with heightened groundwater runoff 3.0–5.0 l/s km^2,
VI. areas with high groundwater runoff 5.0 – 7.0 l/s km^2,
VII. areas with very high groundwater runoff 7.0 – 10.0 l/s km^2,
VIII. areas with extremely high groundwater runoff more than 10 l/s km^2.

A set of maps of water balance elements for Central and Eastern Europe of scale 1:5,000,000 was published under edition of Puskás (1984). A map of groundwater inflow to rivers, also part of this set, Krásný was its co-author for the territory of former Czechoslovakia. Maps of groundwater runoff were compiled after methods of Vsevoložskij et al. (1977).

The above mentioned publications and many others subsequently were concentrated on the methods of groundwater runoff evaluation and its applications to modelled areas in many parts of Slovakia. They only rarely took into account the time and space evolution of base flow changes.

The analysis of groundwater changes can be focused on changes of groundwater exploitable sources and reserves, spring yield changes, groundwater level changes or on low flows in rivers, which represent the base flow from the catchment during dry periods.

The space analysis of changes of groundwater sources and reserves were studied by Kullman (1996), Kullman and Chalupka (1995), Chalupka and Kullman (1992) and by others. Spring yields changes were studied by Fendeková (1994), Gavurník et al. (1994), Kullman Jr. et al. (1995), Fendeková et al. (1995) and by others. Groundwater levels in selected areas were studied by Takáčová (1996), Zaťko (1996) and by others, mainly as a part of National Climatic Program supervised by Slovak Hydrometeorological Institute.

Balco's publication (1990) was oriented toward the low flows of rivers. An evaluation of minimal discharges of surface streams in connection with the climate change, was made by Majerčáková et al. (1995), Szolgay et al. (1997), Trizna (1996) and by others.

Selection of catchment

The results of time-series analysis of minimum stream flow discharges, done by Majerčáková et al. (1995) during the execution of the National Climate Program and FRIEND Project, were considered by the selection of evaluated catchments, based on the following criteria:

– catchment area – catchments with the catchment area up to 500 km^2 were selected,

– length of the series – time series of mean daily discharges with the measurements since 1931 to 1990 were included,

– homogeneity of time series – it was tested by 5 statistical homogeneity tests: Student, Bartlett, Kruskal-Wallis, Abbe-criterion and Spearman rank-correlation method. Based on their results, the selected hydrological series are with high probability homogeneous, but non-stationary.

From 20 catchments assessed by Majerčáková et al. (1995), 15 catchments were chosen. In the process of selection the relative geological homogeneity of the catchment, its representativeness according to prevailing aquifer type and its location in Slovakia were also taken into account.

The basic characterstics of physical-geographical parameters of evaluated catchments are in table 1, their location is on figure 1 (numbers on the map correspond with numbers in table 1, 2 and 4). Mean yearly discharges, precipitation and base flow values are calculated for the period of 1931-1980 used in Slovakia as a reference period.

The evaluated catchments represent different geological conditions for stream flow and base flow formation. Prevailing types of aquifers (crystaline, carbonatic, clastic sedimentary rocks) and permeability in evaluated catchments were taken into account in the process of statistical assessment of the groundwater runoff changes. Among clastic sedimentary rocks other different subtypes with specific conditions of base flow formation can be distinguished (glaciofluvial, volcanic, flysh, alluvial).

Input data and methods of evaluation

Minimum monthly discharges (in m^3/s) of streams in catchments mentioned above (see table 1) were used as input data. All time series had a length of 60 years - since 1931 to 1990. They were assessed as one time series, 1931–1990, and than divided into decades 1931–40, 1941–50, 1951–60, 1961–70, 1971–80 and 1981–90 respectively, to check the possibility of decade - long variations. Trends of mean minimum yearly discharges were also assessed. Values of the mean decade discharge and precipitation decrease as well as of physical-geographical catchment characteristics were used in the process of mutual relationship assessment.

Many methods were created for groundwater runoff estimation. Most of them are based on use of stream flow discharges values. Then the groundwater runoff is estimated by separation (methods of Foster, Natermann and other methods) or by mathematical-statistical processing of data (minimum daily discharges – method of Castany, minimal monthly discharges – method of Kille and other methods). Kille's method is widely used in Slovakia and it was used for task solution, as well. The input data of every time-series were sorted in ascending order and than plotted in semi-logarithmic scale. The account number of every observation was plotted on the x-axis in linear scale and sorted values of minimum monthly discharges in logarithmic scale on the y-axis. A regression straight line was used for straightening of the obtained curve. Thereafter that the value of groundwater runoff was estimated. The time evolution of these results for all catchments and single decades were then compared. Comparison was also made with the results obtained by Krásný (1982). An example of groundwater runoff estimation after Kille is on figure 2.

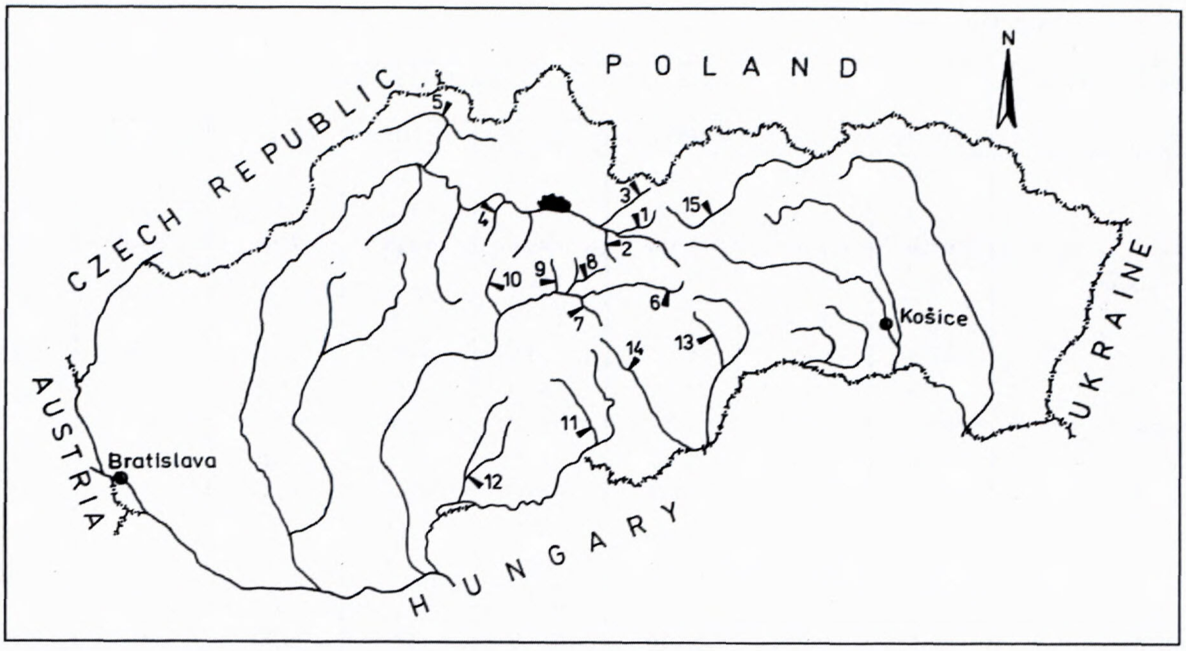

Figure 1 Location of evaluated catchments

Table 1 Basic physical-geographical characteristics of evaluated catchments (modified after Majerčáková et al., 1995).

No.	Name of gauging station	Name of stream	Area	Height of gauging station	Mean yearly discharge	Preci-pitation	Ground-water runoff
			km^2	m a.s.l.	m^3/s	mm	m^3/s
1	Východná	Biely Váh	108.17	731.60	1.640	1196	0.930
2	Kráľova Lehota	Boca	116.60	655.08	2.210	1169	0.985
3	Podbanské	Belá	93.49	922.72	3.540	1948	1.670
4	Ľubochňa	Ľubochnianka	118.48	442.00	2.390	1513	1.370
5	Čadca	Kysuca	492.54	408.36	8.490	1074	1.800
6	Zlatno	Hron	79.28	737.65	1.550	1020	0.680
7	Hronec	Čierny Hron	239.41	480.48	3.170	937	1.300
8	Mýto p. Ďumb.	Štiavnička	47.10	616.71	1.150	1456	0.630
9	Dolná Lehota	Vajskovský p.	53.02	495.28	1.470	1472	0.730
10	Staré Hory	Starohorský p.	62.61	465.95	1.520	1235	0.750
11	Lučenec	Krivánsky p.	204.50	177.50	1.500	752	0.330
12	Plášťovce	Krupinica	302.79	140.61	2.060	712	0.300
13	Štítnik	Štítnik	129.63	84.92	1.610	913	0.660
14	Lehota n. Rim.	Rimavica	148.95	63.56	1.710	919	0.600
15	Poprad-Matejovce	Poprad	311.10	649.42	4.420	893	2.300

The relationships among estimated values of groundwater runoff and some physical-geographical characteristics were studied using statistical methods – regression analysis and factor analysis. The method of cluster analysis was used in looking for relationships among assessed catchments according to estimated values of decade groundwater runoff.

Results and discussion

The results of groundwater runoff estimation for each catchment and each decade are summarised in table 2. They documented a distinct decrease of groundwater runoff values, which has quite serious over the last decade, 1981-1990, in most of the evaluated catchments, except for Ľubochnianka a Kysuca. The strongest decrease comparing with the reference period of 1931-1980 was estimated in catchments of Starohorský potok – 44.7 %, Rimavica – 37.7 %, Štítnik – 33.8 % and Štiavnička – 33.5 %. A greater decrease than 25 % was recorded in the catchments of Biely Váh, Čierny Hron and Vajskovský potok, and greater than 15 % in the catchments of Belá, Boca and Hron.

Statistically significant correlation with the value R_{xy} = -0.614 at the level α = 0.05 was shown between the amount of groundwater runoff decrease and the catchment area. This means, that greater decrease of groundwater runoff occurred in the smaller catchments. Practically no correlation was shown between the percentage of groundwater runoff decrease and the altitude of the gauging station.

Table 2 Estimated groundwater runoff values.

No. and name of river catchment	Groundwater runoff estimated by Kille`s method (m^3/s)							
	1931-40	1941-50	1951-60	1961-70	1971-80	1981-90	1931-80	1931-90
1 Biely Váh	0.960	1.080	1.000	0.790	0.920	0.660	0.930	0.900
2 Boca	1.530	0.895	1.000	0.850	0.855	0.806	0.985	0.970
3 Belá	1.670	1.700	1.610	1.490	1.680	1.290	1.670	1.620
4 Ľubochnianka	1.600	1.240	1.355	1.095	1.527	1.375	1.370	1.370
5 Kysuca	1.900	1.500	1.700	1.500	2.200	1.900	1.800	1.800
6 Hron	0.720	0.685	0.710	0.580	0.635	0.556	0.680	0.668
7 Čierny Hron	1.470	0.940	1.420	1.415	1.250	0.956	1.300	1.230
8 Štiavnička	0.885	0.670	0.570	0.450	0.450	0.419	0.630	0.600
9 Vajskovský p.	0.730	0.680	0.760	0.780	0.700	0.520	0.730	0.720
10 Starohorský p.	0.930	0.600	0.750	0.755	0.600	0.415	0.750	0.701
11 Krivánsky p.	0.295	0.170	0.300	0.450	0.385	0.306	0.330	0.324
12 Krupinica	0.345	0.230	0.270	0.303	0.312	0.266	0.300	0.290
13 Štítnik	1.115	0.755	0.515	0.507	0.517	0.437	0.660	0.609
14 Rimavica	0.615	0.590	0.610	0.615	0.570	0.374	0.600	0.575
15 Poprad	2.800	2.300	2.290	1.960	2.270	2.009	2.300	2.229

Table 3 Results of factor analysis.

Variable	Factor 1	Factor 2	Factor 3
DGR	0.0	0.0	0.682
DMD	0.865	0.0	0.388
DMP	0.752	0.0	0.0
OR	0.0	0.635	0.0
G	0.0	0.890	0.0
HGD	-0.779	0.0	0.0
ARE	0	-0.500	-0.760

Remark: all factor loading values less than 0.250 are replaced by zero value

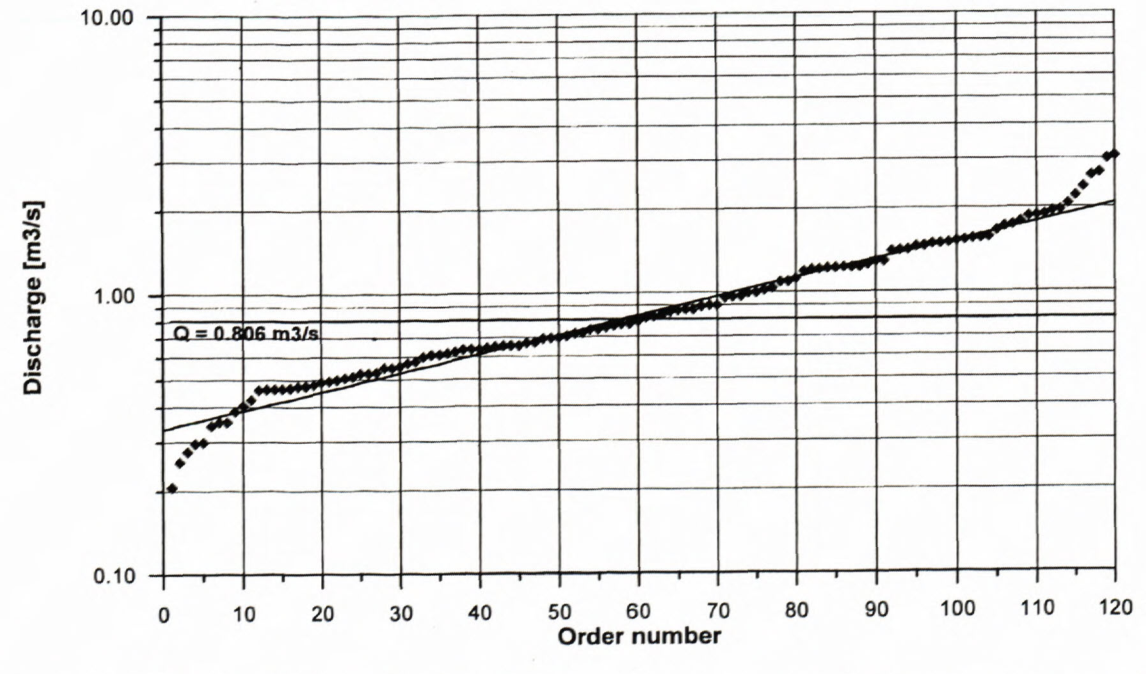

Figure 2 Example of groundwater runoff estimation (river Boca, period 1981–90)

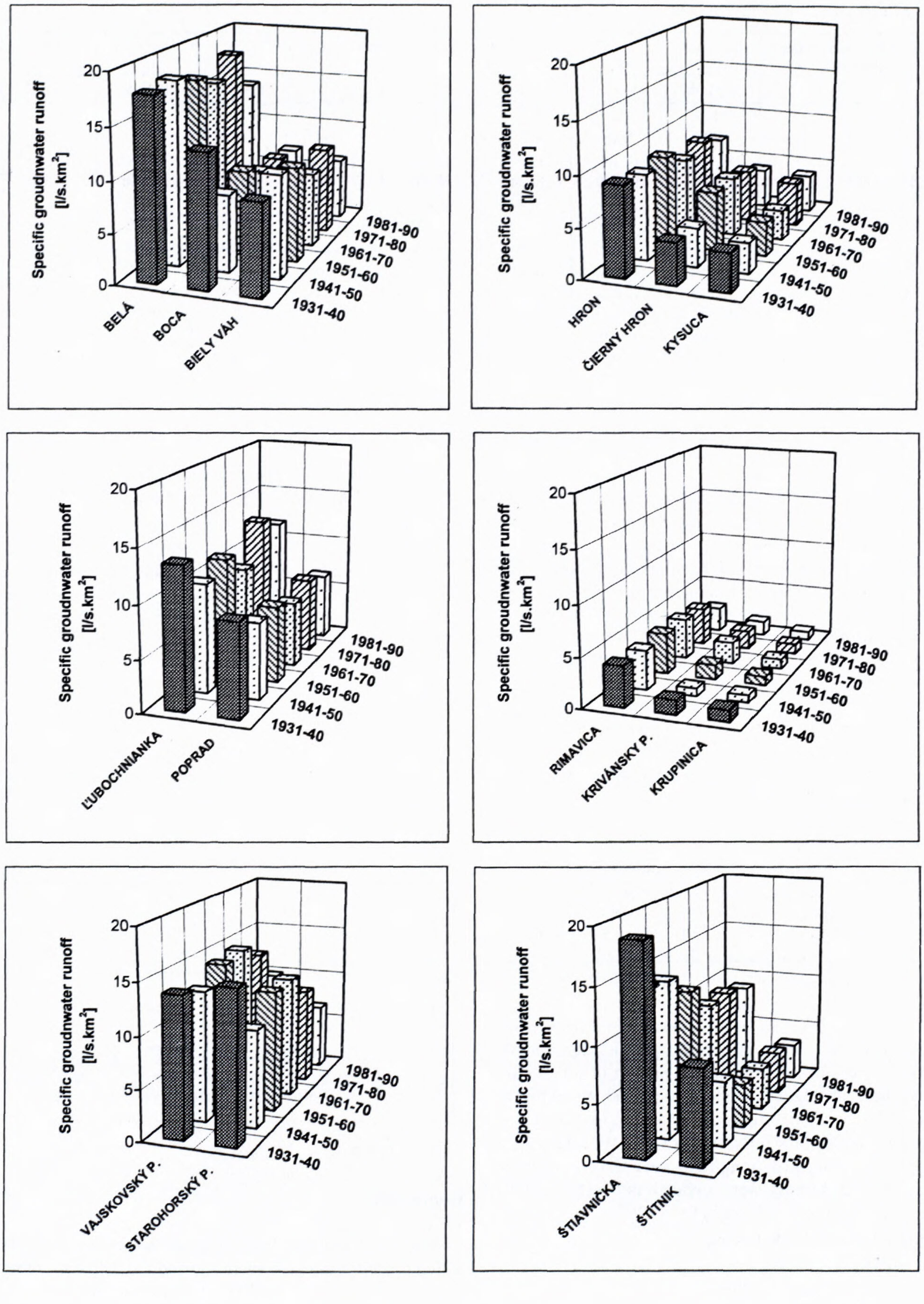

Figure 3 Time evolution of the specific groundwater runoff in selected catchments

Table 4 Estimated values of specific groundwater runoff.

No. and name of river catchment	Specific groundwater runoff (l/s km^2)							
	1931-40	1941-50	1951-60	1961-70	1971-80	1981-90	1931-80	1931-90
1 Biely Váh	9.100	10.20	9.470	7.480	8.710	6.250	8.600	8.520
2 Boca	13.120	7.680	8.580	7.290	7.290	6.910	8.450	8.320
3 Belá	17.860	18.180	17.220	15.940	17.970	13.800	17.860	17.330
4 Ľubochnianka	13.500	10.470	11.440	9.240	12.890	11.610	11.560	11.560
5 Kysuca	3.860	3.050	3.450	3.050	4.470	3.860	3.650	3.650
6 Hron	9.080	8.640	8.960	7.320	8.010	7.010	8.580	8.430
7 Čierny Hron	4.180	3.930	5.930	5.910	5.220	3.990	5.430	5.140
8 Štiavnička	18.790	14.230	12.100	9.550	9.550	8.900	13.380	12.740
9 Vajskovský p.	13.770	12.830	14.330	14.710	13.200	9.810	13.770	13.580
10 Starohorský p.	14.850	9.580	11.980	12.060	9.580	6.630	11.980	11.200
11 Krivánsky p.	1.440	0.830	1.470	2.200	1.880	1.500	1.610	1.580
12 Krupinica	1.140	0.760	0.890	1.000	1.030	0.880	0.990	0.960
13 Štítnik	8.600	5.820	3.970	3.910	3.990	3.370	5.090	4.700
14 Rimavica	4.130	3.960	4.100	4.130	3.830	2.510	4.030	3.860
15 Poprad	9.000	7.390	7.360	6.300	7.300	6.460	7.390	7.160

The results of the method of factor analysis are shown in table 3. Values in every factor column represent the correlation coefficient between factor and every variable. Large values demonstrate a close relationship, low correlation coefficients were replaced by a zero value. Large factor loadings in factor 1 had variables DMD (% decrease of mean discharge in the period 1981-1990 compared to the reference period of 1931-80), DMP (% decrease of mean precipitation in the period 1981-1990 compared to the reference period) and HGD (height of the gauge datum in meters above sea level). The minus sign belonging to the variable HGD means that the decreases of precipitation and discharges are higher in the catchments with the lower height of the gauge datum. Large factor loadings in factor 2 had variables OR (orientation of the catchment according to air movement direction) and G (geology). Both variables were used in the form of categorical variable, therefore they entered into the same factor. In factor 3 large loadings had variables DGR (% decrease of groundwater runoff in the period of 1981-1990 compared to the reference period) and ARE (catchment area in km^2), again with the opposite sign.

The estimated values of groundwater runoff were recalculated to the values of specific groundwater runoff. Evaluated catchments differ in the pattern of alternation of decades with higher and lower specific groundwater runoff values compared to the reference period as well as in the magnitude of the differences (Tab. 4, Fig. 3).

Based on values of long-term specific groundwater runoff, the catchments were divided into eight groups according to method of Krásný et al. (1982):

- group I: none of catchments,
- group II: Krupinica,
- group III: Krivánsky potok
- group IV: Kysuca,
- group V: Štítnik, Rimavica,
- group VI: Čierny Hron,
- group VII: Biely Váh, Boca, Hron, Poprad,
- group VIII: Belá, Ľubochnianka, Štiavnička, Vajskovský potok and Starohorský potok.

Long-term values of specific groundwater runoff were compared to the results obtained for the last decade, 1981-90. For this decade all catchments, except Belá and Ľubochnianka from group VIII, Rimavica from group V and catchments from groups II and III, moved to the next group with smaller values. Descending trends of mean yearly discharges were shown in all catchments except of Kysuca.

The results of cluster analysis are shown on figure 5. The pattern of clusters is conditioned by specific groundwater runoff values – close to each other are catchments with comparable values of specific groundwater runoff.

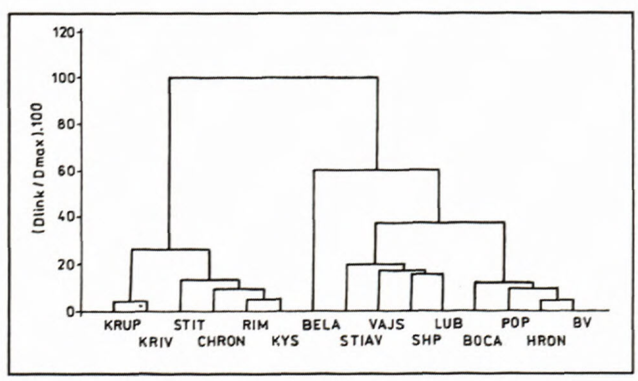

Figure 4 Results of cluster analysis

Conclusion

The results of the study of groundwater runoff of selected catchments in Slovakia showed the different intensity of groundwater runoff changes, as well as the different pattern of their time evolution during the period of 1931-1990, as it can be seen in figures 3. The decrease of groundwater runoff and specific groundwater runoff characteristics in the last decade, 1981-1990, is evident in most catchments. In some cases the decrease of groundwater runoff is strenghtened by overexploitation of groundwater resources, as it was demonstrated in Starohorský potok catchment (Fendeková & Némethy, 1994).

No clear territorial relationship was found. The decrease of groundwater runoff characteristics was closely connected only with the individual catchment area. The lack of data from the Eastern Slovakia did not enable to assess the whole territory of Slovak Republic.

Acknowledgment

The paper presents results obtained during the execution of the Grant Project No. 1/4165/97, financed by VEGA Agency of the Slovak Ministry of Education.

References

Balco, M., 1990: Low flow of the rivers in Slovakia. Veda Bratislava, 264 p. (in Slovak with English summary)

Fendeková, M., 1994: Analysis of changes and variability of spring yields on the territory of Slovakia in areas built by flysh rocks. Partial report of the subproject of National Climate Program, Manuscript, Slovak Hydrometeorological Institute, Bratislava. (in Slovak with English summary).

Fendeková, M., Gavurník, J., Kullman, E. Jr. & Sadloňová, K., 1995: The influence of global climate change on spring yields on the territory of Slovakia. Proceed. of the Conference: AQUA´95. Technical University of Slovakia, 8-18. (in Slovak).

Fendeková, M. & Némethy, P., 1994: Low flows of Starohorský potok brook and their affecting factors. IAHS Publ., Vol. 221, IAHS Press, Wallingford, 165-169. (in English).

Gavurník, J., Kullman, E. Jr. & Sadloňová, K., 1994: Analysis of changes and variability of hydrological elements (analysis of changes and variability of spring yields on the territory of Slovak Republic). Partial report of the subproject of National Climate Program, Manuscript, Slovak Hydrometeorological Institute, Bratislava, 13 p. (in Slovak with English summary).

Hanzel, V. & Melioris L., 1996: Groundwater of Slovakia: their share in public water supplies. Podzemná voda. Vol. 2, Nr. 2, Bratislava, 5-11. (in Slovak with English summary)

Hyánková, K., Fľaková, R., Gulišová, D. & Ženišová, Z., 1993: Qualitative changes of groundwater in fissure-karst Mesozoic rocks. Proceed. of the conference: Water sources and their protection. Bratislava, STU, 257-267. (in Slovak).

Hyánková, K., Némethy, P. & Ženišová, Z., 1991: Changes of chemical composition of surface water during bank filtration. J. Hydrolog. Hydromech., 39, 1991, Nr. 3-4, 280-292. (in Slovak with English resume)

Chalupka, J. & Kullman, E., 1992: Contribution to the evaluation of steady natural decrease of groundwater sources yields caused by influence of climatic factors. Proceed. of the symposium: Use of groundwater relating ecology. Slovak Association of Hydrogeologists, Rajecké Teplice, 95-103. (in Slovak)

Kille, K., 1970: Das Verfahren MoMNQ, ein Beitrag zur Berechnung der mittleren langjährigen Grundwasserneubildung mit Hilfe der monatlichen Niedrigwasserabflüsse. Z. Deutsch. geol. Gessell., 89-95. (in German)

Krásný, J. et al., 1982: Groundwater runoff on the territory of Czechoslovakia. Czech Hydrometeorological Institute, Prague, 52 p. (in Czech with English summary)

Kullman E. & Chalupka, J., 1995: Decrease in the yield of groundwater resources in Slovakia and appraisal of its causes. Podzemná voda. Vol. 1, Nr. 1, Bratislava, 58-74. (in Slovak with English summary)

Kullman, E., 1965: Specific groundwater runoff in the Western Carpathians and possibilities of its utilization by solution of basic hydrogeological questions. Proceed. of Geological science, Hydrogeology 3, Prague, 169-187.

Kullman, E., 1996: Groundwater sources and resources and their protection and relation to ecology. Podzemná voda. Vol. 2, Nr. 2, Bratislava, 12-18. (in Slovak with English summary)

Kullman, E., Jr., Slamka, I. & Gavurník, J., 1995: Assessment of influences of climate changes on spring yields regime and the presumption of their impact on accessible groundwater amounts. Partial report of the subproject of National Climate Program, Manuscript, Slovak Hydrometeorological Institute, Bratislava, 43 p. (in Slovak with English summary)

Majerčáková, O., 1994: Assessment of mean long-term discharges according to possible climatic changes. Vodohospodársky spravodajca, Vol. XXXVII, No. 10, 12-14. (in Slovak)

Majerčáková, O., Lešková, D. & Šedík P., 1995: Selected characteristics of low flows of Slovak rivers. J. Hydrol. Hydromech., 43, 4-5, 331-353. (in English).

Marečková, K. et al., 1997: Country study Slovakia. Final report. U. S. Country Studies Program support for climate change studies, communications and technology assessment. Slovak Hydrometeorological Institute, Bratislava, 107 p. (in English)

Némethy, P., 1996: Management of ground water taking in dependence on climatic conditions. Proc.: Karst-fractured aquifers – vulnerability and sustainability. Prace Naukowe Universitetu Slaskiego w Katowicach, Nr. 1563, Katowice, Poland, 162-168. (in English)

Puskás, T., Vuglinskij, V. S., Mendel, O., Popov, O. V. & Freydank, E. (Eds.), 1984: Water Balance Maps for the Territory of Central and Eastern Europe (Explanatory report). Budapest, 88 p. (in English)

Szolgay, J., Hlavčová, K., Mosný, V. & Parajka, J., 1997: Temporal and spatial changes of hydrological balance at the territory of the Eastern Slovakia. STU Bratislava, 213 p. (in Slovak with extended English resume)

Takáčová, D., 1996: Possible consequences of climate change on groundwater level (middle und lower Hron river). Final report of the subproject NCP SR, Slovak Hydrometeorological Institute, Bratislava. (in Slovak)

Trizna, M., 1996: The regime changes of the outflow of surface flows in Turčianska kotlina. AFRNUC, Geographica, Nr. 39, 67-88. (in Slovak with English resume)

Vsevoložskij, V. A., Zekcer, I. S., Konopljancev, A. A. & Fideli, I. F., 1977: The main principles of regional estimation and mapping of ground-water flow of the Central and Eastern Europe. J. Hydrol. Sci., 4, 1977, Nr. 2, 85-95. (in English)

Zaťko, M., 1996: Analysis of average monthly and weekly values of the groundwater table in Turčianska kotlina. AFRNUC, Geographica, Nr. 39, 51-66. (in Slovak with English resume)