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Hydrogeological parameters trend analysis in the Slanec village landslide area (Slovakia), crossed by transit gas pipeline of European imporance

MARIÁN STERCZ, DANIEL GREGA, KATARÍNA PAČAJOVÁ and ĽUBOMÍR PETRO

State Geological Institute of Dionýz Štúr, Mlynská dolina 1, SK-817 04 Bratislava, Slovakia

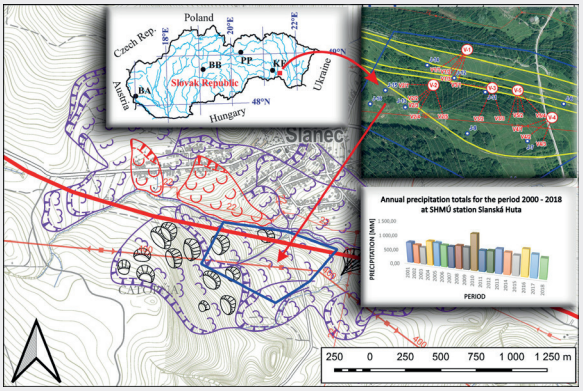
Abstract: Time change of hydrological parametres was analysed in the landslide area near the Slanec village in the time span of 2003–2019. Five branches of international gas pipeline of European importance are crossing this landslide area, as well as two branches of international Družba pipeline, optical telecomunication lines and high-voltage power-lines.

Regime observations included measuring the groundwater levels in 11 observation boreholes and outflow in 20 drainage boreholes, concentrated in 5 outposts. The data file was supplemented by monthly precipitations from the nearby meteorological station.

Conducted trend analysis, using Mann-Kendall (MK) test, did not proved the existence of statistically important trend in the data file of monthly and yearly precipitations, even after calculations for each month – no statistical change in average amount of precipitations was revealed. Concerning drainage boreholes, MK test proved statistically importand declining trend of outflow for the whole measured period and for each of 5 outposts. This result can indicate e.g. clogging of drainage boreholes. The groundwater levels values demonstrated an average lowering by one meter during examined period. This result indicates lowering of the groudwater amount in the landslide and long time improvement of geotechnical parametres of the landslide slope.

Key words: trend analysis, monitoring, regime observation, remedial measures, landslide, Slanec, Mann-Kendall test, Sen's slope

Graphical abstract



Highlights

- The Mann-Kendall test did not confirm any statistically important evolution trend of rain precipitations on the landslide area.
- Despite lowering of outflow in drainage subhorizontal boreholes, the lowering trend of groundwaters was revealed in almost all vertical boreholes.
- The results of trend analysis show that at standard climate conditions, the drainage measures have sufficient effect.

Introduction

This contribution deals with time changes of hydrogeological situation parameters in the landslide area near the Slanec village. They were gathered as a part of regime observations between years 2003 and 2019. Results of those evaluations can help with overall reassessment of the situation and functionality of remediation measures and also the actual situation of monitored landslide area.

The Slanec village is located on the southern and southeastern slopes of Milič stratovolcano, developed on the southern side of the Slanské vrchy hills. Geomorphologically accurate location is – part of Slanské Hills, subassembly Milič, Východoslovenská pahorkatina unit and Podslanská pahorkatina subassembly (Mazúr & Lukniš, 1986). Whole village and surrounding area are situated in large landslide area. Large amount of residential or farm buildings are affected by landslide, similarly as the 2nd class state road. Five branches of transit gas pipeline, two branches of international pipeline Družba, telecommunication and optical lines and also high-voltage powerlines are crossing the landslide, too. Route of underground lines is crossing the valley of the Bradlo creek between villages Slanec and Nový Salaš, and the Slanské vrchy hills through the pass near Rákoš village (Fig. 1). Morphological and geological conditions

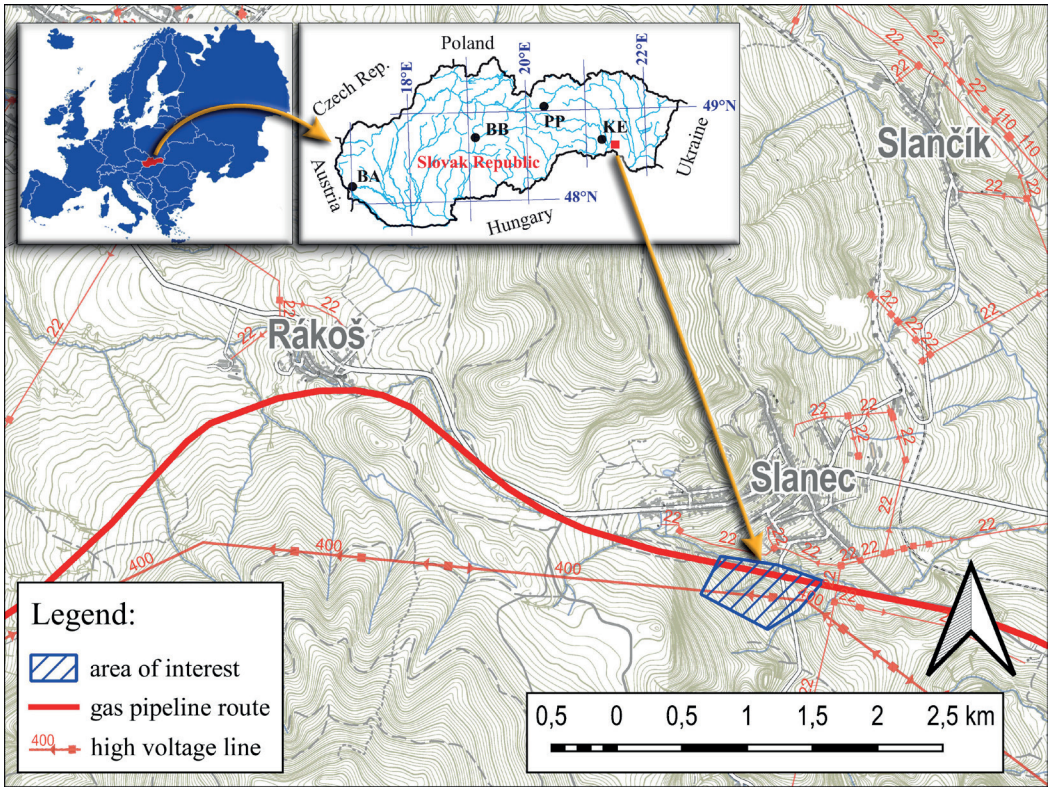


Fig. 1. Position of interest area in Slovakia with the gas pipeline route (thick red line).

of surrounding area of the current route – continuous mountain range of the Slanské vrchy hills, ranging from the north to south – made it impossible to apply different route for engineering networks.

Investigated landslide area is located south of the Slanec village. Because of numerous networks are traversing here, the location of Slanec was in 2003 included into set of regular measurements within a project of "Partial Monitoring System – Geological Factors" (PMS GF), where the State Geological Institute of Dionýz Štúr became the main research organization. The PMS GF forms an integral part of national environmental monitoring network. It is focused mainly on so-called geologic hazards, representing harmful natural or anthropogenic geological processes, which threat natural environment and ultimately also humans (www.geology.sk).

From a geological point of view, examined area is formed of Neogene sediments of Stretava Formation, in particular of clays and claystones, tuffitic clays, sands and volcanic rocks. Quaternary sedimetns are presented by colluvial sediments, less by fluvial deposits. In the overlay of grey Neogene clays with general dip 5–10° in the direction of the slope, which were verified by drilling works throughout the measured territory, the geodynamic processes are active until today (Fig. 2). Ongoing movements can be classified as very slow, with significant influence of the groundwater (Míka & Boľha, 2000).

Considering the extreme overload of geological environment by anthropogene interventions and high sensitivity of underground networks to potential slope instabilities, engineering geological survey was performed in 2000, and extensive remediation measures were designed (Míka & Boľha, 2000). Recently, performed monitoring is mainly focused on changes of the groundwater levels and outflow from drainage boreholes after realized remediation, which proved its functionality (Ondrejka et al., 2017).

Monitoring

The regime observations at Slanec area consist of monitored level changes in 11 vertical observation boreholes and outflow from 20 subhorizontal drainage boreholes. The drainage boreholes are gathered into 5 outposts (Fig. 2). The surface drainage measures are not monitored.

Measurements, performed from 2003, are done applying a tape with Rang´s well whistle or electric water level meter without automatic recording at regular intervals, but with a minimum frequency of 10 measurements a year. Data file is supplemented by monthly rain precipitations from rain gauge station situated in Slanská Huta with indicative number 51160, operated by Slovak Hydrometeorological Institute (SHMI). Names of

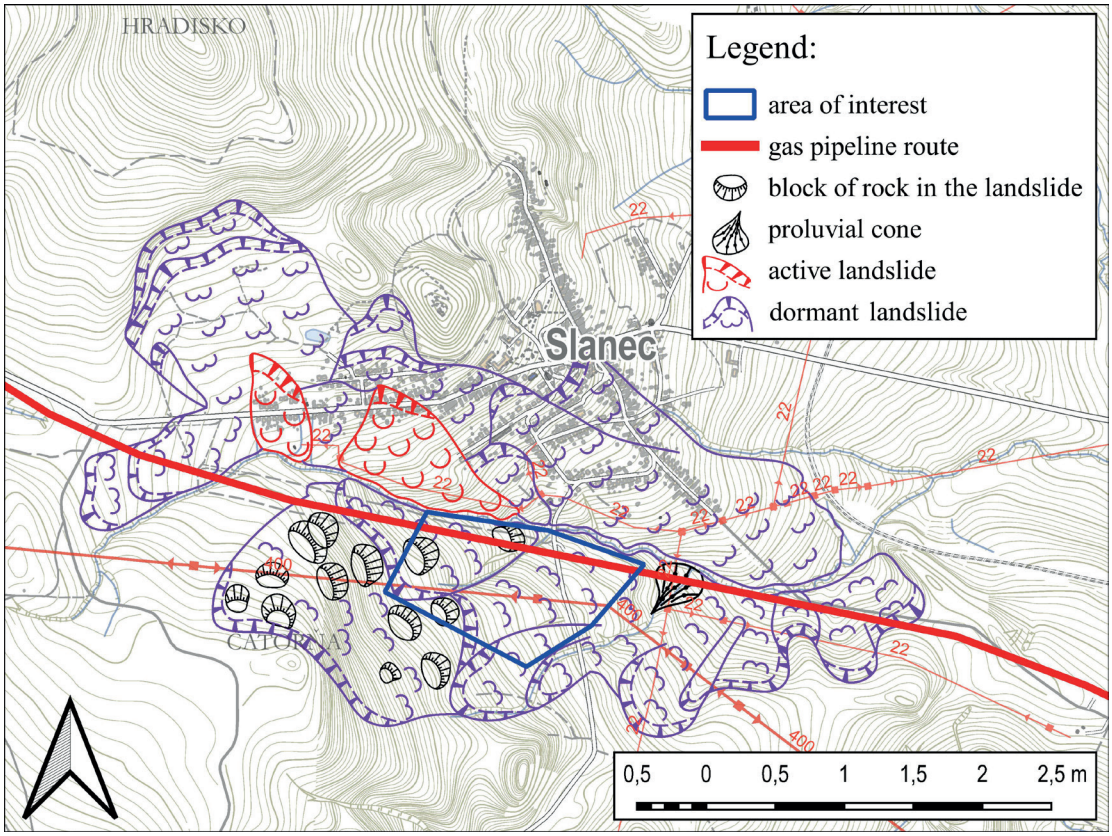


Fig. 2. Slope deformations in Slanec village and its vicinty, position of study area (polygon bordered by blue line).

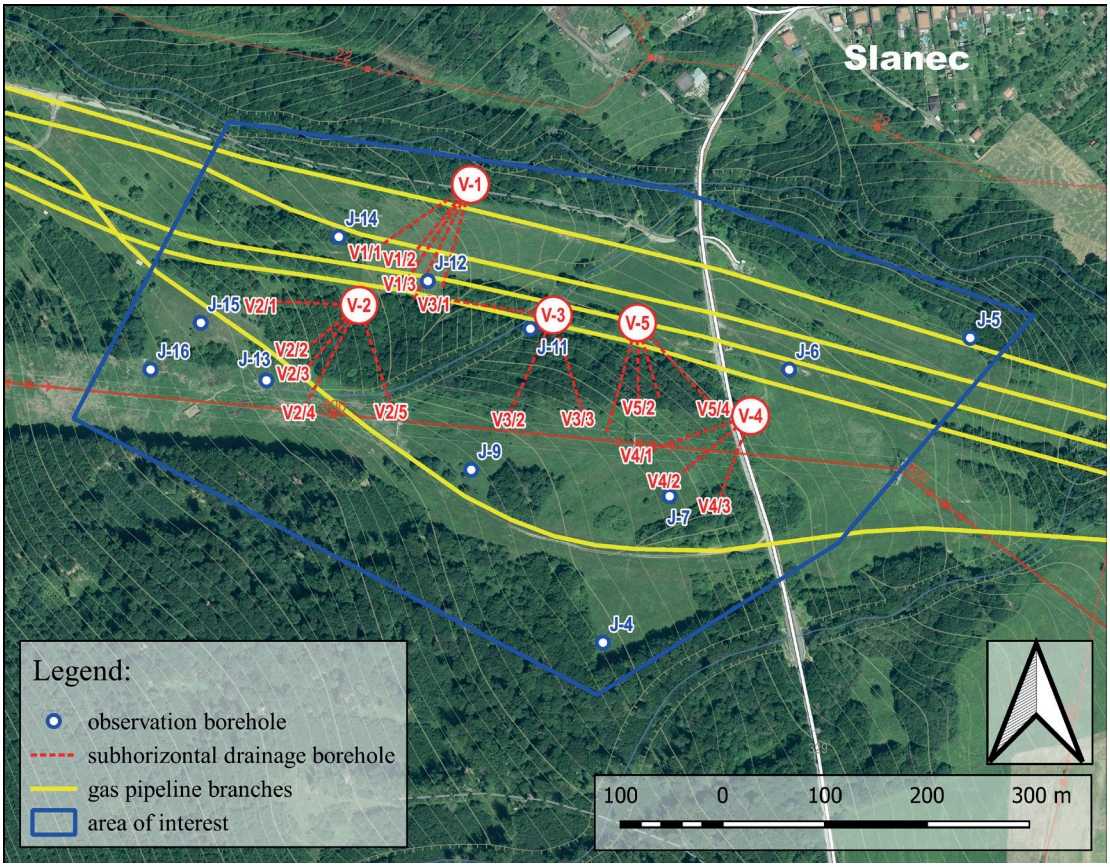


Fig. 3. Situation of remediation technical measures and monitoring – observation boreholes.

the boreholes, included in regime measurements, are listed with their basic characteristic in following table (Tab. 1).

Trend analysis – methodics

One of goals of the evaluation of regime mea-surements is represented by investigation and demonstration of the presence of statistically significant trends in timed values of individual measured datasets.

From various statistical procedures used for analysis of time series, suitable for processing of environmental data (Gibbons et al., 1955), unparametrical Mann-Kendall trend test (MK-test) is most common. As an unparametrical test, MK-test does not create any premise for division of probability of random variable. Using of unparametrical technique offers better way to deal with data that differ from normality, while being tested. It is known, that unparametrical techniques are less suggestible with values more distant from the average (so-called remote) values (Zeleňáková et al., 2016).

Original author of the test – H. B. Mann – published it in 1945. In 1975 it was improved by M. G. Kendall – the founder of respective statistics. This type of test was widely applied for trend analysis in environmental sciences and its results showed up as very consistent (Önöz & Bayazit, 2003). It is more suitable for a larger statistical files. The MK-tests assess in time series without specification, if those are linear or non-linear trends.

Mann-Kendall test is based on value S (Önöz & Bayazit, 2003), which is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

wher **n** – total number of processed values
x_i a x_j – individual values in time i and j

For value $sgn(x_j - x_i)$ the following relationship applies:

$$sgn(x_j - x_i) = \begin{cases} 1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases}$$

Tab. 1
List of technical objects for regime observations.

Observation boreholes (11 boreholes)							
borehole	coordinate		depth (m)	borehole	coordinate		depth (m)
	X (S-JTSK)	Y (S-JTSK)			X (S-JTSK)	Y (S-JTSK)	
J-4	-247 227.32	-1 250 757.36	14	J-12	-247 398.66	-1 250 403.68	9
J-5	-246 868.07	-1 250 459.24	20.2	J-13	-247 556.59	-1 250 500.82	10.8
J-6	-247 045.14	-1 250 490.30	17	J-14	-247 485.78	-1 250 360.44	10
J-7	-247 162.18	-1 250 614.13	16	J-15	-247 620.76	-1 250 444.48	14
J-9	-247 356.20	-1 250 588.26	23	J-16	-247 669.95	-1 250 490.26	14
J-11	-247 298.35	-1 250 450.36	8.8				
Subhorizontal drainage boreholes (20 boreholes in 5 groups)							
borehole	coordinate		length (m)	borehole	coordinate		length (m)
	X (S-JTSK)	Y (S-JTSK)			X (S-JTSK)	Y (S-JTSK)	
V1/1	-247 356.91	-1 250 309.19	110	V3/1	-247 275.95	-1 250 436.89	120
V1/2	-247 356.91	-1 250 309.19	90	V3/2	-247 275.95	-1 250 436.89	100
V1/3	-247 356.91	-1 250 309.19	110	V3/3	-247 275.95	-1 250 436.89	100
V1/4	-247 356.91	-1 250 309.19	120	V4/1	-247 082.87	-1 250 535.53	100
V1/5	-247 356.91	-1 250 309.19	100	V4/2	-247 082.87	-1 250 535.53	100
V2/1	-247 466.02	-1 250 427.33	90	V4/3	-247 082.87	-1 250 535.53	90
V2/2	-247 466.02	-1 250 427.33	80	V5/1	-247 193.60	-1 250 444.57	110
V2/3	-247 466.02	-1 250 427.33	90	V5/2	-247 193.60	-1 250 444.57	80
V2/4	-247 466.02	-1 250 427.33	110	V5/3	-247 193.60	-1 250 444.57	80
V2/5	-247 466.02	-1 250 427.33	100	V5/4	-247 193.60	-1 250 444.57	110

Value S in MK-test presents sum of all considered values sgn ($x_j - x_i$). If S > 0, examined values, placed in time series later tend to be larger than values that are recorded in time series earlier. The opposite is true in case, if S < 0. Value S indicates the direction of the investigated trend (if it exists) – in case of positive value it will have increasing tendency, in the case of negative value the trend will be decreasing.

Assessment of the statistical significance of the trend is done by testing of hypothesis. In trend MK-test is tested null hypothesis (H_0), which assumes, that there is trend and the data are random and independent. Alternative hypothesis (H_1) is, that in tested file the trend exists. If the total number of values is n > 10, the statistics of the test can be aproximate by normal distribution and then normalized statistics Z_S can be calculated. (Helsel & Hirsch, 1992):

$$Z_S = \begin{cases} \dfrac{S-1}{\sigma_S} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sigma_S} & if\ S < 0 \end{cases}$$

where $\boldsymbol{\sigma_s}$ is standard deviation: $\sigma_S = \sqrt{Var(S)}$

Var(S) is variation:

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)]$$

n – total number of data
m – number of linked groups (zero values between the compared groups)
t_i – number of data in i-ish bounded group

The p-value can be used to decide the validity or invalidity of the null hypothesis:

$$p = 2(1 - P(Z \leq Z_S))$$

where $(Z \leq Z_S)$ – the value of the distribution function of the standardized normal distribution in point Z_S.

The P-value expresses probability, by using of under the validity of the hypothesiss H_0 we get the same or less probable value of tested statistics. In comparison with determined level of significance α (generally α = 5 %) is hypothesis H_0 rejected in case, if p-value is lower than value α. In this case it means, that hypothesis H_1 is confirmed, so in file under consideration the existence of statistically important trend is confirmed in confidence interval 95 %.

Determining the size of the proven statistically significant trend can be done using of Sen´s slope. The Sen's slope method expects a linear trend in time series and is widely used for the determination of the size of trends e.g. in hydro-climatic time series (Zeleňáková et al., 2016). In this method the regression line directive is calculated as follow:

$$\beta = median\left(\frac{x_j - x_k}{j-k}\right)$$

where x_j, x_k are data in time j and k (j > k)

Positive value of the directive β indicates growing trend and negative value indicates decreasing trend in time series. Median is the number in the middle of variation series.

For confidence interval 1-α for Sen's slope, upper and lower limit can be calculated:

lower limit: lower = $\beta_{(N-k)/2}$
upper limit: upper = $\beta_{(N+k)/2+1}$

where N is number of pairs in time series $N = C(n, 2)$

k is inverse distribution function of the standardized normal distribution for the selected level of significance α

$$k = \sigma_S Z_\alpha$$

Results of statistical analysis

Set of precipitation totals

Near the site (ca 3.5 km) the hydrometeorological station of SHMI Slanská Huta is located. The trend analysis of regime observations in the frame of PMS GF encompasses monthly total precipitations, provided by SHMI, which are measured on this station (Fig. 4).

Monthly data since 2001 are avilable for monitoring purposes. Because the direct precipitations represent primary and probably the most important phenomenon, which influences the hydrogeological situation of the area, it was appropriate to analyse also this data file.

The file in question included 216 elements. Within the Mann-Kendall test, hypothesis H_0 was tested, on the basis of the test results we could confirm or deny the existence of statistically important trend within the confidence interval of 95 % (for α = 0.05). Results are shown in table (Tab. 2).

In order to exclude the effects of cyclically recurring effects with a one-year period (e.g. the intensity of evapotranspiration), trends for individual months (Tab. 3), as well as annual precipitation totals (Tab. 4) for the entire measured period were tested using the same methodology.

Based on calculations in tested file of monthly and annual total precipitations from rain gauge station of SHMI Slanská Huta, no statistically important trend of the significance level α = 0.05 was demonstrated. So the presented data have character of independend and random data.

Tab. 2
Results of MK-test for file of monthly total rain precipitations.

Mann-Kendall test for monthly precipitation totals in the period 2001 - 2019							
n	α	S	Var(S)	σ_S	Zs	p	trend
216	0.05	308	94864	1061.814	0.289	0.772	NO

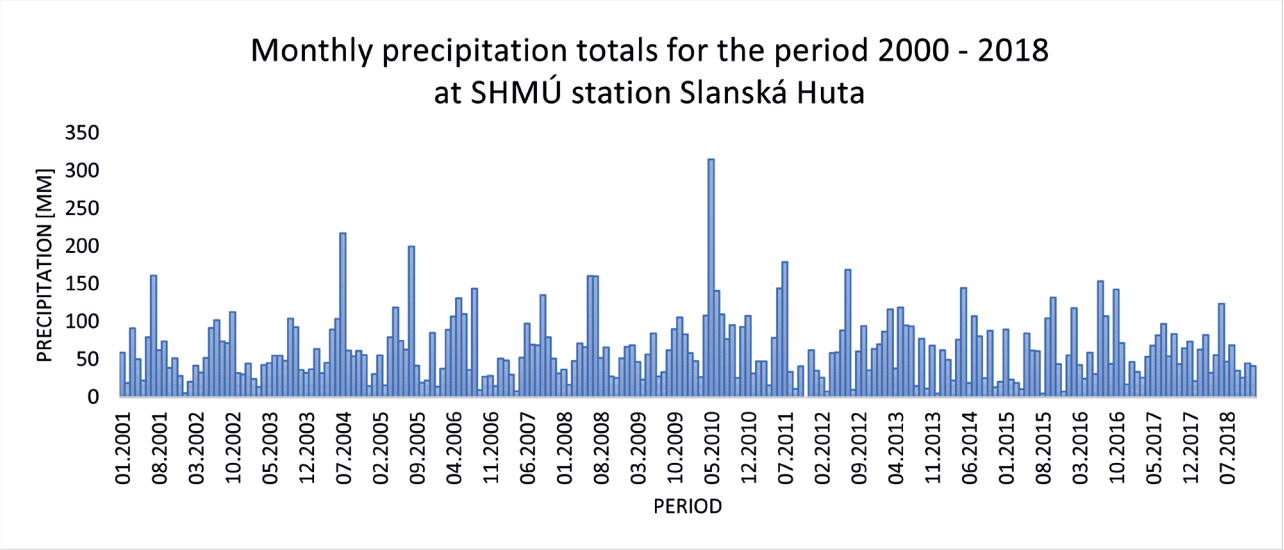


Fig. 4. Graphic representation of monthly total precipitations.

Set of groundwater level measurements

Statistical evaluation of hydrogeological data results from measurements, collected since 2003. These are periodical monthly measurements in 11 observation boreholes which represents set of data, sufficient for long term trend evaluation.

In terms of annual cycle, lowest average groundwater levels were measured in August – November, and highest average levels were measured in spring months March and May, while in this period, also largest variance of levels were recorded (Figs. 5, 6 and 7).

Trend analysis was conducted separately for each borehole. Range of tested files, corresponding to number of measurements was 162. In the case of boreholes J-6, J-7, J-9 and J-16, for technical reason not all measurements were made, so the range of files was lower (Tab. 5).

As is evident from Tab. 6, trend on statistically important level was confirmed in 10 of 11 cases. For this

Tab. 3
Results of the MK-test for monthly precipitation totals for individual months.

MK-test for monthly precipitation totals for individual months in the period 2001 - 2019								
mounth	n	α	S	Var(S)	σ_S	Zs	p	trend
JAN	18	0.05	27	697	26.40	0.98	0.32	NO
FEB	18	0.05	39	697	26.40	1.44	0.15	NO
MAR	18	0.05	-7	697	26.40	-0.23	0.82	NO
APR	18	0.05	-15	697	26.40	-0.53	0.60	NO
MAY	18	0.05	31	697	26.40	1.14	0.26	NO
JUN	18	0.05	-5	697	26.40	-0.15	0.88	NO
JUL	18	0.05	-13	697	26.40	-0.45	0.65	NO
AUG	18	0.05	-24	696	26.38	-0.87	0.38	NO
SEP	18	0.05	-15	697	26.40	-0.53	0.60	NO
OKT	18	0.05	7	697	26.40	0.23	0.82	NO
NOV	18	0.05	15	697	26.40	0.53	0.60	NO
DEC	18	0.05	7	697	26.40	0.23	0.82	NO

Tab. 4
Results of the MK-test for annual precipitation totals.

Mann-Kendall test for annual precipitation totals in the period 2001 - 2019							
n	α	S	Var(S)	σ_S	Zs	p	trend
18	0.05	-11	697	26.401	-0.379	0.705	NO

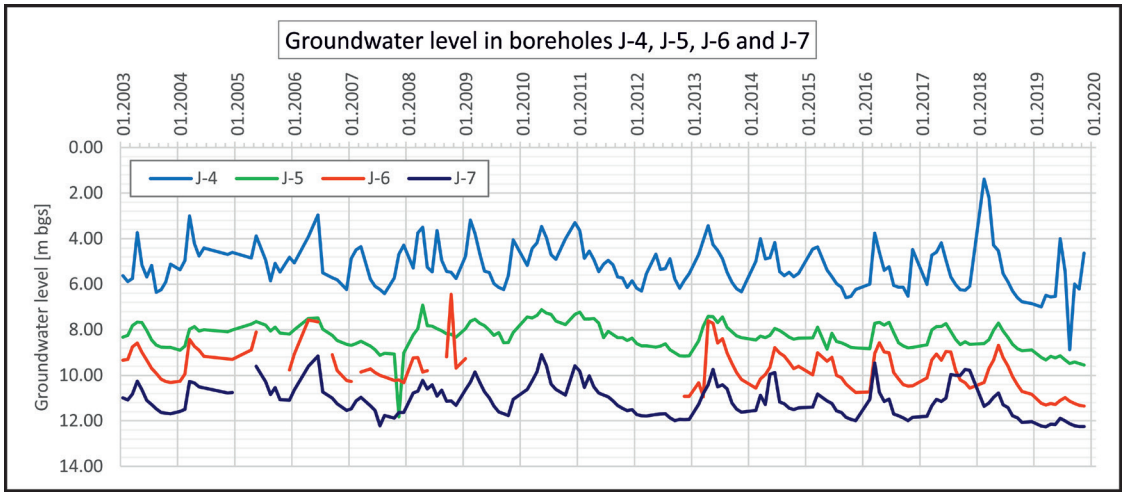


Fig. 5. Graphs of groundwater levels in boreholes J-4, J-5, J-6 and J-7.

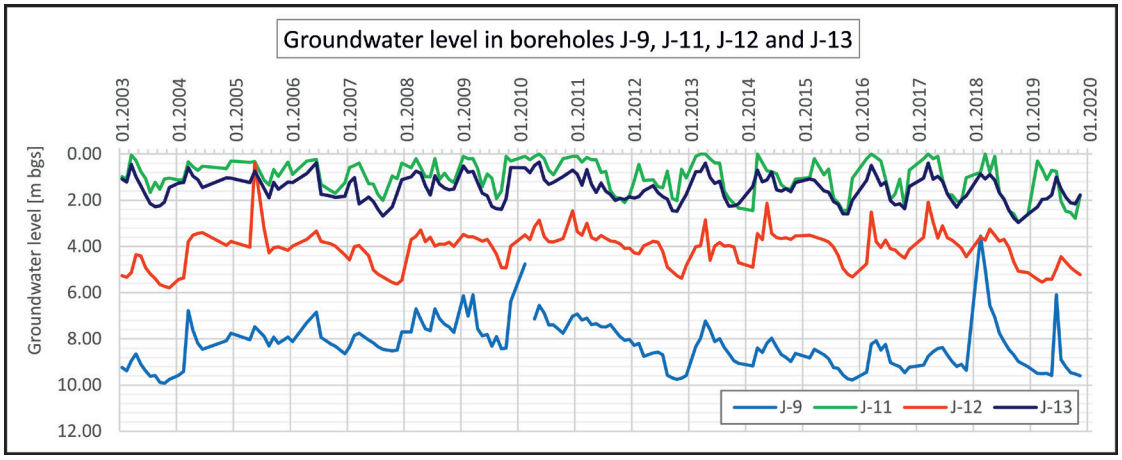


Fig. 6. Graphs of groundwater levels in boreholes J-9, J-11, J-12 and J-13.

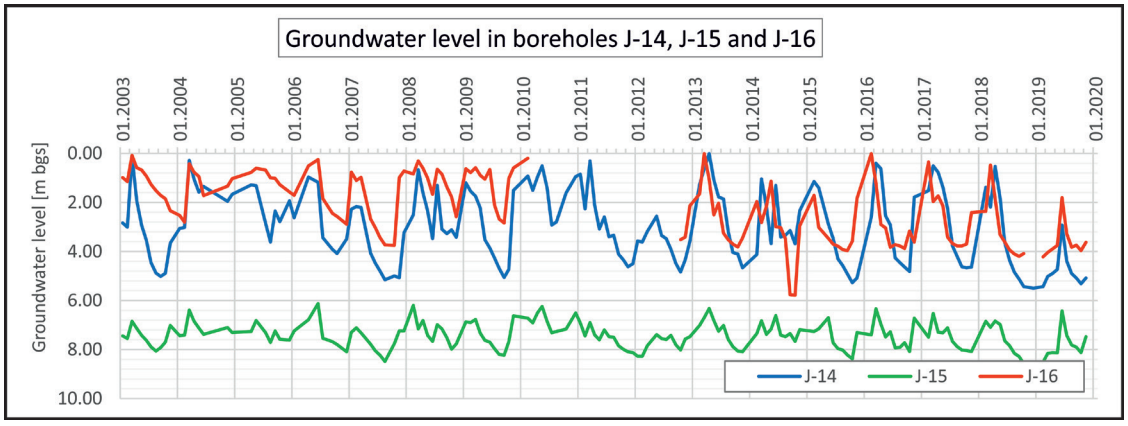


Fig. 7. Graphs of groundwater levels in boreholes J-14, J-15 and J-16.

Tab. 5
Results of MK-test for set of measurements of groundwater levels.

Mann-Kendall test	Monitored boreholes										
	J-4	J-5	J-6	J-7	J-9	J-11	J-12	J-13	J-14	J-15	J-16
n	162	162	124	161	161	162	162	162	162	162	136
α	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S	2185	2560	1833	2928	2391	1727	-396	1781	2236	1719	3969
Var(S)	476671	476648	214190	467908	467931	476356	476647	476656	476695	476632	282511
σ_S	690.414	690.397	462.807	684.038	684.055	690.185	690.397	690.403	690.431	690.386	531.518
Zs	3.163	3.707	3.958	4.279	3.494	2.501	-0.572	2.578	3.237	2.488	7.465
p	0.00156	0.00021	0.00008	0.00002	0.00048	0.01239	0.56723	0.00993	0.00121	0.01283	8.3E-14
trend	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES

Tab. 6
Calculation results of Sen's slope for set of groundwater level measurements.

Sen's slope	Monitored boreholes										
	J-4	J-5	J-6	J-7	J-9	J-11	J-12	J-13	J-14	J-15	J-16
trend (MK)	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES
α	0.05	0.05	0.05	0.05	0.05	0.05		0.05	0.05	0.05	0.05
N	13041	13041	7626	12879	12880	13041		13041	13041	13041	9180
σ_S(MK)	690.414	690.397	462.807	684.038	684.055	690.185		690.403	690.431	690.386	531.518
Zα(MK)	1.960	1.960	1.960	1.942	1.960	1.960		1.960	1.960	1.960	1.960
k	1353.19	1353.15	907.09	1328.35	1340.72	1352.74		1353.16	1353.22	1353.13	1041.76
β	0.0053	0.0038	0.0090	0.0050	0.0063	0.0035		0.0027	0.0088	0.0023	0.0206
β-lower	0.0021	0.0019	0.0044	0.0029	0.0028	0.0005		0.0007	0.0033	0.0005	0.0154
β-upper	0.0083	0.0056	0.0128	0.0071	0.0095	0.0063		0.0048	0.0136	0.0042	0.0252
Δh[m]	0.9	0.6	1.1	0.8	1.0	0.6		0.4	1.4	0.4	2.8
Δh-lower	0.3	0.3	0.5	0.5	0.5	0.1		0.1	0.5	0.1	2.1
Δh-upper	1.3	0.9	1.6	1.1	1.5	1.0		0.8	2.2	0.7	3.4

data files, the slope of trend β was then calculated by using Sen's slope method – it is regression line slope.

Set of drainage boreholes measurements

Statistical file of data from boreholes for underground drainage of area covers period from the end of 2001 until the start of 2019. For simplification, data are covered for 5 outposts, where the water is collected, drained from the area by subhorizontal drainage boreholes in count of 3–5 boreholes for outpost. Summary figure for outpost is formed as a sum of outflows from each borehole. Set of measurements for examined period is plotted in following graph (Fig. 8):

Trend analysis was realized similar to groundwater levels by MK-test. When testing, the hypothesis H_0 was in each of 5 cases denied and statistically important trend on the significance level α = 0,05 was confirmed (Tab. 7). By using of Sen's method, for each outpost, trend regression line direction was calculated. Results are listed in tables 5 and 6.

Discussion

According to SHMI study (Zeleňáková et al., 2016), time series of rain precipitations in Slovak rain gauge stations have mostly growing trend, mainly in July. Analysis of annual trend of time series of rain gauges by means of MK-test has identified statistically important trend in 452 from 487 evaluated rain gauge stations of SHMI, which is 93 % of evaluated stations. Important negative trends were indentified in northern part of Slovakia, near Orava water reservoir, important positive trends were indentified all across Slovakia.

Based on our processed statistical file of monthly precipitations from Slanská Huta station, the growing trend was not confirmed, in the 95 % interval of reliability, the data appear as random and independent. This reality

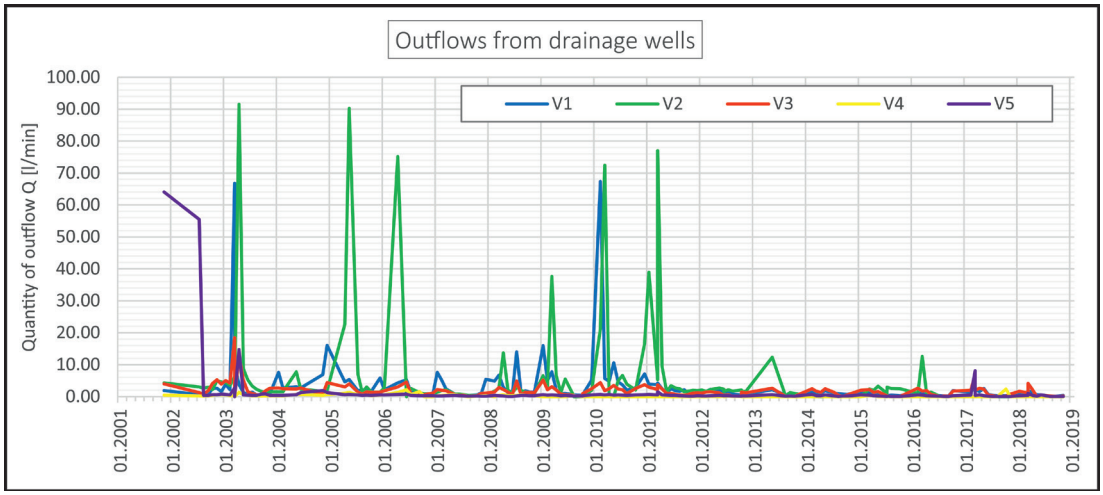


Fig. 8. Graphs display of outpot outflows – each outpot V1–V5 consists of 2–5 subhorizontal drainage boreholes (their location is visualized in Fig. 3).

Tab. 7
Results of MK-test for set of measurements of drainage wells outflows.

Mann-Kendall test	Names of drainage boreholes groups				
	V1	V2	V3	V4	V5
n	151	150	150	150	150
α	0.05	0.05	0.05	0.05	0.05
S	-3485	-4187	-2951	-4894	-4057
Var(S)	386285	371863	378669	309256	378511
σ_S	621.518	609.806	615.361	556.108	615.232
Zs	-5.606	-6.864	-4.794	-8.799	-6.593
p	2.07E-08	6.67E-12	1.64E-06	1.38E-18	4.32E-11
trend	**YES**	**YES**	**YES**	**YES**	**YES**

Tab. 8
Results of Sen's slope for measurements set of drainage boreholes outflows.

Sen's slope	Names of drainage boreholes groups				
	V1	V2	V3	V4	V5
trend (MK)	**YES**	**YES**	**YES**	**YES**	**YES**
α	0.05	0.05	0.05	0.05	0.05
N	11325	11175	11175	11175	11175
σ_S (MK)	621.518	609.806	615.361	556.108	615.232
Zα(MK)	1.960	1.960	1.960	1.960	1.960
k	1218.15	1195.20	1206.08	1089.95	1205.83
β	-0.0128	-0.0190	-0.0102	-0.0017	-0.0027
β-lower	-0.0183	-0.0265	-0.0150	-0.0026	-0.0035
β-upper	-0.0078	-0.0132	-0.0057	-0.0006	-0.0020
ØQ [l/min]	3.15	5.51	1.80	0.20	1.33
ΔQ [l/m]	-1.9	-2.8	-1.5	-0.3	-0.4
ΔQ-lower	-2.8	-4.0	-2.3	-0.4	-0.5
ΔQ-upper	-1.2	-2.0	-0.9	-0.1	-0.3

had to be taken into account while evaluation other parts of regime measurements.

Generally assumed, these measured values of regime measuremens are dependent on amount of rain precipitations. However, in this case no correlation analysis was performed, because for its correct realization, data with comparable method of collection were required, which is not the case. When comparing timelapse data, such as monthly rain precipitations with point data, like groundwater measurements in monthly intervals, inaccuracies can appear, which can discard the analysis. But results of unparametrical trend analysis can be compared regardless of input data character.

Despite the fact that we assume dependence of groundwater levels on amount of precipitations and data file shows no trend, in a set of groundwater level measurements the increasing trend was confirmed in the vast majority of evaluated boreholes. Because those data present depth of groundwater levels – that means distance of level from the surface, the increasing trend means that groundwater levels are decreasing in time. After recalculation of Sen´s slope β (trend line guideline), it is possible to quantify this trend and calculate statistical decrease of groundwater level in each borehole during the measured period. This value is in the range between 0.4 m in the borehole J-13 up to 2.8 m in the borehole J-16T (credibility of value in J-16 is debatable, because borehole had collapsed during measurements and on its place a new borehole was drilled to restore functionality of remediation messures). Average statistical decrease of the groundwater level for the whole measured period is 1.0 m, while within the interval of reliability 95 % it can reach value from 0.5 to 1.5 m. Despite the results are relatively favourable, they are quite unexpected, because in general, remediation issues lose their effectiveness after some time and there is rather an repeated increase in the groundwater level.

Decreasing amount of the water, drained by remediation issues from the measured area is observable from the trend analysis of outflow from drainage boreholes. It should be noted, that in original data file of each borehole a large variance of values is evident, because some boreholes, strongly responsive to precipitations, can in short amount of time drain water from rock enviromnent with outflow 100-times bigger, than is its average outflow. These are mainly boreholes V2 and V4, where the outpost was often flooded over the outlet because of high outflow, so the immediate outflow was only estimated. This is why high values (over 100 l/min) were omitted from tested file. Considering, that high values were omitted throughout the period of data collection and considering the unparametrical character of the test, we do not expect important affect of its results.

The MK-test demonstrated in all groups of drainage boreholes statistically important decreasing trend – the groundwater levels in rock environment were decreasing in time. Applying the Sen´s slope calculation we tried to quantify this proces. After recalculation on the whole period of data collection, 37 % statistical decrease of outflow has occured, representing a decrease of outflow by 5.3 l/min at average outflow by 14.3 l/min. By using calculations of Sen´s slope for 95 % confidence interval, it can be stated, that statistical decrease of the outflow in drainage boreholes can reach values in interval from 2.4 to 8.5 l/min, which corresponds to 20–60 % decrease. It can be assumed, that decreasing outflow of drainage boreholes relates with their clogging (colmatation), or there is a relation with total statistical decrease of the groundwater volume in rock environment of the landslide area?

Conclusion

Trend analysis proved decreased outflow of drainage boreholes during the measurement period by 37 % in average. It also confirmed decrease in the groundwater levels in almost all measured boreholes by 1 m during whole measured period in average. As the decreasing trend of rain precipitations was not confirmed, there must be another explanation of this phenomenon:

It is possible, that groundwater in the measured area had the character of static volumes (Mika & Boľha, 2000) and remediaton measures caused their gradual drainage.

The groundwater levels had lowered under level, which can be reached by drainage boreholes.

Because under the regime observations, effectiveness of surface measurements was not evaluated – surface drain and drainage ribs, proposed together with deep drainage of the groundwater (Mika & Boľha, 2000). It is possible, that they result into important decrease in transporting of the rainwater into the rock.

Based on meteorological observations, there is some change in climate (Zeleňáková et al., 2016) – and even if there was not confirmed decreasing trend of amount of rain precipitations, their character can change – the torrential rains are becoming more frequent, where the rainwater drains more frequently on the surface (with a significant contribution of the surface remediation measures) and less intensive subsidizes the rock environment.

Despite the fact that long-term trends indicate positive state in the development of hydrogeological situation of the landslide area, emergency situations arise during extreme weather fluctuations. It is necessary to keep, or even increase the capacity of drainage units, so they can sustain the extreme situations and drain even the extreme amount of the rain precipitations away from the landslide area.

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Trendová analýza hydrogeologických parametrov zosuvného územia v trase tranzitného plynovodu európskeho významu pri obci Slanec

Príspevok sa zaoberá hodnotením časových zmien parametrov charakterizujúcich hydrogeologickú situáciu v zosuvnom území v blízkosti obce Slanec. Údaje boli namerané v rámci režimových pozorovaní v rokoch 2003 – 2019. Závery z týchto hodnotení môžu prispieť k celkovému posúdeniu stavu a funkčnosti realizovaných sanačných opatrení, ako aj aktuálnej situácie monitorovaného zosuvného územia.

Obec Slanec leží na južnej strane Slanských vrchov na svahoch stratovulkánu Milič v rozsiahlom zosuvnom území (obr. 2), ktorým prechádza trasa dôležitých podzemných a nadzemných vedení. V tejto súvislosti bola lokalita Slanec v roku 2003 zaradená do súboru monitorovaných lokalít v rámci projektu *Čiastkový monitorovací systém – Geologické faktory* (ČMS GF). ČMS GF tvorí neodmysliteľnú súčasť národnej environmentálnej monitorovacej siete so zameraním na tzv. geologické hazardy – škodlivé prírodné alebo antropogénne geologické procesy ohrozujúce prírodné prostredie a človeka.

Geodynamické procesy prebiehajúce na tomto území je možné klasifikovať ako veľmi pomalé svahové pohyby, podstatne ovplyvnené podzemnou vodou (Míka a Boľha, 2000). Monitorovacie práce vykonávané v súčasnosti sa preto sústreďujú na hydrogeologické parametre územia – merania zmien výšky hladiny podzemnej vody vo vrtoch a výdatnosti odvodňovacích zariadení, realizovaných v rámci sanácie geologického prostredia, čím sa overuje ich funkčnosť (Ondrejka et al., 2017).

V rámci režimových pozorovaní sa na lokalite Slanec monitoruje hladina podzemnej vody v 11 pozorovacích vrtoch a meria sa výdatnosť 20 odvodňovacích zariadení (subhorizontálnych odvodňovacích vrtov) sústredených do 5 stanovíšť (obr. 3). Súbor údajov je doplnený o mesačné zrážkové úhrny z blízkej meteorologickej stanice Slanská Huta, poskytované Slovenským hydrometeorologickým ústavom (SHMÚ).

Jedným z cieľov vyhodnotenia režimových meraní je preukázanie prítomnosti štatisticky významných trendov v časových radoch monitorovaných údajov.

Z rôznych štatistických postupov používaných na analýzu časových radov vhodných na spracovanie environmentálnych údajov (Gibbons et al., 1955) je najbežnejší neparametrický Mannov-Kendallov trendový test (MK-test). Tento typ testu bol široko aplikovaný na analýzy trendov v environmentálnych vedách a jeho výsledky sa ukázali veľmi konzistentné (Önöz a Bayazit, 2003).

Posúdenie štatistickej významnosti trendu sa robí testovaním hypotéz. V trendovom MK-teste sa testuje nulová hypotéza (H_0), ktorá predpokladá, že v testovanom súbore neexistuje trend a že údaje sú náhodné a nezávislé. Alternatívnou hypotézou (H_1) je, že v testovanom súbore trend existuje. Stanovenie veľkosti preukázaného štatisticky významného trendu je možné realizovať výpočtom Sen-koeficientu. Senova metóda predpokladá lineárny trend v časových radoch a široko sa využíva na určenie veľkosti trendov napr. v hydroklimatických časových radoch (Zeleňáková et al., 2016).

Výsledky štatistickej analýzy

Súčasťou trendovej analýzy režimových pozorovaní v rámci ČMS GF sú mesačné úhrny zrážok zo zrážkomernej stanice Slanská Huta poskytnuté SHMÚ (obr. 4).

Podľa výpočtov v testovanom dátovom súbore mesačných a ročných zrážkových úhrnov z tejto stanice nebol

preukázaný štatisticky významný trend na hladine významnosti $\alpha = 0{,}05$. Prezentované údaje majú teda charakter nezávislých a náhodných údajov.

Ďalšou skupinou testovaných údajov sú periodické mesačné merania výšky hladiny podzemnej vody (HPV) na 11 pozorovacích vrtoch, zhromažďované od roku 2003. Tieto údaje predstavujú z každého vrtu súbor údajov v rozsahu do 162 meraní, dostatočný na celkové zhodnotenie dlhodobého trendu (tab. 5). Ako je evidentné, trend na štatisticky významnej úrovni (pokles HPV) sa potvrdil v 10 z 11 prípadov. Z týchto dátových súborov bol následne Senovou metódou vypočítaný sklon trendu β – smernica regresnej priamky (tab. 6).

Poslednou skupinou testovaných údajov je štatistický súbor údajov zo zariadení na podpovrchové odvodňovanie územia. Súbor zahŕňa údaje za obdobie od konca roka 2001 do začiatku roka 2019. Údaje sa kvôli zjednodušeniu vzťahujú na 5 stanovíšť – V-1 až V-5, na ktoré sa sústreďuje voda odvádzaná z územia subhorizontálnymi odvodňovacími vrtmi (SHV), a to v počte 3 – 5 vrtov na stanovište. Pri testovaní hypotézy H_0 bola pri všetkých 5 prípadoch táto hypotéza zamietnutá a potvrdil sa štatisticky významný trend – pokles výdatnosti (tab. 7). Senovou metódou bola za každé stanovište vypočítaná smernica regresnej priamky trendu (tab. 8).

Diskusia

Napriek tomu, že predpokladáme závislosť HPV od množstva zrážok a dátový súbor úhrnov zrážok nevykazuje žiaden trend, v súbore meraní hladín podzemnej vody sa štatisticky významný trend potvrdil v prevažujúcej väčšine hodnotených vrtov. Vypočítaním Senovho koeficientu β (smernice trendovej priamky) bol kvantifikovaný priemerný štatistický pokles hladiny podzemnej vody – jeho priemerná hodnota za celé merané obdobie je približne 1,0 m, pričom v rámci intervalu spoľahlivosti 95 % môže nadobudnúť hodnotu z intervalu od 0,5 až do 1,5 m.

Pokles množstva vody odvádzanej odvodňovacími opatreniami z monitorovanej oblasti je badateľný z trendovej analýzy výdatnosti odvodňovacích vrtov. MK-test preukázal pri všetkých skupinách odvodňovacích vrtov štatisticky významný klesajúci trend. To znamená, že množstvo vody odvádzanej z horninového prostredia postupom času klesá. Použitím Senovho výpočtu sme sa pokúsili tento pokles kvantifikovať. Po prepočítaní na celé obdobie zberu údajov došlo k štatistickému poklesu výdatnosti v priemere o 37 %.

Keďže sa nepotvrdil klesajúci trend množstva zrážok, klesajúce trendy HPV a výdatnosti SHV sú v rozpore s predpokladom závislosti hydrogeologických parametrov od množstva zrážok. Tento jav môže mať viacero vysvetlení:

- podzemná voda v skúmanom území mala z veľkej časti charakter statických zásob a sanačnými opatreniami bola postupne odvedená,
- hladina podzemnej vody vplyvom hĺbkovej drenáže poklesla v okolí odvodňovacích vrtov pod úroveň, z ktorej odvodňovacie vrty vodu drénujú,
- vplyvom povrchových odvodňovacích zariadení (navrhovaných spolu s hĺbkovým odvedením podzemnej vody – ich účinnosť sa v rámci režimových pozorovaní nehodnotila) sa významne znižuje prestup zrážkovej vody do horninového prostredia,
- zmena charakteru zrážok – čoraz častejšie sa vyskytujú krátko trvajúce prívalové dažde, keď zrážková voda vo významnejšej miere odteká po povrchu (za výrazného prispenia povrchových sanačných opatrení) a menej dotuje horninové prostredie.

Napriek tomu, že dlhodobé trendy indikujú priaznivý stav vo vývoji hydrogeologickej situácie zosuvného územia, havarijné stavy vznikajú častejšie pri extrémnych výkyvoch počasia. Je nevyhnutné udržiavať kapacitu odvodňovacích zariadení a ak je to možné, aj ju zvyšovať, aby zvládli náporové situácie a rýchlo odviedli aj extrémne množstvo zrážok preč zo zosuvného územia.

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