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Influence of Land Use on Water Quality in Mountainous Areas – A case study from Slovakia

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Abstract:

Geologic and geomorphologic conditions of Slovakia are very complicated, which is reflected also in the complex hydrogeologic conditions of the territory. Several surveys of regional character studied in detail all factors controlling groundwater quantity and quality on the territory of Slovakia. However, the authors only rarely studied the effects of land use character (type) on groundwater quality.

Key words: natural water, contamination, land use, technogenic condition

(8 Figs., 5 Tabs.)

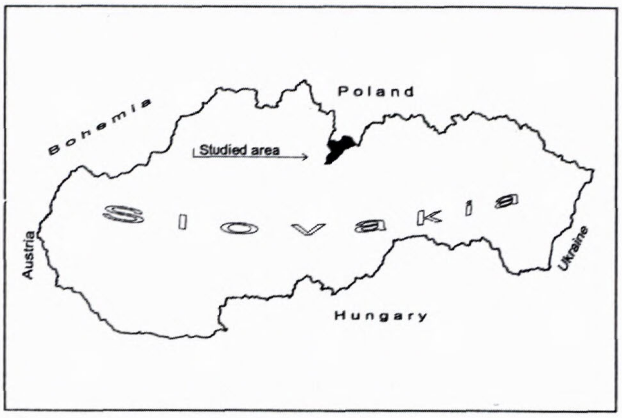

Fig. 1: Localisation of the studied area

Introduction

Geologic and geomorphologic conditions of Slovakia are complicated, which is reflected also in the complex hydrogeologic conditions of the territory. In several surveys of regional character (GAZDA, 1983, HANZEL et al., 1984, HANZEL et al., 1989) all factors controlling groundwater quantity and quality have been studied in detail. However, the authors studied only rarely in detail the effects of land use character (type) on groundwater quality.

The territory of Slovakia may be divided from the viewpoint of relief type and economic exploitation into several units (MAZÚR, 1980):

- Areas of lowlands and open basins – relief with very high potential for economic activities
- Areas of closed basins and flat furrows – relief with high potential for economic activities
- Areas of foothills, low platforms and closed furrows – relief with limited potential for economic activities
- Areas of disjointed uplands and platforms – relief with low potential for economic activities
- Areas of massive uplands, mountains and high mountain ranges – relief with very low potential for economic activities

The presented contribution is focused on the analysis of the relationship between water quality and type of land use on the example of the river Belá, Tatry Mts., Slovakia.

The upper part of the Belá catchment is found in the Vysoké and Západné Tatry Mts., representing the mountainous part of the Slovak territory, and the lower part is located in the Liptov Basin, representing the foothills (Fig.2). From the viewpoint of land use they are two different units (two land structures), with different potential of use.

The lower part of the catchment (Liptov Basin) is a high-lying basin accumulation-erosion land. The upper part (Tatry Mts.) is a mountainous land with higher altitude levels.

The Liptov Basin represents the type of a multifunctional, industrial-recreational-agricultural land with three subtypes. One of them are areas of urban industrialised land, with predominant technical-constructional elements (industry, communications etc.). Another subtype is agricultural land of rural to

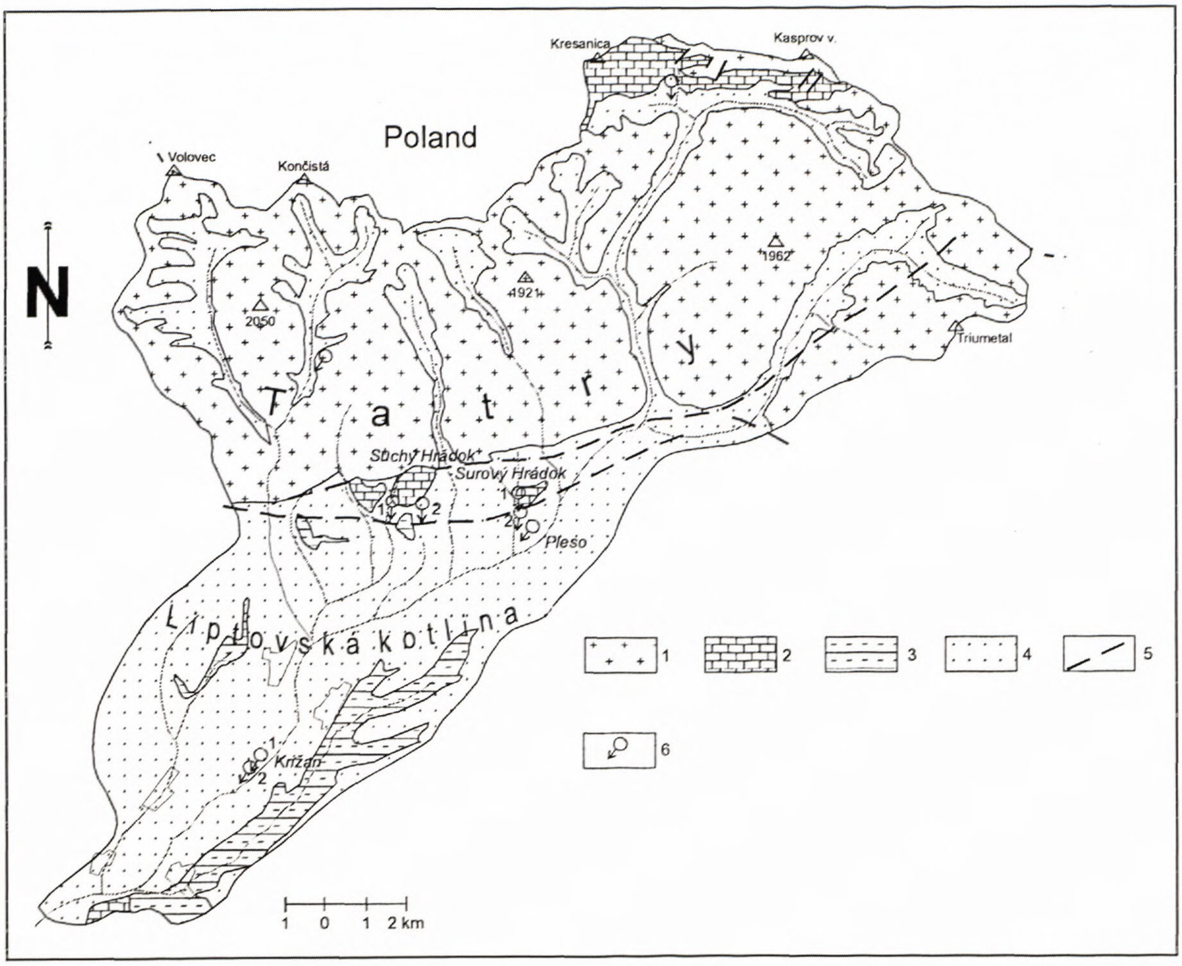

Fig. 2: Hydrogeologic sketch of the Belá river catchment

1 – granitoids, crystalline schists, fracture permeability, 2 – limestones, dolomites, quartzites, Mesozoic as a whole, fracture and karst-fracture permeability, 3 – alternation of sandstones and claystones, Paleogene, as a whole unpermeable, 4 – gravel-sand and boulder sediments, Quartenary, intergranular permeability, 5 – faults, subtatric fault zone, 6 – important springs

transitional-rural settlement structure, with arable land - grassy cultures, which is the greater part of the basin. Only on the northern margin of the basin there is agricultural-recreational to recreational land with predominant grassy-forest cultures and recreation facilities. The last two subtypes are characteristic of the lower part of the studied catchment. From the viewpoint of raw material the potential of the Liptov Basin is connected only with occurrences of construction materials (gravels, building stone).

The economic potential of the upper part of the catchment (in Tatry Mts.) is limited by the topography and altitude, reflected in the low population density and low degree of agricultural land use. This part of the territory has great tourism and recreation potential, manifested in the construction of various tourist facilities, sports facilities (ski lifts), building of tourist paths and roads. In this way the visitors rate of the territory increases extremely. In spite of this, Vysoké and Západné Tatry Mts. is a land type with little damaged structure.

The upper part of the catchment belongs to the Tatry National Park (TANAP), which should ensure land protection, connected with limited forest exploitation and protection of raw material resources.

Hydrology and hydrogeology

The Belá river catchment has a surface of 244.3 sqkm. With its altitude it belongs to the highest-lying catchments of Slovakia, the average altitude being 1283 m a.s.l. From the viewpoint of altitude range, the S part of the catchment (Liptov Basin) has the character of uplands (up to 300 m) and the N part (Západné Tatry and Vysoké Tatry Mts.) are high mountains (above 640 m) with typical glacial relief and glacially remodelled valleys (Tab.1).

According to the Atlas of Slovak Socialist Republic (1980), the runoff regime in the Tatry Mts. (upper part of catchment) is transitional mountainous nival, in their lower parts nival-pluvial, and in the lower part (Liptov Basin) nival-pluvial. The higher is the relief, the more rapid is the water runoff toward erosion bases and the shorter is the contact with rock environment.

Precipitation is the only source of water supply in the catchment. No surface water flows into the catchment, nor any surface water flows off. Similarly, groundwater does not flow in, but outflow of groundwater cannot be excluded. Water discharge in the Belá river catchment in the years 1984–1990 is listed in Tab. 2.

The conditions of groundwater source formation are considerably different in the upper and in the lower part of the catchment. A natural boundary (separating line) is the subtatric fault (Fig. 2).

The upper part of the catchment has a surface of 155.9 sqkm and is built predominantly of granitoids, partly crystalline schists (Fig. 2), with a surface of 148.5 sqkm, and in the highest-lying part of the catchment also by Mesozoic rocks of the Červené vrchy Mts., with a surface of 7.4 sqkm. The inhomogeneous crystalline massif of the Tatry Mts. is characterised by the presence of various local groundwater circulation ways and intensive infiltration of atmospheric precipitation, which is in fact the only source of water supply to groundwater resources. Important is however the hydrogeologic function of glacigenic sediments in valleys and at foot of slopes, the water of which is almost in all cases directly hydraulically connected with streams at the bottom of valleys. The groundwater regime of the crystalline massif in the upper part of the catchment is affected by the hydrogeologic structure of the Červené vrchy Mts. Mesozoic, built of

Tab.1 Characteristics of the studied catchment

Part of catchment	Mountain range Vysoké and ZápadnéTatry Mts.	Foothills Liptov Basin
Drainage area [sqkm]	155,9	88,4
Altitude [m a.s.l.]	900–2428 to	630–900
Length of river km	16,5	19,2
Inclination of drainage area %	14–30	0–6
Energy of relief [r = 1 km]	180-640 m and above extremely cut relief in part deeply to very deeply	30–180 m slightly hummocky to slightly cut relief
Climatogeographical type	mountain climate, cool to very cold	basin climate, cool
Temperature	January: -6 to -10° C July: 4 to 14°C	January: -5 to -6°C July: 14 to 17°C
Snow cover	180-250 days	120–180 days
Maximum snow cover	75–150 cm	25–75 cm
Annual precipitation	800 up to over 2000	700–800
Soil type	humus-ferriferrous podsols and primitive litosols	fluvial plane illmenised soils
Average annual elementary runoff [$l.s^{-1}$. sqkm]	20 to 60	10 to 20
Type of runoff regime	transitional nival, in lower parts also nival-pluvial	nival-pluvial

Data according to Atlas of Slovak Socialist Republic, 1980

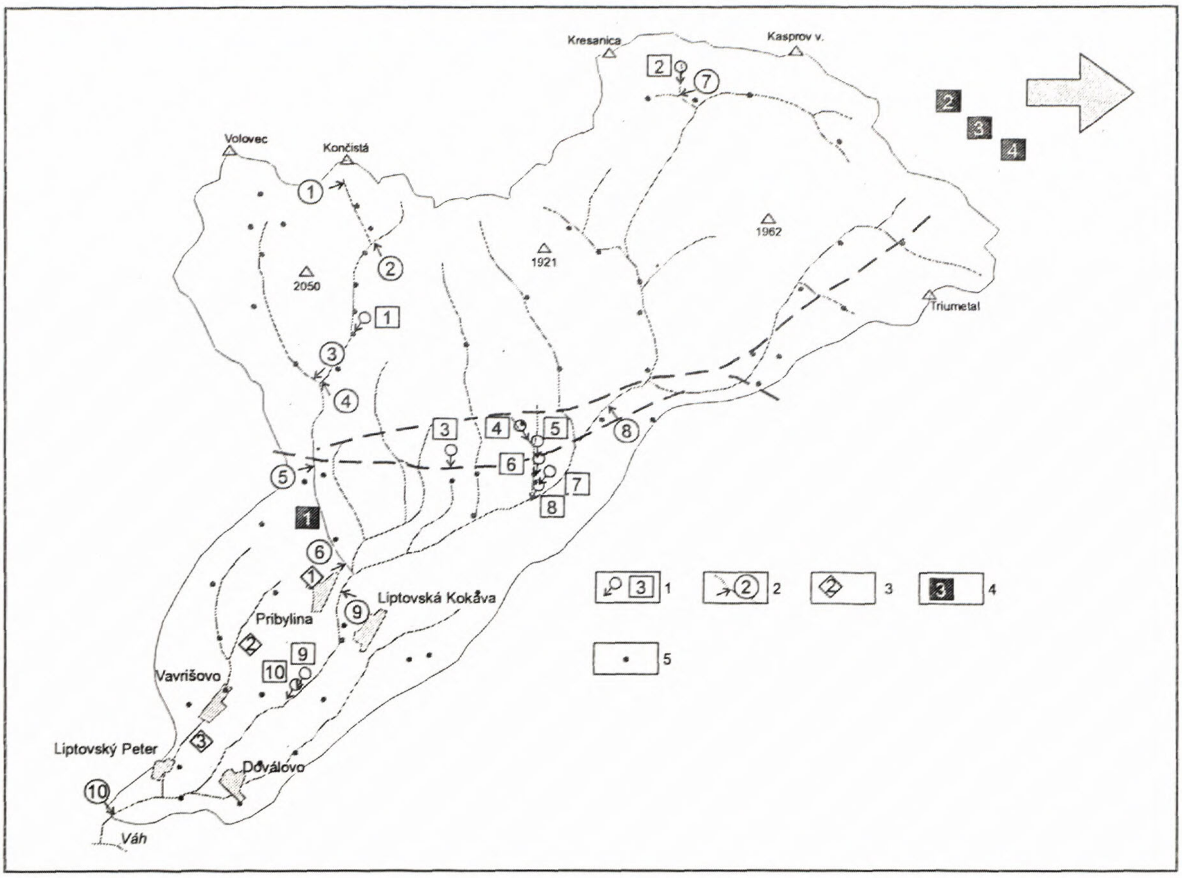

Fig.3: Localisation of sampling sites of water for chemical analysis in the Belá river catchment1
1 – spring , 2 – surface stream, 3 – borehole, 4 – snow, 5 – hydrochemical material (groundwater chemistry) from the project of VRANA *(1992)*

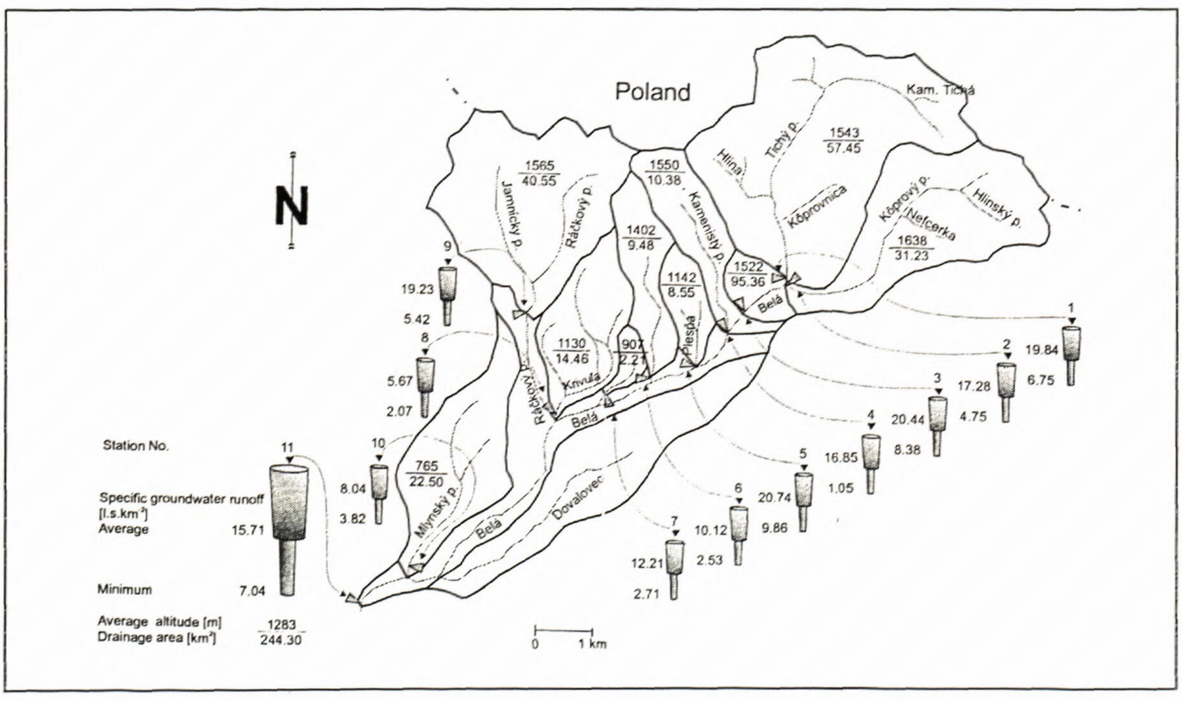

Fig.4: Specific groundwater runoff (l.s. sqkm) in the Belá river catchment (after MATUŠKA *et al., 1980)*

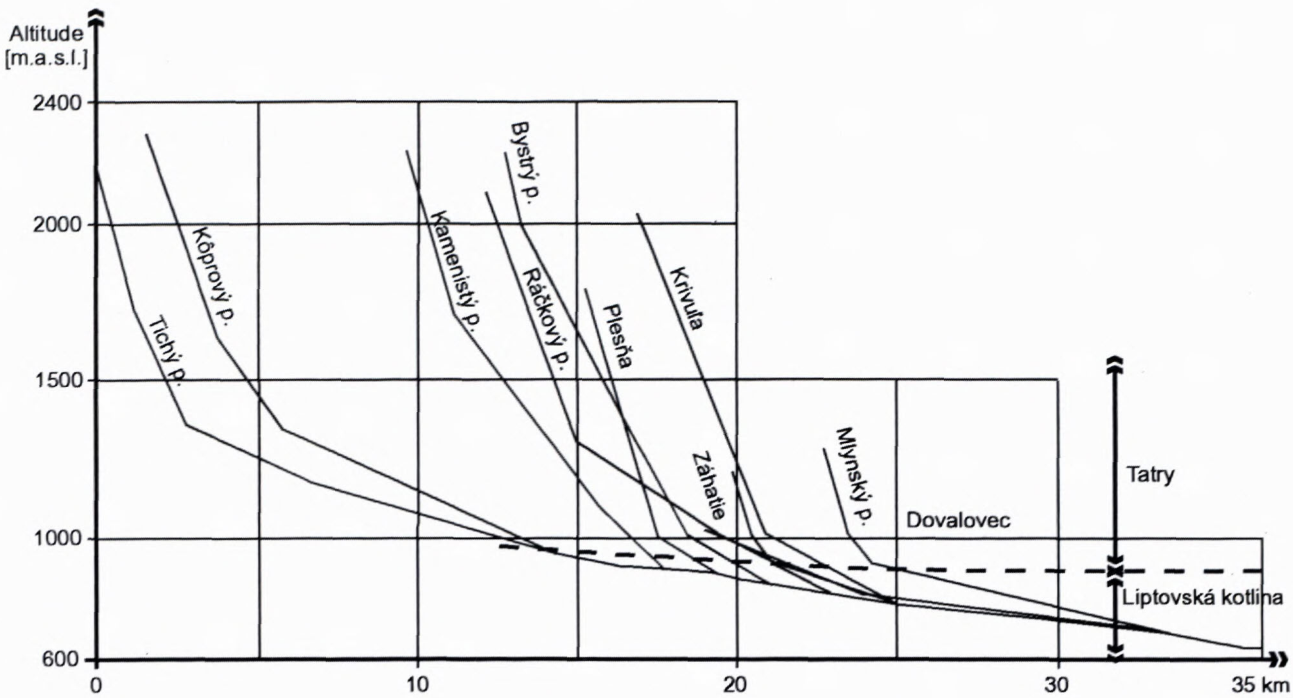

Fig. 5: Schematic lengthwise profile of river network in the Belá river catchment

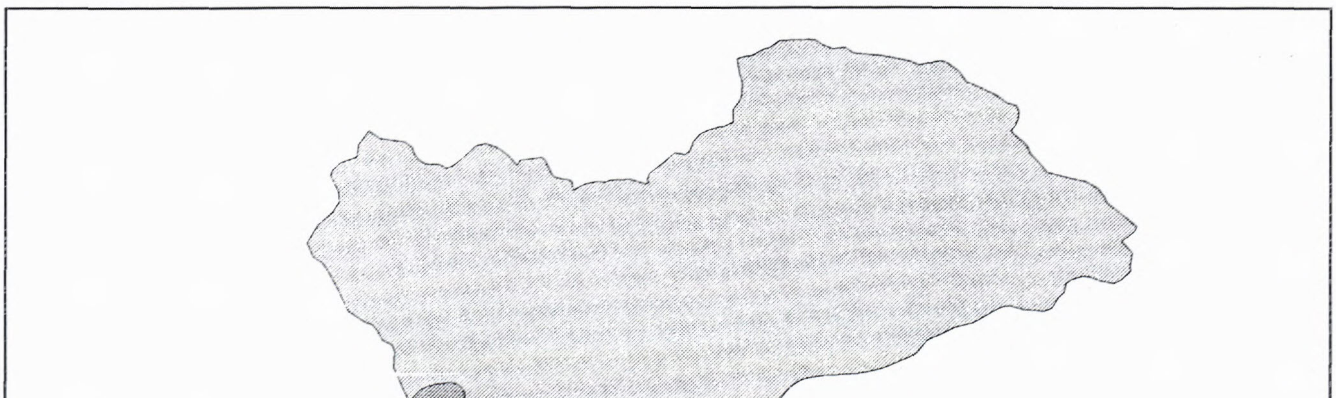

Fig. 6: Distribution of T.D.S. values (mg.l^{-1}) in groundwater. 1: <200; 2: 200-400; 3:400-600; 4: >600

strongly karsted Middle Triassic limestones. Three springs on the Slovak side of the Tatry Mts. have capacities of 18.5 to 60.0 l/s^{-1}. The substantial part of the carbonate structure is however drained into the Dunajec catchment on the Polish side of the Tatry Mts. Groundwater discharge from the Belá catchment is shown on Fig. 4. A lengthwise profile of the Belá catchment river network is presented on Fig. 5.

The crystalline massif has a great influence on the groundwater regime and circulation also in the lower part of the catchment, since along the subtatric fault it is neighbouring the Mesozoic, Paleogene and Quaternary sediments of the Liptov Basin (Fig.2). Due to its exposure and high precipitation, the Tatry Mts. crystalline massif is to a considerable extent the direct or indirect source of water supply to groundwater of younger sedimentary complexes. In spite of the fact that only small carbonate areas appear on the surface in the "islands" of Surový and Suchý Hrádok (with a surface of 0.25 and 1.17 sqkm, respectively), springs with very high capacities (average capacities 1 to 28 $l.s^{-1}$, see springs Suchý Hrádok 1, 2 and Surový Hrádok 1, 2 /No. 3, 4, 5, 6 on Fig. 3) are flowing out from these Mesozoic "islands". The springs are flowing out on the contact with impermeable Paleogene flysch sediments. High capacities of these springs are the result of extensive drainage effect of highly permeable carbonates and the subtatric fault, which are also draining groundwater from the adjoining crystalline massif and Quaternary sediments (HANZEL et al., 1990).

The lower part of the catchment in the Liptov Basin has a surface of 88.37 sqkm and it is built predominantly of Quaternary sediments, the underlier of which as a whole is formed of a relatively impermeable Paleogene flysch formation. Glacifluvial and fluvial Quarternary sediments (presenting the most favourable conditions for groundwater accumulation) are filling the fluvial plain of Belá from Podbanské to the confluence with Váh river, and they occur as well in the form of terraces. Hydraulic parameters of these sediments are documented in Tab. 3. Groundwater flow direction in Quaternary sediments is consistent with the inclination of the impermeable flysch underlier. The Belá fluvial plain becomes narrower in the direction of river flow, from about 2.0 km at Vavrišov to several tens of meters at Liptovský Peter (Fig. 2). As a result of this, groundwater cannot flow uninhibited in the fluvial sediments and a part is flowing out as springs.

Discharges of the significant springs from Quatenary sediments are in Tab. 4.

The river Belá drains its fluvial sediments all year long, only at high water levels in the river infiltration from the river into fluvial sediments may occur (however only in the area NE of Pribylina). Supply of water to Quaternary groundwaters in the lower part of the Belá catchment is mostly from snowmelt and by influx of groundwater from the higher situated cone of Račkova Valley (TUŽINSKÝ et al., 1971).

Groundwater of Quaternary sediments in the lower part of the catchment is supplemented by infiltration from precipitation, especially in the hilly part of the catchment, by infiltration from surface streams and, as documented by hydrometric work in the years 1985, 1988 and 1989, also by penetration of groundwater from the adjoining part of the Tatry Mts., from the entry of the Račkova Valley to Podbanské, where losses of water from surface streams have been recorded.

The mentioned natural and technogenic conditions affect in a decisive way the chemical composition of water on the territory.

Water chemistry

Chemical composition of natural water (snowmelts, streams, springs, boreholes) is listed in Tab. 5. These data are complemented for further graphical evaluation by chemical analyses of water from springs and boreholes obtained from the project "Geochemical Atlas of Slovakia" (VRANA, 1992). Their localisation is shown on Fig. 3. The presented snow chemistry allows to estimate initial chemistry of infiltrating water in the catchment.

Figs. 6, 7 and 8 show the distribution of total mineralisation, sulphate and nitrate values in the Belá river catchment. The distributions have been calculated using the inverse distance method and thus obtained data were subsequently smoothened by moving average method.

Discussion and conclusion

The presented hydrochemical data show that natural conditions in the Belá catchment are the reason for the differentiation of water chemistry, due to different hydrogeologic and hydrogeochemical properties of silicate and carbonate rocks. Springs in Mesozoic carbonates flowing out even in great altitudes (e.g. No. 2) have 2 to 3 times higher

Tab.2 Average monthly and annual discharge in the Belá river catchment in the years 1984-1990 (according to SHMÚ)

Flow station	surface (sqkm)	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Ann. average
1. Tichý brook Tichá Val.	57,45	776	691	620	559	614	2301	5972	3704	2158	1751	2139	1139	1874
2. Kôprový brook Kôprová Val.	31,23	473	381	357	297	264	867	3136	2327	1328	1072	1228	790	1152
4. Kamenistý brook Podbanské	10,38	122	126	93	95	119	437	1282	717	279	210	310	200	334
9. Račkov brook Račková Val.	40,55	797	734	561	463	689	2187	4990	2528	1507	1219	1726	1134	1550
3. Belá Podbanské	95,36	1350	1155	1068	919	957	3629	10683	5472	3895	2985	3723	2184	3263
11. Belá Lipt. Hrádok	244,30	2789	2566	2039	1862	2587	7645	19089	11209	6624	5042	6605	4231	6038

Tab. 3 Hydraulic parameters from Quaternary sediments of Belá

Profile	Number of boreholes	Thickness of Quaternary sediments	Water level (m)	max. Q ($l.s^{-1}$)	q ($l.s^{-1}.m^{-1}$)	k ($m.s^{-1}$)
Príbylina	5	8,0–17,0	1,0–5,5	0,16–11,0	0,07–8,17	$1,0.10^{-5}$– $8,4.10^{-4}$
Vavrišovo	6 5	4,0–14,5 6,6–14,0	1,3–2,2 1,5–6,2	2,6–20,0 2,9–15,0	1,74–8,0 1,35–7,95	$3,5.10^{-4}$– $4,2.10^{-3}$ $3,0.10^{-4}$– $1,1.10^{-3}$
Liptovský Peter	3	4,0–12,0	1,4–3,0	0,6–9,9	0,3–3,8	$5,6.10^{-4}$– $5,8.10^{-4}$

Q – volume discharge, q – specific capacity, k – hydraulic conductivity

Tab. 4 Discharge of springs in Quaternary sediments

Spring locality	Altitude a.s.l m	Discharge $l.s^{-1}$ min	max	average	Observed – time,who
Križan-1 Vavrišovo	720,0	27,7	61,8	41,5	1985–1990, SHMÚ
Križan-2 Vavrišovo	720,0	21,0	58,4	28,1	1985–1990, SHMÚ
Pleso Príbylina	883,0	10,9	52,1	23,3	1985–1990, SHMÚ

total mineralisation (up to 150 $mg.l^{-1}$) than springs flowing out in crystalline complexes. As it has been already mentioned, specific conditions are associated with springs in lower altitudes connected with carbonate "islands". The value of their total mineralisation is variable, but generally it attains about 100 $mg.l^{-1}$. Large springs flowing out in Quaternary sediments as a result of change in hydraulic conditions (springs No. 9 and 10) characteristically reflect already by their primary chemistry the influence of predominant silicate type of rocks of groundwater circulation.

All springs in the catchment display a very low contamination degree, which may be documented by low concentration values of chlorides, nitrates and sulphates, comparable with initial values of infiltrating precipitation water. However, certain anthropogenic influences may be observed in slightly increased sulphate values, especially in springs flowing out in the lowermost part of the catchment (No. 9 and 10).

As it can see on data from Tab. 5, surface waters differ very little in their chemistry in the whole

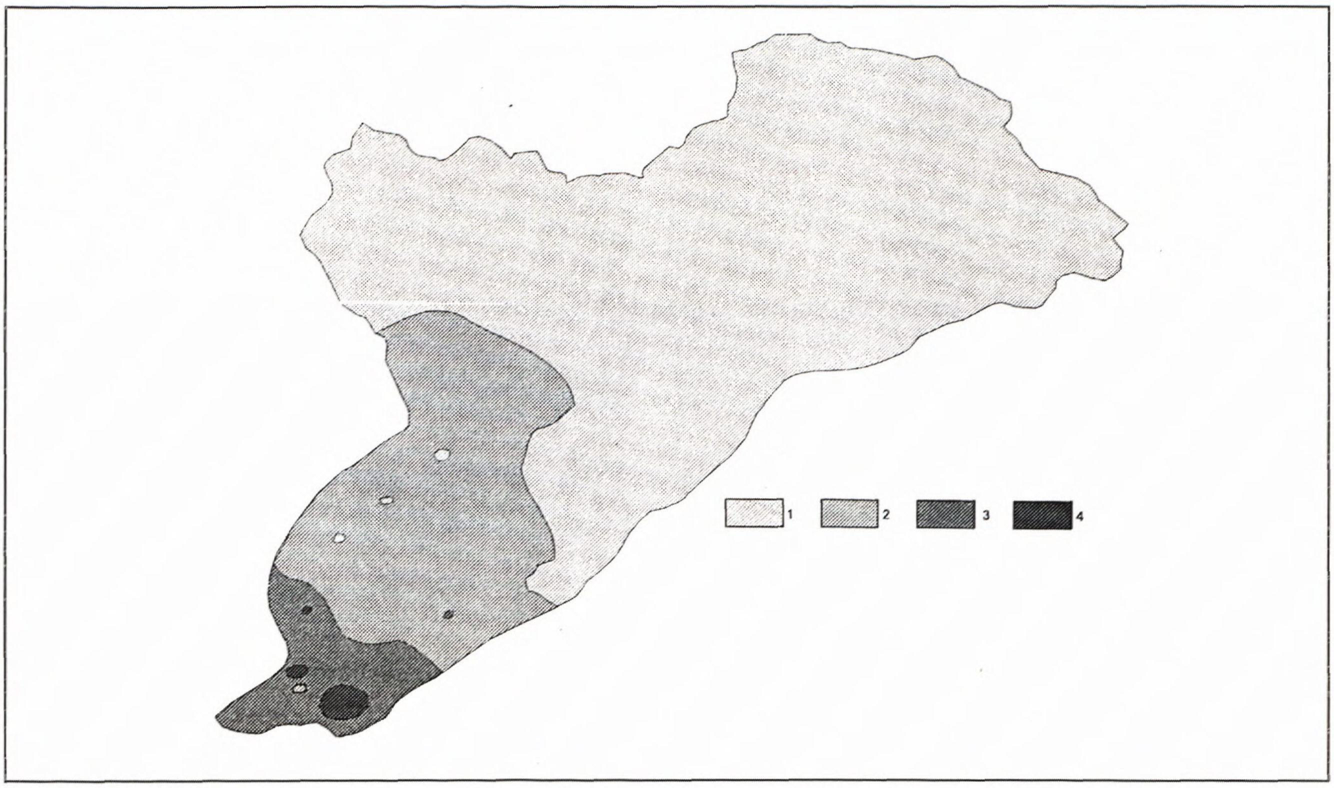

Fig.7: Distribution of sulphate concentration values (mg.l^{-1}) in groundwater. 1: < 10; 2:10-25; 3: 25-50; 4: > 50

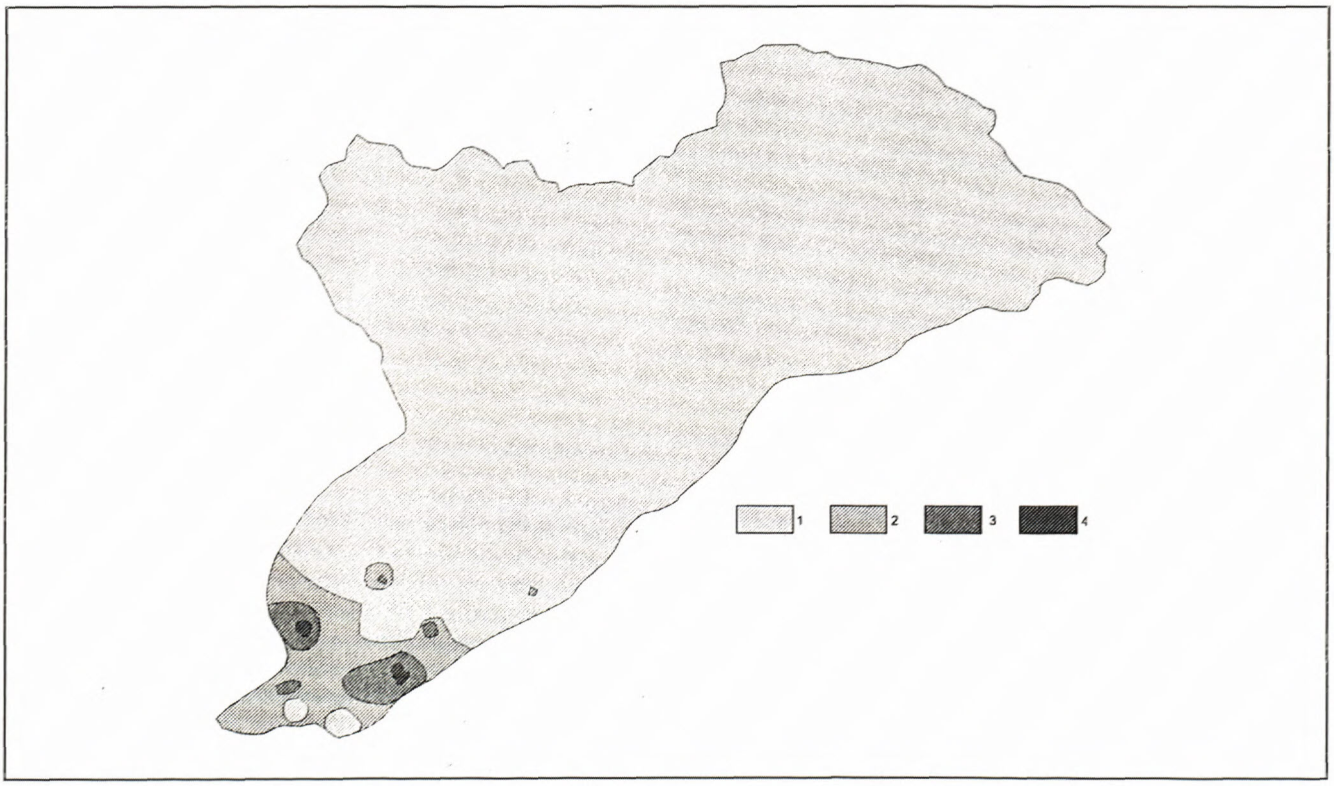

Fig.8: Distribution of nitrate concentration values (mg.l^{-1}) in groundwater. 1: <15; 2: 15-25; 3: 25-50; 4: >50

Tab. 5 Water chemistry in Belá river catchment

Water	pH	TDS	Na	K	NH_4	Ca	Mg	Cl	NO_3	SO_4	HCO_3
		mg . l^{-1}									
■ Snowmelt											
1	4.57	14.7	0.31	0.20	0.59	1.47	0.25	2.93	1.55	4.36	-
2	4.44	10.3	0.32	0.09	0.40	0.81	0.14	2.51	1.32	3.15	-
3	4.70	13.0	0.52	0.10	0.37	1.56	0.36	4.80	0.68	2.45	-
4	4.85	7.6	0.11	0.04	0.91	0.23	0.10	0.70	1.15	2.30	-
Stream											
1 n = 5	6.76	34.4	0.42	0.04	<0.05	4.01	1.85	2.13	1.46	4.77	18.31
2 n = 4	6.61	35.0	0.43	0.02	<0.05	4.01	1.40	2.70	1.53	5.97	16.78
3 n = 5	6.83	47.7	0.80	0.34	<0.05	5.77	1.46	1.77	1.94	7.00	21.97
4 n = 12	7.13	52.2	1.00	0.23	<0.05	7.81	1.73	1.61	1.87	8.27	23.98
5 n = 11	7.00	53.3	1.07	0.35	<0.05	7.89	1.66	1.41	2.09	9.65	22.83
6 n = 4	6.75	44.6	0.80	0.23	<0.05	5.61	1.58	1.91	1.58	6.90	21.36
7 n = 1	8.00	159.8	0.10	0.10	<0.05	33.27	4.13	1.06	3.10	5.76	103.73
8 n = 9	7.57	72.2	1.25	0.31	<0.05	12.17	1.78	1.34	2.59	8.99	33.99
9 n = 9	7.50	78.1	1.54	0.39	<0.05	12.25	2.58	2.23	2.47	10.54	37.79
10 n = 8	7.54	113.2	2.69	0.96	<0.05	17.69	3.89	4.40	4.41	14.37	54.52
□ Spring											
1 n = 4	6.73	50.3	1.08	0.10	<0.05	6.41	1.58	2.52	2.43	6.58	22.89
2 n = 1	7.90	148.0	0.10	0.05	<0.05	30.46	3.40	1.24	2.70	4.53	103.70
3 n = 1	7.45	71.9	1.80	0.50	0.10	8.02	2.43	1.24	0.70	6.17	36.61
4 n = 1	6.80	55.3	1.50	0.10	0.11	6.01	2.92	0.89	0.60	6.17	24.41
5 n = 1	7.45	103.0	1.80	0.40	0.09	14.03	4.86	1.77	1.00	11.52	54.92
6 n = 1	7.80	106.7	1.60	0.30	<0.05	15.23	4.38	0.89	1.60	8.64	61.02
7 n = 3	7.03	61.3	1.63	0.30	<0.05	8.55	2.11	1.24	1.87	7.08	28.48
8 n = 1	7.45	64.3	1.70	0.40	<0.05	8.82	1.70	1.55	2.80	10.29	24.41
9 n = 7	6.97	79.0	1.72	0.56	<0.05	12.39	2.57	1.90	2.94	12.37	36.73
10 n = 2	6.89	89.4	2.20	0.62	<0.05	13.77	3.20	2.75	3.08	12.77	42.16
◇ Borehole											
1 n = 3	6.70	96.8	1.53	0.80	<0.05	14.29	4.46	5.26	3.10	12.08	45.56
2 n = 4	6.74	171.3	5.63	5.90	<0.05	23.40	6.51	9.35	18.91	28.89	58.73
3 n = 4	6.74	150.8	4.20	1.93	<0.05	23.87	5.72	8.78	29.65	25.36	38.98

Note: Data on average snowmelt chemistry (1–3) after VRANA et al. (1989), single sample no. 4 taken 26. 1. 1990. Other chemical analyses were obtained within the frame of realization of the hydrogeological project, described in the report for years 1985–1990 (HANZEL et al., 1990)
n – number of samples

catchment. From the presented chemical components, significant for the indication of water pollution in the relevant land use type (agricultural-recreational to recreational land) are especially ammonium, chlorides, nitrates and sulphates. It is however evident that due to the runoff regime (relatively large discharge of brooks during the whole year) the produced pollution is immediately "diluted" to values approaching the typical background concentration values in "clean" mountainous environment.

Principal changes in water chemistry are caused by anthropogenic influences reflecting in principle the type of land use. The distribution of nitrate and sulphate values (as pollution indicators) in groundwater of the catchment (Figs. 6 and 7) shows that these anthropogenic influences are concentrating in the lower half of the catchment, especially in its lowermost part. This corresponds generally to the T.D.S. value distribution (Fig.6) with the exception of the fact that in the area of the subtatric fault we may find also groundwater outflows with increased T.D.S. values, due to CO_2 saturation, and thus also with naturally increased hydrogencarbonates. Since we are evaluating only the first aquifer, we do not deal with this problem in greater detail.

The lower half of the catchment, belonging to the Liptov Basin, is thus characterised by influences of communal and agricultural type contamination. Areally increased chloride and sulphate concentrations in groundwater of the first aquifer occur only in the lowermost part of the catchment, as it is documented by Figs. 7 and 8. The influence of increased concentrations of contaminants is then reflected also in increased T.D.S. values, locally even exceeding 600 $mg.l^{-1}$, although in undisturbed natural conditions expected T.D.S. values even in the lowermost part of the catchment are only about 100-150 $mg.l^{-1}$. This is supported by T.D.S. values and the character of chemistry of large springs (No 9 and 10) flowing out in Quaternary sediments due to already discussed changes of hydraulic parameters of water circulation rock environment.

Finally it must be stressed that the task of hydrogeology in the next period will be to define, in co-operation with land ecologists, characteristic pollution types of natural water in different land units, distinguished on the basis of land use type. This method may contribute significantly to redefining of distinguished territorial units and thus allow considerably more qualified and effective decision-making in the state's ecological policy.

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