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Use of Chemical Analysis of Descending Spring Waters for Permeability and Transmissivity of the Rock Environment

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Abstract. Using of indirect method for evaluation of permeability and transmissivity on neovolcanic rocks of the Vihorlatské vrchy Mts., Slanské vrchy Mts. is presented in the paper. For evaluation was used hydrochemical method based on chemical analyses of descending spring waters and geomorphometric characteristics of territory. Achieved results of used method appear satisfactory.

Key words: descending spring water, neovolcanic rocks, indirect methods of evaluation hydraulic parameters of rocks, coefficient of hydraulic conductivity, coefficient of transmissivity

Introduction

Paper deals with possibility of use the chemical analyses of descending spring waters for regional assesment hydraulic parameters of neovolcanic rocks Vihorlatské vrchy Mts. and Slanské vrchy Mts. This method belongs to the group of indirect methods (Jetel, 1989, 1997a, 2002; Jetel & Kullman, 1987) for regional assesment hydraulic parameters of rocks. Indirect methods for estimation hydraulic parameters don´t use data from hydrodynamic tests, but different type data (baseflow, geomorphometric characteristics of territory, chemical composition descending spring water). When data are properly interpreted, they provide indirect informations about hydraulic parameters of rock enviroment.

Use of indirect methods is necessary for regional assesment hydraulic parameters of rocks when application of direct methods is not possible (borehole exploration of region is low, results of hydrodynamic tests were wrong interpreted).

Paper compares differences between estimates of direct and indirect hydrochemical method and evaluates application of hydrochemical method.

Permeability and transmissivity of neovolcanic rocksaccording the direct methods and systematic assumptions of hydrochemical method application

Permeability and transmissivity of Vihorlatské vrchy Mts. neovolcanic rocks elaborated Jetel (1997b) by direct methods. Permeability and transmissivity of Slanské vrchy Mts. neovolcanic rocks published Olekšák (2002) using borehole database from southern part of the territory (Jetel, 1993). Data are presented in tables 1 and 2.

Schematization of the formation of descending spring water chemical composition may be described as follows (Jetel, 1989, 2002)

Tab. 1 Distribution characteristics of coefficient of hydraulic conductivity k in the Vihorlatské vrchy Mts. (Jetel, 1997b) and the Slanské vrchy Mts. (Olekšák, 2002)

	n	R(k) $m.s^{-1}$	Md(k) $m.s^{-1}$	G(k) $m.s^{-1}$	G1 - G2 $m.s^{-1}$	E(k) $m.s^{-1}$
Vihorlatské vrchy Mts.	84			$1.4.10^{-5}$	$1.1.10^{-5}$ - $1.9.10^{-5}$	$3.5.10^{-5}$
Slanské vrchy Mts.	69	$1.6.10^{-7}$ - $1.1.10^{-3}$	$1.3.10^{-5}$	$1.1.10^{-5}$	$7.4.10^{-6}$ - $1.5.10^{-5}$	$3.7.10^{-5}$

Explanation: n=number of data; R(k)=range of k values; Md(k)=median of k; G(k)=geometric mean of k; G1, G2=lower and upper limit of 90 % confidence interval for the estimate of the geometric mean of the hydraulic conductivity k; E(k)=mathematical expectance of hydraulic conductivity k derived by Aitchison and Brown function

Tab. 2 Distribution characteristics of coefficient transmissivity T in the Vihorlatské vrchy Mts. (Jetel, 1997b) and the Slanské vrchy Mts. (Olekšák, 2002)

	n	R(T) $m^2.s^{-1}$	Md(T) $m^2.s^{-1}$	G(T) $m^2.s^{-1}$	G1 - G2 $m^2.s^{-1}$	E(T) $m^2.s^{-1}$
Vihorlatské vrchy Mts.	84	$2.6.10^{-5}$ - $3.5.10^{-2}$	$6.5.10^{-4}$	$6.7.10^{-4}$	$5.0.10^{-4}$ - $9.1.10^{-4}$	$1.9.10^{-3}$
Slanské vrchy Mts.	69	$5.7.10^{-6}$ - $2.3.10^{-2}$	$9.7.10^{-4}$	$7.1.10^{-4}$	$5.0.10^{-4}$ - $9.9.10^{-4}$	$2.3.10^{-3}$

Explanation: R(T) = range of T values; Md(T) = median of T; G(T) = geometric mean of T; G1, G2 = lower and upper limit of 90 % confidence interval for the estimate of the geometric mean of the transmissivity T; E(T) = mathematical expectance of transmissivity T derived by Aitchison and Brown function

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- a relatively short vertical descent of infiltrated water through soil and unsaturated zone to the first groundwater body (saturated part of near-surface zone),
- a descending-lateral groundwater movement in the saturated part of the near-surface zone over the slope from infiltration to the spring,
- an approximate accordance between the average dip of the first groundwater body level during the descending-lateral movement with the average dip of ground surface (slope),
- a quasi-linear growth of M_i concentration of the considered i component with the lateral filtration length L.

The resulting concentration M_i of the i component is determined by the relation

$$M_i = M_{i0} + \Delta M_i \qquad (1)$$

where M_{i0} = initial concentration entering the process of the quasi-linear growth – i. e. concentration in water after the vertical descent through the soil and unsaturated zone to the lateral flow, ΔM_i = increase in concentration during lateral flow from infiltration to the spring.

Increase in concentration ΔM_i can be expressed (Jetel, 1989)

$$\Delta M_i = (W_i/k) \cdot (m_A/m_e) \cdot (L/J) \qquad (2)$$

where w_i = i-component transition rate to solution from rock volume unit (interaction rate) ($g.m^{-3}.s^{-1}$), k = average effective value of ceofficient of hydraulic conductivity of near-surface zone ($m.s^{-1}$), m_A = filtration cross-section effectiveness („effective areal porosity") (-), m_e = chemically effective porosity (-), L = average length of lateral filtration path of near-surface zone (m), J = piezometric gradient, average dip of the first groundwater body approximated by average dip of terrain surface (slope) between the start of infiltration and outflow.

For each other studied component i we will gather linear regressing equation of the type

$$M_i = a_i + b_i \cdot (L/J) \qquad (3)$$

M_i values we will gain from chemical analyses of spring waters, the geomorphometric characteristics L a J may be read from a level line map. For L value is usuallly used a half-distance from the spring to the infiltration (Jetel, 1989).

The next, relationship between M_i and L/J are studied for M_i = T. D. S., Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, $SO4^{2-}$, Cl^-.

Average hydraulic conductivity k_{ch} of the near-surface zone in the feeding area of descending springs according to the value of the regression coefficient b_i of the equation of (3) is determined by the equation

$$k_{ch}=(1/b_i).w_i.m_A/m_e \qquad (4)$$

Practical application of the method is only possible at knowledge or reliable estimation of the values of interaction rates w_i and m_A/m_e. For the sake of comparability of single regions, constant value m_A/m_e = 0,4 (Jetel et al., 1993) was accepted. Probable range and medians of w_i are in table 3.

From the k_{ch} estimates we will derive estimate of the near-surface zone transmissivity:

$$T_{ch} = k_{ch} \cdot H \qquad (5)$$

Tab. 3: Probable range and medians of interaction rates w_i ($g.m^3.s^{-1}$) according to present-day knowledge (Jetel et al., 1993)

w_i	w(min)	w(max)	Md(w)
w(CM)	$5.8.10^{-8}$	$7.1.10^{-7}$	$2.0.10^{-7}$
w(Ca)	$8.4.10^{-9}$	$1.2.10^{-7}$	$2.0.10^{-8}$
w(Mg)	$2.2.10^{-9}$	$1.4.10^{-8}$	$1.1.10^{-8}$
w(Na)	$5.8.10^{-9}$	$6.2.10^{-9}$	$6.0.10^{-9}$
w(HCO_3)	$4.5.10^{-8}$	$5.9.10^{-7}$	$1.0.10^{-7}$
w(SO_4)	$3.6.10^{-8}$	$5.9.10^{-8}$	$5.1.10^{-8}$
w(Cl)	$3.4.10^{-8}$	$4.8.10^{-8}$	$4.1.10^{-8}$

Explanation: w(min), w(max), Md(w)=probable minimum, maximum and median iterraction rate wi; CM=total dissolved solid T.D.S.

where H = accepted effective thickness of water-saturated part of near-surface zone (m).

First experiences with practical application of presented method in Vihorlatské vrchy Mts. neovolcanic rocks (table 4) were published by Jetel (1989).

Tab. 4 Relation of T. D. S. ($mg.l^{-1}$), concentration HCO_3^- ($mg.l^{-1}$), Ca^{2+} ($mg.l^{-1}$) to parameter L/J in Vihorlatské vrchy Mts. (Jetel, 1989)

i	n	r^2	a_i ($g.m^{-3}$)	b_i ($g.m^{-4}$)
CM	22	0.826	70.9	0.0182
$HCO3^-$	22	0.859	7.4	0.0122
Ca^{2+}	22	0.820	6.5	0.00182

Explanation: r^2 = determination coefficient; a_i = locating regression constant; b_i = regression coefficient

Practical application of average permeability and transmisivity estimate method from hydrochemical and geomorphometric characteristics of descending springs

Basic data derived from application of hydrochemical method in neovolcanic rocks are in table 5.

Basic statistical processing of data from the table 5 is in the table 6 (only data of higher r^2 values were elaborated).

From the table 6 results, that in Vihorlatské vrchy Mts. differences of estimates of mean values between k_{ch} (from hydrochemical method) and G(k) (from direct method) were lowest for mean values (geometric mean, arithmetic mean and median) of MA(k_{ch}). These mean values occur within the G1-G2 interval (table 1). Estimates of mean values k_{ch} from Max(k_{ch}) values are slightly overestimated in compare with values of G1-G2 interval. Estimates of mean values k_{ch} from Md(k_{ch}) values are more underestimated in compare with values of G1-G2 interval.

In Slanské vrchy Mts., differences of estimates of mean values between k_{ch} and G(k) were least for arithmetic mean and median of Md(k_{ch}) values. These mean values occur within the G1-G2 interval (table 1). Estimates of mean values k_{ch} from Max(k_{ch}) values are overestimated in compare with values of G1-G2 interval. Estimates of mean values k_{ch} from MA(k_{ch}) values are

Tab. 5 Relation of T.D.S. ($mg.l^{-1}$) and concentrations of selected ions ($mg.l^{-1}$) to parameter L/J in Vihorlatské vrchy Mts, Slanské vrchy Mts. and estimates of coefficient of hydraulic conductivity k_{ch} according the type of interaction rates

VIHORLATSKÉ VRCHY Mts. (JETEL, 1989)								
i	n	r^2	a_i ($g.m^{-3}$)	b_i ($g.m^{-4}$)	$Min(k_{ch})$ ($m.s^{-1}$)	$Max(k_{ch})$ ($m.s^{-1}$)	$Md(k_{ch})$ ($m.s^{-1}$)	$MA(k_{ch})$ ($m.s^{-1}$)
CM	22	0.826	70.9	0.0182	$1.27.10^{-6}$	$1.56.10^{-5}$	$4.40.10^{-6}$	$1.00.10^{-5}$
HCO_3	22	0.859	7.4	0.0122	$1.48.10^{-6}$	$1.93.10^{-5}$	$3.28.10^{-6}$	$1.13.10^{-5}$
Ca	22	0.820	6.5	0.0018	$1.85.10^{-6}$	$2.64.10^{-5}$	$4.40.10^{-6}$	$1.54.10^{-5}$
VIHORLATSKÉ VRCHY Mts.								
i	n	r^2	a_i ($g.m^{-3}$)	b_i ($g.m^{-4}$)	$Min(k_{ch})$ ($m.s^{-1}$)	$Max(k_{ch})$ ($m.s^{-1}$)	$Md(k_{ch})$ ($m.s^{-1}$)	$MA(k_{ch})$ ($m.s^{-1}$)
CM	16	0.656	78.444	0.0145	$1.60.10^{-6}$	$1.96.10^{-5}$	$5.52.10^{-6}$	$1.26.10^{-5}$
HCO_3	16	0.720	12.659	0.0088	$2.05.10^{-6}$	$2.68.10^{-5}$	$4.55.10^{-6}$	$1.57.10^{-5}$
SO_4	16	0.115	11.231	-0.0007	-2.06E-05	-3.37E-05	-2.9E-05	
Cl	16	0.127	1.856	-0.00008	-1.70E-04	-2.40E-04	-2.1E-04	
Ca	14	0.631	7.507	0.0015	$2.24.10^{-6}$	$3.20.10^{-5}$	$5.33.10^{-6}$	$1.87.10^{-5}$
Na	16	0.374	2.808	0.0003	$7.73.10^{-6}$	$8.27.10^{-6}$	$8.00.10^{-6}$	
Mg	15	0.696	1.408	0.0004	$2.20.10^{-6}$	$1.40.10^{-5}$	$1.10.10^{-5}$	$1.25.10^{-5}$
SLANSKÉ VRCHY Mts.								
i	n	r^2	a_i ($g.m^{-3}$)	b_i ($g.m^{-4}$)	$Min(k_{ch})$ ($m.s^{-1}$)	$Max(k_{ch})$ ($m.s^{-1}$)	$Md(k_{ch})$ ($m.s^{-1}$)	$MA(k_{ch})$ ($m.s^{-1}$)
CM	35	0.636	126.430	0.0073	$3.18.10^{-6}$	$3.89.10^{-5}$	$1.10.10^{-5}$	$2.48.10^{-5}$
HCO3	31	0.707	27.908	0.0066	$2.73.10^{-6}$	$3.58.10^{-5}$	$6.06.10^{-6}$	$2.09.10^{-5}$
SO4	35	0.028	25.533	0.0008	$1.80.10^{-5}$	$2.95.10^{-5}$	$2.55.10^{-5}$	
Cl	35	0.091	2.433	0.0001	$1.36.10^{-4}$	$1.92.10^{-4}$	$1.64.10^{-4}$	
Ca	32	0.687	13.644	0.0009	$3.73.10^{-6}$	$5.33.10^{-5}$	$8.89.10^{-6}$	$3.11.10^{-5}$
Na	35	0.047	4.753	0.0001	$2.32.10^{-5}$	$2.48.10^{-5}$	$2.40.10^{-5}$	
Mg	31	0.610	3.320	0.0003	$2.93.10^{-6}$	$1.87.10^{-5}$	$1.47.10^{-5}$	$1.67.10^{-5}$

Explanation: $Min(k_{ch})$ = coefficient of hydraulic conductivity derived from w(min); $Max(k_{ch})$ = coefficient of hydraulic conductivity derived from w(max); $Md(k_{ch})$ = coefficient of hydraulic conductivity derived from Md(w); $MA(k_{ch})$ = arithmetic mean of $Max(k_{ch})$ and $Md(k_{ch})$ – i. e. $MA(k_{ch}) = (Max(k_{ch})+Md(k_{ch}))/2$

Tab. 6 Statistical analyse of neovolcanic rocks permeability from the hydrochemical method data

Vihorlatské vrchy Mts. (Jetel, 1989)										
	G	G/G(k)	Md	Md/G(k)	M	M/G(k)	Vr^2	$Vr^2/G(k)$	Vnr^2	$Vnr^2/G(k)$
$Max(k_{ch})$ ($m.s^{-1}$)	$2.00.10^{-5}$	1.43	$1.93.10^{-5}$	1.38	$2.04.10^{-5}$	1.46	$2.04.10^{-5}$	1.46		
$Md(k_{ch})$ ($m.s^{-1}$)	$3.99.10^{-6}$	0.28	$4.40.10^{-6}$	0.31	$4.02.10^{-6}$	0.29	$4.01.10^{-6}$	0.29		
$MA(k_{ch})$ ($m.s^{-1}$)	$1.20.10^{-5}$	0.86	$1.13.10^{-5}$	0.81	$1.22.10^{-5}$	0.87	$1.22.10^{-5}$	0.87		
Vihorlatské vrchy Mts.										
	G	G/G(k)	Md	Md/G(k)	M	M/G(k)	Vr^2	$Vr^2/G(k)$	Vnr^2	$Vnr^2/G(k)$
$Max(k_{ch})$ ($m.s^{-1}$)	$2.20.10^{-5}$	1.57	$2.32.10^{-5}$	1.66	$2.31.10^{-5}$	1.65	$2.30.10^{-5}$	1.64	$2.28.10^{-5}$	1.63
$Md(k_{ch})$ ($m.s^{-1}$)	$6.19.10^{-6}$	0.44	$5.43.10^{-6}$	0.39	$6.60.10^{-6}$	0.47	$6.63.10^{-6}$	0.47	$6.59.10^{-6}$	0.47
$MA(k_{ch})$ ($m.s^{-1}$)	$1.46.10^{-5}$	1.05	$1.41.10^{-5}$	1.01	$1.49.10^{-5}$	1.06	$1.48.10^{-5}$	1.06	$1.47.10^{-5}$	1.05
Slanské vrchy Mts.										
	G	G/G(k)	Md	Md/G(k)	M	M/G(k)	Vr^2	$Vr^2/G(k)$	Vnr^2	$Vnr^2/G(k)$
$Max(k_{ch})$ ($m.s^{-1}$)	$3.43.10^{-5}$	3.12	$3.73.10^{-5}$	3.39	$3.67.10^{-5}$	3.33	$3.71.10^{-5}$	3.38	$3.73.10^{-5}$	3.39
$Md(k_{ch})$ ($m.s^{-1}$)	$9.65.10^{-6}$	0.88	$9.92.10^{-6}$	0.90	$1.01.10^{-5}$	0.92	$9.97.10^{-6}$	0.91	$9.99.10^{-6}$	0.91
$MA(k_{ch})$ ($m.s^{-1}$)	$2.28.10^{-5}$	2.07	$2.29.10^{-5}$	2.08	$2.34.10^{-5}$	2.13	$2.36.10^{-5}$	2.14	$2.37.10^{-5}$	2.15

Explanation: G = geometric means; Md = medians; M = arithmetic means; Vr^2 = weighted arithmetic means after determination coefficient r^2; Vnr^2 = weighted arithmetic means after conjunctions of data number n and relevant determination coefficients r^2 - i.e. (n. r^2)

Tab. 7 Transmissivity neovolcanic rocks derived from hydrochemical method (H = 42 m)

	$T_{ch}(G_{MA})$	$T_{ch}(G_{MA})/G(T)$	$T_{ch}(Md_{MA})$	$T_{ch}(Md_{MA})/G(T)$	$T_{ch}(M_{MA})$	$T_{ch}(M_{MA})/G(T)$
Vihorlatské vrchy Mts. (from data of Jetel, 1989)	$5.04.10^{-4}$	0.75	$4.75.10^{-4}$	0.71	$5.12.10^{-4}$	0.76
Vihorlatské vrchy Mts.	$6.13.10^{-4}$	0.92	$5.92.10^{-4}$	0.88	$6.26.10^{-4}$	0.93
Slanské vrchy Mts.	$9.58.10^{-4}$	1.35	$9.62.10^{-4}$	1.35	$9.83.10^{-4}$	1.38

Explanation: Tch = koefficient of transmissivity derived from k_{ch}: G_{MA} = geometric mean of kch calculated from $MA(k_{ch})$; Md_{MA} = median of kch calculated from $MA(k_{ch})$; M_{MA} = arithmetic mean of kch calculated from $MA(k_{ch})$

also overestimated in compare with values of G1-G2 interval.

For calculation of k_{ch} in neovolcanic rocks is recommended to use choose some mean value (geometric mean, arithmetic mean, median) for $MA(k_{ch})$ values as a resultant mean value of coefficient of hydraulic conductivity, despite the fact that in Slanské vrchy Mts. the least difference is between G(k) and k_{ch} derived from mean values of $Md(k_{ch})$. In this case for calculation of transmissivity coefficient T_{ch} from hydrochemical method after formula (5), we recommend to use empirically determined value of H = 42 m (accepted effective thickness of water-saturated part of near-surface zone). Data are shown in table 7. By substituting value H=42 m it is secured, that almost all estimates of mean value T_{ch} are in G1-G2 interval for 90 % confidence of the estimate for geometric mean of transmissivity T (table 2).

Conclusion

Application hydrochemical method based on chemical composition descending spring water and geomorphometric characteristics for regional assessment of hydraulic parameters of neovolcanic rocks in Vihorlatské vrchy Mts. and Slanské vrchy Mts confirms, that method is usable in neovolcanic rock regions. Ions HCO_3^-, Ca^{2+}, Mg^{2+}, a CM are decisive for estimate of mean value k_{ch}. In Vihorlatské vrchy Mts., differences of estimates of mean values between k_{ch} and G(k) were lowest for geometric mean, arithmetic mean and median of $MA(k_{ch})$ values.

In Slanské vrchy Mts., differences of estimates of mean values between k_{ch} and G(k) were least for arithmetic mean and median of $Md(k_{ch})$ values.

For calculation of k_{ch} in neovolcanic rocks of Slovakia it is recommended to use above mentioned process and choose some mean value (geometric mean, arithmetic mean, median) for $MA(k_{ch})$ values as a resultant mean value of coefficient of hydraulic conductivity. Recommended value for H (accepted effective thickness of water-saturated part of near-surface zone) is 42 m.

For improvement of process of representative mean value selection (coefficient of hydraulic conductivity) from hydrochemical method in neovolcanic rock areas it will be necessary to apply presented method in other neovolcanic regions of Slovakia.

Literature

Jetel, J., 1989: Relationship between hydrogeochemical characteristics of near-surface zone of rock massif and hydrodynamic conditions. Západ. Karpaty, Sér. Hydrogeol. inž. Geol. 8. 67-104.

Jetel, J., 1993: Priepustnosť a prietočnosť neovulkanitov v južnej časti Slanských vrchov. Geol. Práce, Spr. (Bratislava), 98. 83-93.

Jetel, J., 1997a: Metodické postupy hodnotenia priemernej prietočnosti a priepustnosti v horských oblastiach nepriamymi metódami. Manuskript – archív ŠGÚDŠ, Bratislava. 85 s.

Jetel, J., 1997b: Hydrogeológia. In: Žec, B. (ed.), Vysvetlivky ku geologickej mape Vihorlatských a Humenských vrchov. Vydavateľstvo Dionýza Štúra, Bratislava. 178-193.

Jetel, J., 2002: Hodnotenie priemernej prietočnosti a priepustnosti v horských územiach nepriamymi metódami. Podzemná voda č. 2, ročník 7. 24-30.

Jetel, J. & Kullman, E., 1987: Nepriame stanovenie priemernej prietočnosti horninových telies pre zostavovanie hydrogeologických máp. Manuskript – archív ŠGÚDŠ, Bratislava. 83 s.

Jetel, J., Nemčok, J. & Tkáč, J., 1993: Hydrogeologický výskum Spišskej Magury – záverečná správa. Manuskript – archív ŠGÚDŠ, Bratislava. 222 s.

Olekšák, S., 2002: Priepustnosť a prietočnosť neovulkanitov vybraných území Slovenska. Podzemná voda č.1, ročník 8. 5-16.