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A hydrogeological study of springs in the western part of the Pieniny Klippen Belt, southern Poland

Grażyna ŻURAWSKA

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The Pieniny Klippen Belt is characterised by diverse lithologies and complex tectonic strukture. The hydrogeological regime of sources can help in the recognition of regional hydrogeological conditions of this lithological-structural unit, as they exemplify groundwaters on the surface in a natural state. Long-term stationary observations, have enabled characterisation of water flow rates and chemistry for nine springs, representative of various parts of the Pieniny Klippen Belt. These analyses demonstrate a seasonal variability. The value of the boundary discharge is similar in all analysed springs and reaches values of 4 to 6 dm^3/min.

Grażyna Żurawska, Faculty of Geology, University of Warsaw, PL-02-089 Warszawa, Al. Żwirki i Wigury 93; e-mail: grace76@poczta.onet.pl *(received: January 4, 2002; accepted: September 11, 2002).*

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INTRODUCTION

The Pieniny Klippen Belt is a complex geological unit as regards both lithology and tectonics and thus is an area of particular interest for geologists and hydrogeologists. In the last few years several projects supported by the National Committee for Scientific Research focused on the investigation of springs in this area. In consequence, the general hydrogeological regime of the area was determined; boundaries of the study area and controlling springs were selected and a stationary observation network was created.

In order to further characterise the hydrogeological regime and to determine the resource area and drainage dynamics, 9 control springs were selected. During fieldwork, spring discharges were measured once a month (based on the volumetric method), the basic physical-chemical properties were determined (temperature, pH, electrical conductivity) and water samples were collected to analyse the ion content. The content of four anions (bicarbonates, chloride, sulphate and nitrate) and four cations (calcium, magnesium, potassium and sodium) were established, as well as the TDS (total dissolved solids). A total of 800 analyses of these particular macrocomponents were made. For three springs the measurements of discharge and temperature were taken every 24 hours.

RESULTS OF THE OBSERVATIONS

The study area covers the Polish part of the Pieniny Klippen Belt from the western state border to Lake Czorsztyn. The investigations were carried out on fissure-type springs, characterised by the highest discharges and draining strata of different lithology (Fig. 1). Because most springs in the study area have small discharges, within classes VI, VII and VIII (Małecka, 1981; Żurawska, 1999), according to the classification of Meinzer (Pazdro and Kozerski, 1990), springs of class VI were selected for the analyses (Fig. 2) and for the calculations of hydrogeological parameters crucial for the determination of the drainage dynamics. Table 1 presents the basic hydrogeological parameters obtained in 2000.

Based on the variability index, the springs were included within the highly variable and variable springs of the classification of Maillet (Pazdro and Kozerski, 1990). All springs except one are included in the discharge class VI. They are represented by springs with mean annual discharges of 6 to 60

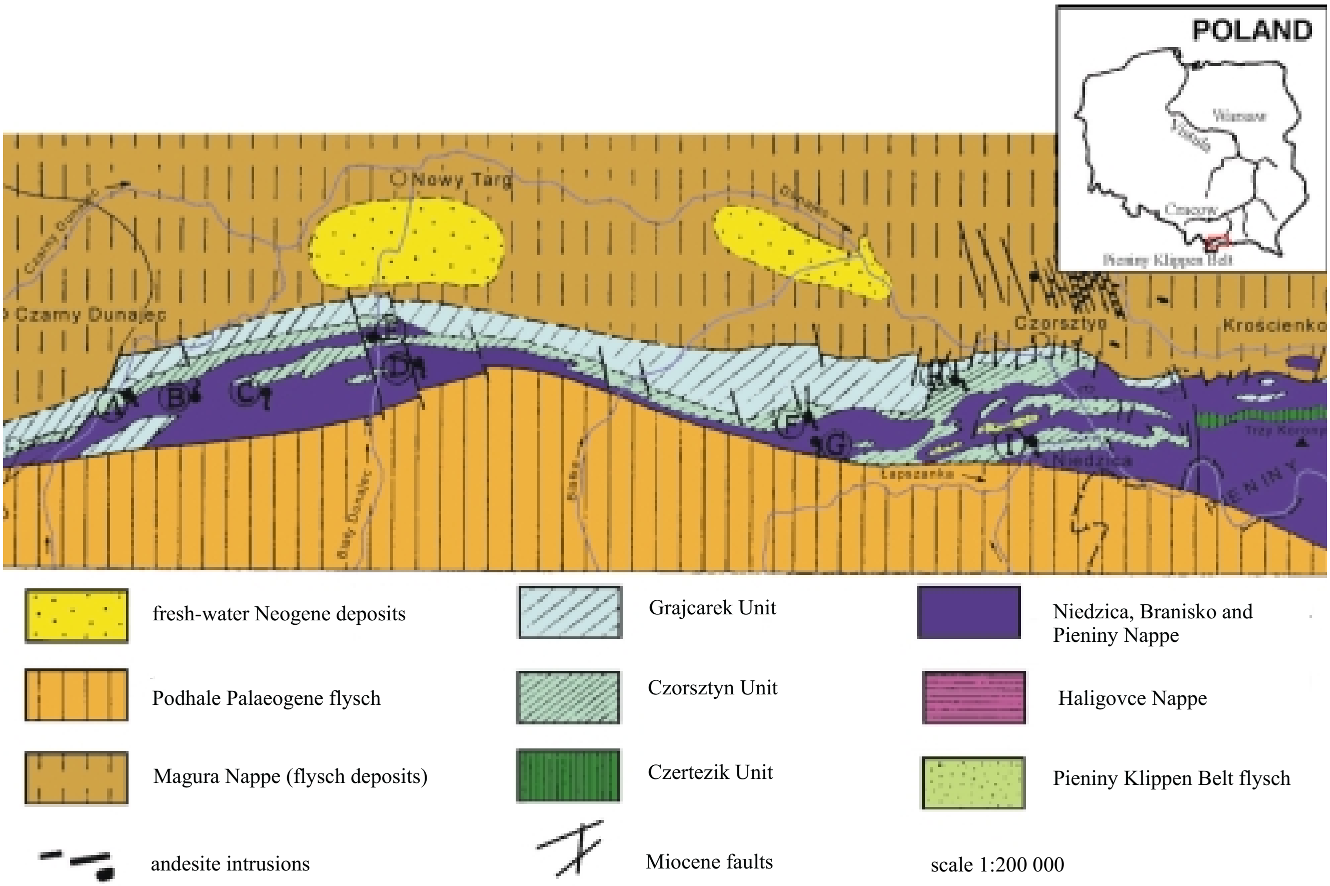

Fig. 1. Location of the springs studied (on a geological sketch map of the Pieniny Klippen Belt, after Birkenmajer, 1985)

Springs: A — Stare Bystre, B — Maruszyna 2, C — Maruszyna 1, D — Szaflary 1, E — Szaflary 2, F — Dursztyn 1, G — Dursztyn 2, H — Falsztyn, I — Niedzica

dm^3/min. The only exception is the "Szaflary 2 (E)" spring, which in 2000 had a lower mean annual discharge of 0.6 to 6 dm^3/min, and thus is included in class VII.

In all cases analysed the recession curves are distinctly bipartite, indicating the existence of two reservoirs recharging each spring — a local and a regional one. The drainage of the two reservoirs is reflected by the steep part of the curve, and the gently sloping part of the curve represents the drainage of water resources only from a regional reservoir (Fig. 2). The dependence of the Maruszyna spring regime from two recharging res-

Table 1

Maximum and minimum discharges from selected springs

Spring localisation (Fig. 1)	Max. discharge [dm^3/min]	Min. discharge [dm^3/min]	Spring variability index *R*	Discharge class of Meinzer
Stare Bystre (A)	42	10.8	3.89	VI
Maruszyna 2 (B)	60	0.6	100	VI
Maruszyna 1 (C)	30	3	10	VI
Szaflary 1 (D)	39.6	2.88	14	VI
Szaflary 2 (E)	10.5	1.26	8.33	VII
Dursztyn 1 (F)	21	0.6	35	VI
Dursztyn 2 (G)	66	0.48	137.5	VI
Falsztyn (H)	180	25	7.2	VI
Niedzica (I)	27.6	2.1	10.5	VI

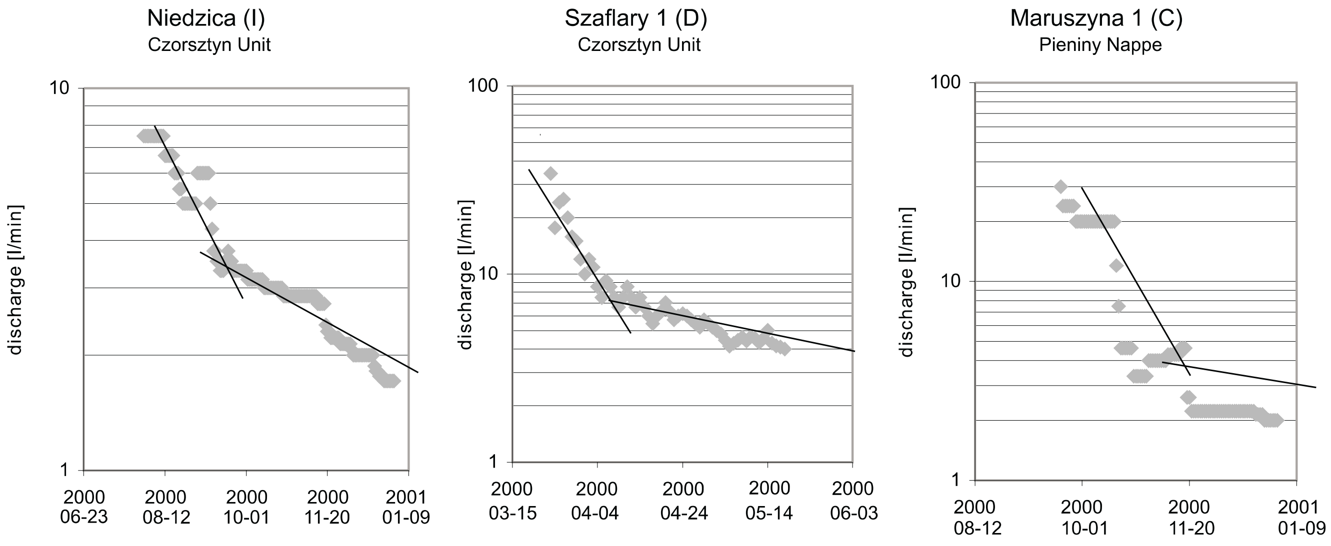

Fig. 2. The "drying up" curve for control springs from Niedzic, Szaflary and Maruszyna on selected days

ervoirs, one of a small resource and a second which is much larger, reflecting a regional pattern, was indicated initially by Małecka (1981). This regularity is also observed in springs investigated by the author. The solitary rock massifs or isolated elevations dewatered by the springs represent the local reservoirs. The reservoir for the Maruszyna spring is the Żar Hill, in Szaflary — Długa Hill and in Niedzica — Humbark Hill. The unequivocal determination of the area of the regional reservoir is difficult at this level of geological and hydrogeological knowledge. In order to calculate the Q_{R0} parameter (boundary spring discharge, at which all the water is removed from the local reservoir) the equation applied that of Mangin (1975):

$$Q = Q_{R0} \times e^{-\alpha t} + q_0 \times \frac{1-\eta \times t}{1+\varepsilon \times t}$$

where: Q — expected spring discharge in time t [m^3/s]; Q_{R0} — initial discharge of the regional reservoir [m^3/s]; e — natural logarithm base; α — recession coefficient [1/d]; q_0 — $Q_0 - Q_{R0}$ (where Q_0 — discharge at the beginning of recession) [m^3/s]; t — time [s]; η — parameter determining the lowering time; ε — spring recession curve concavity coefficient.

The equation can be applied in the analysis of bipartite recession curves in fissure-karst areas. The method gives positive results in investigations of the karst of the Tatra Mts. (Małecka *et al.*, 1985; Barczyk, 1994, 1997; Barczyk *et al.*, 1999). Table 2 presents the boundary discharge and other parameters of the equation in the springs studied (hydrogeological year 2000).

Comparing the results of analyses from previous years it is worth noting that the value of the boundary discharge is similar in all analysed springs and reaches values of 4 to 6 dm^3/min. The measurements of the basic physical and chemical parameters indicate a similar reaction of all springs in the study area to climatic changes taking place in yearly cycles. At baseflow higher values of electrical conductivity were observed, reflecting the proportional increase of mineralization. At maxi-

Table 2

The Mangine formula parameters for the springs selected

Spring location (Fig. 1)	Recession coefficient α [1/d]	Q_0 [dm^3/min]	Q_{R0} [dm^3/min]	t [days]
Maruszyna 1 (C)	0.007	24.38	5.62	29
Szaflary 1 (D)	0.0078	27.72	6.57	25
Niedzica (I)	0.0042	3.41	4.09	50

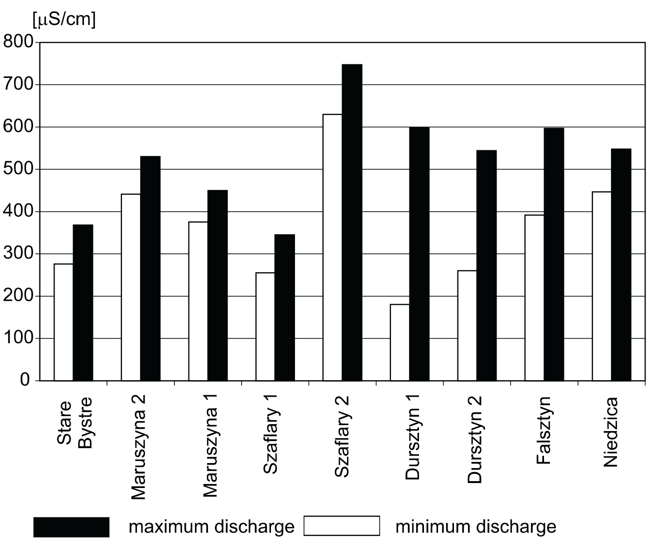

Fig. 3. Electrical conductivity of the water compared with the maximum and minimum discharge of the springs

mal water levels the lowest values of electrical conductivity and mineralization were observed (Fig. 3).

Analyses of the ion content of spring waters monitored indicate a seasonal variability, linked with oscillations of groundwater and surface water levels, as well as precipitation values, these being factors undergoing seasonal changes (Żurawska, 2001). The variability is of a quantitative character — the percentage content of the particular ions varies, whereas the ion content is stable. This allows classification the waters from the springs analysed as HCO_3-Ca waters with a uniform content of the dissolved components.

CONCLUSION

The analyses obtained from springs of the Pieniny Klippen Belt confirmed the efficacy of the methodology employed. The determination of the recharge areas for these springs will enable determination of the directions and circulation routes of groundwater, whereas the specification of the chemical and physical parameters will from a basis to determine the detailed hydrogeological conditions of this complicated, although interesting, geological unit.

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