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Factors affecting the groundwater regime in the High Tatra Mountains

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Abstract The groundwater regime of the Quaternary sediments of the High Tatra Mountains was studied in order to estimate factors affecting the regime, to assess the present status of groundwater resources and to outline their future development regarding the envisaged climate change. Data from 24 wells and three springs of the state monitoring network and temporary monitoring wells, as well as data on precipitation, air temperature and streamflow discharge, were analysed. Four types of groundwater level regime were distinguished based on the results of correlation matrix, factor and cluster analyses. The climatic and hydrological factors were identified as the principal influencing factors. The altitude is also of utmost importance controlling, through the air temperature, the length of the freezing period during which the water is stored in the drainage basin in the form of snow. The decrease in groundwater resources was documented by comparison of the present research results with results from the 1980s.

Key words Slovakia; High Tatra Mountains; groundwater regime; influencing factors; factor and cluster analyses

INTRODUCTION

The groundwater regime develops as a result of the influence of the regime-affecting factors within a certain area. The identification of those factors, together with the analysis of developments in their temporal trends is fundamental for assessment of the present state and the future development of the groundwater regime itself.

The groundwater regime of the Quaternary sediments of the High Tatra Mountains and their foreland was studied within the research project “Crystalline of the part of the High Tatra Mts and the Quaternary of their foreland – Hydrogeological District QG-139” financed by the Ministry of the Environment of the Slovak Republic (Fendek *et al.*, 2003). An estimation of usable groundwater resources in the area was the main goal of the investigation.

NATURAL CONDITIONS

The area of interest, the High Tatra Mountains, is located in the northern part of the Slovak Republic where it forms a natural border between Slovakia and Poland.

Hydrogeological District QG-139 has very variable geomorphic and climatic conditions influenced mainly by the very different geological setting and altitude differences between the mountainous part and the River Poprad valley bordering the district from the south. The highest point of the area – Gerlachovsky peak reaches 2655 m a.m.s.l.; the lowest point is Kezmarok precipitation gauging station at only 626 m a.m.s.l.

The Slovak Republic is situated in the mild climate zone where the effects of ocean and continental climate meet together and mix. The area of interest, however, belongs to the cold climate district, where the annual air temperature varies between –3.9ºC on the mountain ridge (Lomnicky Peak) and 5.8ºC in the river valley (Poprad city). The precipitation comes mainly from the west and northwest with the average annual amounts of 600–700 mm in the river valley and more than 2000 mm on the mountain peaks (*Landscape Atlas of the Slovak Republic*, 2002).

From the hydrological point of view, the area studied belongs to the River Poprad drainage basin with the main stream flowing into the Baltic Sea. The River Poprad headwaters come mainly from the High Tatra Mts; the main stream has a lot of short left-side tributaries and only a few tributaries from the other side of the valley bordered by the Low Tatra Mts. The discharge regime is natural, with the low flow period during the winter months. The discharges increase gradually from March and peak in the period from May to June depending on the altitude. Summer–autumn decreases in the discharge reach their minima in the winter low flow period (January and February).

The area studied is built of the crystalline complexes of the High Tatra Mts in its mountainous part, and of Palaeogene flysch sediments and Quaternary sediments in the foreland. All these complexes have very different hydrogeological properties which influence the groundwater flow and accumulation in the rock environment. The crystalline complexes, composed mainly of granitoids, typically have shallow groundwater flow and fissure springs with quite low yields, mainly less than 1 L s^{-1} (Hanzel *et al.*, 1984). The Palaeogene flysch sediments consist of three different sequences: basal Borove Sequence (conglomerates), Huty Sequence (claystone) and the uppermost Zuberec Sequence consisting of typical flysch sediments, i.e. an alternation of sandstone and claystone layers. The hydrogeological importance of the Palaeogene complexes is not very high. The Huty Sequence is an aquitard and the water retaining properties of the Zuberec Sequence are higher only in the case of tectonic failures. The main aquifers in the area are made of different types of the Quaternary sediments, which are mainly of glacial, glacial-fluvial and fluvial origin. Different types of slope sediments are present as well.

INPUT DATA AND METHODS

The groundwater regime was evaluated using data from 21 groundwater level monitoring wells and three monitored springs. Being factors that possibly influence the regime, the data from four discharge gauging stations, nine precipitation gauging stations and six stations measuring air temperature, were involved, too. The stations represent different altitudes in the drainage basin.

The assessed time series were not shorter than 10 years (1992–2001); the longest time series (more than 40 years) were available for some types of groundwater level monitoring (1962–2001). The data analysis consisted of a basic statistical characterization, data set normality and homogeneity assessment, time series analysis and analysis of inter-relationships among variables and classification of the groundwater regime using factor and cluster analyses.

RESULTS

The climatic characteristics, average annual precipitation amounts and average annual air temperatures calculated for the period 1991–2001, were compared with the long-term averages for the period 1951–1980. The comparison of these two periods has shown that the average annual air temperatures increased within the range from +1.1ºC (ΔT) in the river valley to +0.6ºC (ΔT) on the mountain peaks (see Table 1). However, the average annual precipitation amounts varied around the long-term average with the exception of the highest altitude, where they reached 129% (ΔP) of the long-term average (Table 1). There were obtained different results for the station P 12020 at Strbske Pleso. The deviations from the coincident developments at the other stations are explained by the misplacement of the gauging station in 1992. The change in its placement resulted in systematically lower values of measured air temperatures of 1.2 to 2.0ºC and lower precipitation amounts due to precipitation shadow (Fasko, personal communication).

The statistical evaluation of river discharges has shown a rather low variability expressed by the coefficient of variation (C_v) with values less than 25% (1977–2001). The same result was obtained for variability of groundwater levels in almost all monitoring objects. The values of C_v varied between 6 and 24%; but in two cases they reached 41% (W 8906) and 87% (W 999). The coefficient of variation for spring yields ranged from 22 to 67%.

Table 1 Differences in long-term average temperatures and precipitation amounts between periods 1951–1980 and 1991–2001 in selected gauging stations.

Number and name of the gauging station	Gauging station altitude (m a.m.s.l.)	T (ºC)	ΔT (ºC)	P (mm)	ΔP (%)
12100 Lomnicky stit	2653	–3.4	+0.5	1979	129
12120 Skalnate Pleso	1778	2.2	+0.6	1420	109
12020 Strbske Pleso*	1354	3.1	–0.4	737	77
12140 Tatranska Lomnica	827	–	–	809	102
12040 Poprad	694	6.3	+1.1	600	101
12180 Kezmarok	626	–	–	615	105

* Location of the gauging station changed in 1992.

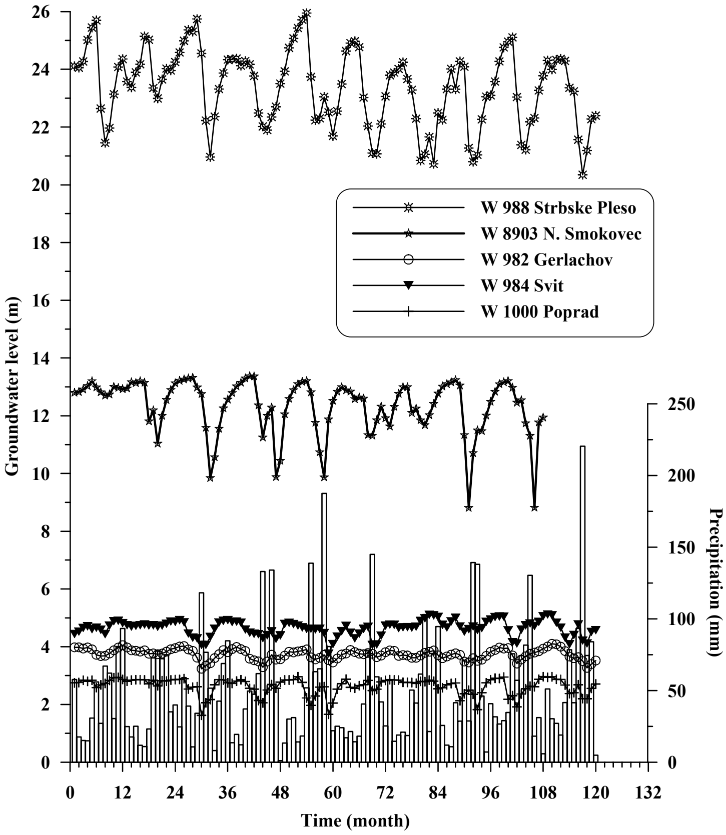

Fig. 1 Time series of mean monthly groundwater levels in selected wells with monthly precipitation from Poprad gauging station (western part of the area).

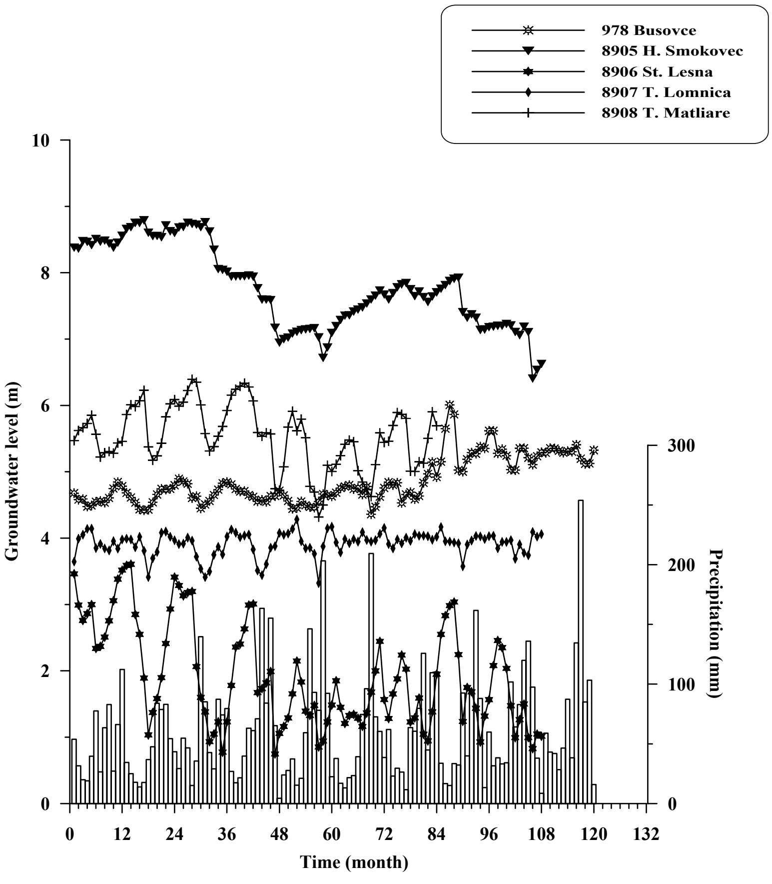

Fig. 2 Time series of mean monthly groundwater levels in selected wells with monthly precipitation from Poprad gauging station (central and eastern part of the area).

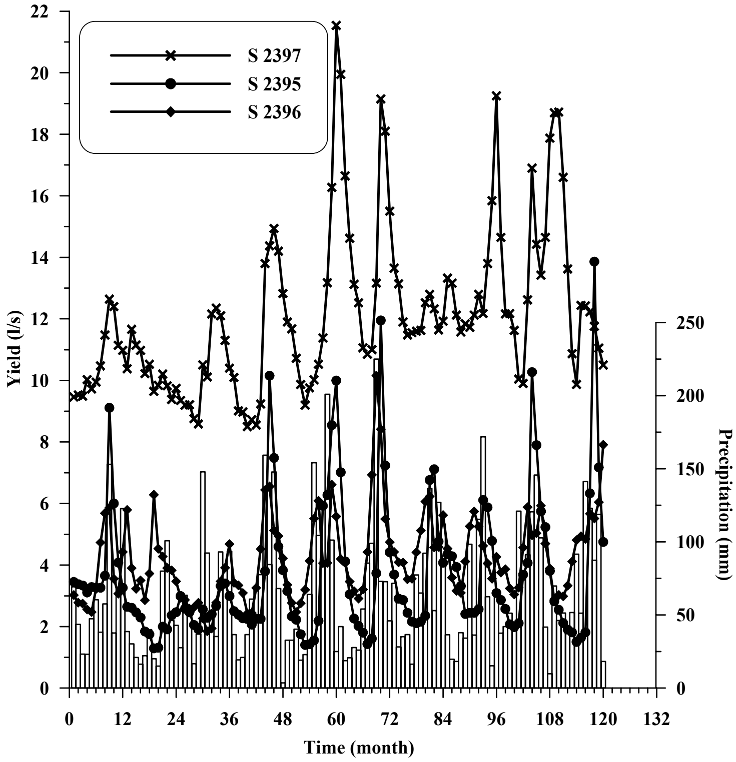

Fig. 3 Time series of mean monthly spring yields with monthly precipitation from Stara Lesna gauging station.

The time series analysis of groundwater levels (1992–2001 period) has shown a quite stable course without distinct trends except for three wells. An increasing trend was confirmed for wells W 988 Strbske Pleso and 8903 Stary Smokovec in the western and central part of the study area (Fig. 1); a decreasing trend was quite distinct in the well W 978 Busovce in the eastern part (Fig. 2). The time series analysis of spring yields confirmed an increasing trend of yields for spring No. 2397, which also manifests an increase in maximum extreme values for the last six years (Fig. 3). There is a visible matching of the course of spring yields and monthly precipitation (vertical bars) with the lag of zero or one month in Fig. 3.

The analyses of the altitude data, climatic, hydrological and hydrogeological settings at the monitoring locations enabled assessment of the temporal differences and causal factors of the groundwater regime formation. Based on the results of correlation matrix, factor analysis (Table 2) and cluster analysis (Fig. 4), four groups of groundwater level regimes were distinguished. The groups were characterized by describing regime temporal and causal factors, where the precipitation, air temperature (controlling the length of the freezing period of the top-most soil layer and starting time of snow melt) and surface stream discharges were identified as the main affecting factors. The altitude is also very important, influencing through the air temperature the length of period during which the precipitation is stored in the area in the form of snow. Therefore, the time of the groundwater level increase is closely connected with the change in altitude.

The first type of groundwater regime is represented by wells W 983 Batizovce, 984 Svit, 998 Poprad-Spisska Sobota, 999 and 1000 Poprad, located in the western part of the area in the alluvial sediments of the Poprad River, as well as W 993 Kezmarok in the eastern part (Fig. 4, Type 1). They can be characterized by increase of the groundwater level in the period from April till August with maxima in May due to high discharges of the surface streams and response to the frequent storms typical of the summer season. The subsequent decline of the groundwater levels continues reaching the minima period during the autumn and winter months. High correlation coefficients in the correlation matrix were obtained for the relation of groundwater levels with stream discharges and precipitation amounts. The seasonal fluctuation of the groundwater levels is quite distinct.

The second type of the groundwater regime is represented by wells W 979 Spisska Bela and 1375 Velka Lomnica (the eastern part of the area). The seasonal component of the groundwater level

Table 2 Factor loadings after VARIMAX rotation.

Type, no. and location	F1	F2	F3	F4	F5	F6
S 2395 Tatr. Polianka	–0.045	**–0.859**	0.179	–0.173	0.023	0.296
S 2396 Tatr. Lomnica	0.185	**–0.569**	–0.062	–0.494	0.122	0.116
S 2397 Tatr. Matliare	–0.061	–0.372	**0.526**	**–0.528**	–0.185	–0.155
W 978 Busovce	0.151	–0.092	–0.012	–0.128	**0.906**	0.026
W 979 Spisska Bela	**0.743**	0.166	–0.219	0.460	–0.162	0.086
W 993 Kezmarok	**0.846**	0.103	–0.166	0.133	0.106	0.116
W 1373 St. Smokovec	0.348	**0.862**	–0.112	0.083	0.003	0.186
W 1375 V. Lomnica	**0.659**	0.158	–0.188	0.272	**–0.558**	0.098
W 8904 St. Smokovec	0.376	**0.699**	–0.474	0.069	0.075	0.202
W 8905 H. Smokovec	0.087	0.337	–0.007	**0.819**	–0.259	–0.013
W 8906 St. Lesna	0.445	**0.525**	–0.084	**0.474**	–0.081	0.324
W 8907 T. Lomnica	0.432	–0.155	–0.452	–0.117	0.284	0.171
W 988 Strbske Pleso	–0.044	**0.643**	–0.495	0.188	–0.100	**0.408**
W 8901 N. Polianka	0.043	**0.901**	–0.083	0.210	–0.186	0.131
W 8903 N. Smokovec	0.281	**0.749**	–0.426	0.148	0.048	0.147
W 982 Gerlachov	**0.606**	0.541	–0.140	–0.124	0.021	**0.415**
W 983 Batizovce	**0.879**	–0.138	–0.080	0.095	–0.103	–0.130
W 984 Svit	**0.795**	0.246	–0.084	0.070	0.298	0.018
W 998 Spiska Sobota	**0.832**	0.181	–0.211	–0.052	0.036	0.266
W 999 Poprad	**0.739**	0.054	–0.385	–0.255	0.319	–0.022
W 1000 Poprad	**0.818**	0.261	–0.314	–0.180	–0.052	0.106
P 12090 St. Lesna	–0.183	–0.173	**0.903**	–0.001	0.037	0.049
P 12040 Poprad	–0.185	–0.128	**0.899**	0.067	0.061	0.031
D 7990 Poprad-S.Pleso	–0.185	–0.191	**0.699**	–0.072	–0.064	**–0.592**
D 8000 Poprad-Svit	–0.287	–0.161	**0.689**	–0.039	–0.019	**–0.582**
D 8060 Velicky brook	–0.387	–0.245	**0.769**	–0.222	0.006	–0.253
D 8070 Slavkovsky br.	**–0.584**	–0.380	**0.616**	–0.147	0.006	0.029

S spring, W well, P precipitation gauging station, D streamflow discharge

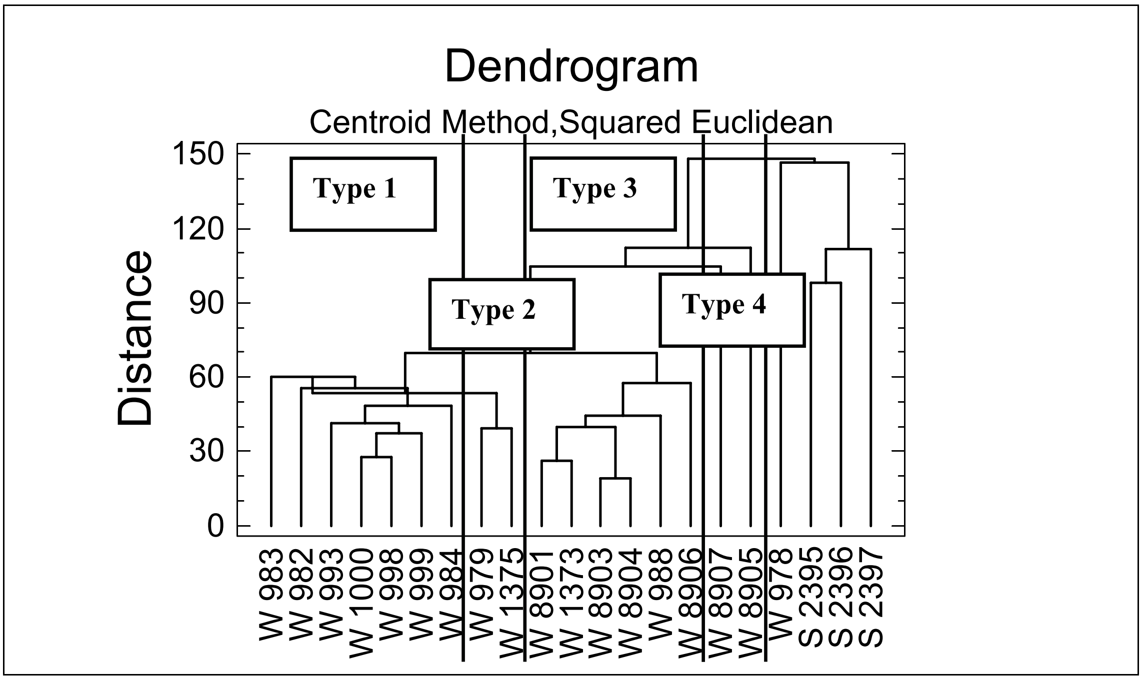

Fig. 4 Dendrogram of clusters for main objects of interest (S: spring, W: well, P: precipitation, D: discharge).

fluctuation is distinct; the time components are similar to those in the first group (Fig. 4, Type 2). The difference is in the shifting of the groundwater level increase to earlier in the spring months March–April, because of the wells location downstream of the Poprad River and the earlier snowmelt time.

The third type of the groundwater regime is represented by the group of wells W 988 Strbske Pleso, 8901 Nova Polianka, 8903 Novy Smokovec, 8904 Stary Smokovec and 1373 Stary Smokovec (Fig. 4, Type 3). These wells are located at relatively high altitudes. The groundwater level increase maximum is shifted to June–July because of later snowmelt and thawing of the ground in the mountainous part of the area. The lowest levels are typical for the winter and the early spring periods. A similar groundwater regime is typical for well W 8908 Tatranske Matliare, the only difference is in a slightly earlier starting time of the groundwater level increase, i.e. February. Well W 8906 Stara Lesna stands on the border between type 3 and type 4 of the groundwater regime.

The fourth type of groundwater regime is represented by wells 8905 Horny Smokovec and 8907 Tatranska Lomnica (Fig. 4, Type 4). They are located at middle altitudes and their regime is the most complicated. The groundwater levels show two maxima, the first one in the early spring March–April period and the second one, the less distinct, in June. They react to increased streamflow discharges and later also to snow melting in the mountainous part of the area. According to the seasonal component of the time series, well W 992 Strane pod Tatrami belongs to this group, too.

It was not possible to place unambiguously the two wells into any of the above groundwater regime types. At well 978 Busovce (Fig. 4) human interference is probable. At well 982 Gerlachov the interference of the groundwater regime affecting factors is more complicated as was shown by the results of factor (loadings in F1 and F6) and cluster analyses (Type 1). The springs created a separate cluster, however, the position of S 2397 is a bit different from S 2395 and S 2396, as was confirmed by the results of the factor analysis. It may be caused by the location of the spring at the lowest altitude of the assessed springs.

The research results have confirmed that there is a decrease in groundwater amounts in the area, which is in agreement with the prediction by Majercakova *et al.* (1997). However, the change is caused by the more extreme behaviour of precipitation influencing the surface and groundwater runoff distribution in the specific conditions of crystalline complexes.

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