Influence of extreme climatic conditions upon landslides development in the Slovak Republic

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Abstract: The paper demonstrates that the analysis of rainfall data allows to predict landslides occurrence within certain regions of Slovakia. For definition of relation between climatic conditions and groundwater table level in slopes a method of cumulative line of effective precipitation has proven to be competent. Based upon knowledge of daily effective precipitations intensity and groundwater table fluctuations it is possible to predict the groundwater level rising and, if measuring data on landslide activity are at hand, it is possible to predict future development of any landslide.

Key words: landslides, effective precipitation, snow melting, groundwater table regime

1. Introduction

From the observations of slope movements initiation it follows that very frequently a short-term process of intense subsurface infiltration of precipitation waters is a crucial (triggering) factor. Consequently, the infiltrated water partially supplies humidity in the zone of aeration and in the case of full saturation it may result in groundwater level rise. As a source of infiltrated water there may serve rain precipitation, however, very important there is snow melting process, mainly in the case of quick process. Based upon available data (inquiry, SHMI) this paper points out the regional influence of relatively short-term climatic events upon landslides evolution:

- intense precipitation in July 1997 and other summer periods
- snow melting and precipitation in March and April 2000.

2. Method of cumulative line of effective daily precipitation

In order to analyse the relation between fluctuations of the groundwater level and rainfall intensity, or the quantity of water released by melting snow, there has been adopted the method of cumulative line of the effective potential amount of water daily precipitation. Under the term effective precipitation we understand the maximum potential amount of water that can infiltrate the ground. The part of the rainfall that flows off as surface runoff or is intercepted by plants is disregarded.

The estimation of effective rainfall is based on subtracting the evapotranspiration value from the falling rainfall value:

$$Z_{ef} = Z - ET_{pot} \text{ [mm]}, \qquad (1)$$

where:

Z_{ef} – effective precipitation,
Z – precipitation fallen,
ET_{pot} – potential evapotranspiration.

Daily values of the potential evapotranspiration ET_{pot} were calculated according the formula by Haude (in Hölting, 1996.

From the relation (1) it follows, that the effective precipitation during rainless periods manifests a negative value because of evapotranspiration. During this period there does not occur infiltration into the rock environment; on the contrary, the humidity is released from the soil.

For periods when the infiltration of rainfall into a rock environment occurs or humidity is released, a method to determine the cumulative line of daily effective rainfall (positive and negative values) was applied. The rising sections represent periods with infiltration of the rainfall; the downward ones indicate the release of the humidity from the rock environment. The horizontal parts of the line evidence for a balance between rainfall and evapotranspiration; the effective rainfall is equal to zero.

The course of this cumulative line may almost truly reflect the fluctuation of dominantly shallow groundwater level horizons, which is depicted in Fig. 1.

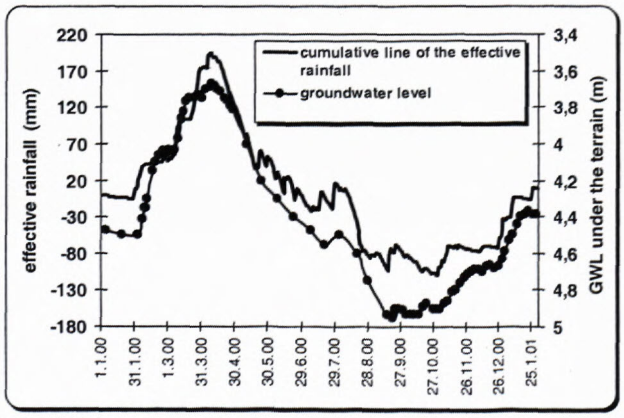

Fig. 1. Dependence between groundwater level fluctuation and the cumulative line of the effective rainfall

It is relatively easy to acquire values of the effective precipitation during the summer period according to the formula (1). However, during the winter period the situa-

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tion is far more complicated. During the rainless cold period with daily air temperatures ranging around 0 °C and less, we may calculate with evapotranspiration from the snow surface. According to Rachner (1987) the daily evapotranspiration from temporary winter snow cover is estimated in January above 0.1 mm and in March up to 0.2 mm. The fallen precipitation in form of snow is not calculated as the effective one, only its equivalent corresponding the melting.

There is possible to define the water amount in mm released from melting snow according to the formula:

$$h = h_s \times s \text{ [mm]}, \qquad (2)$$

where:
h_s is snow cover height [mm],
s is water equivalent of snow cover – WESC.

However there is necessary to define the snow cover thickness and water equivalent of snow cover (WESC). The WESC is not measured daily at majority of climatic stations; generally it is measured only once a week. Therefore it is inevitable to distribute evenly the weekly effective precipitation from melting snow according number of days between separate WESC measurements. Even more complicated there is determination of effective precipitation, when mutual snow melting and rainfall occur and the evapotranspiration has to be taken into calculation.

Only this complex way calculated daily effective precipitation allows us to construct **cumulative line** and to adopt it to analyse climatic conditions influence upon the groundwater level regime and, consequently, upon the slope stability.

3. Landslides in Slovakia triggered by intense rainfall in July 1997 and in further summer periods

July 1997 has become known thanks to floods, which were concentrated in the NW Slovak regions, prevailingly. Since 1881 this was the second richest July in rainfall on the Slovak territory (Faško et. al., 1997). The most intense period recorded was 5th to 9th July, when within 5 days there fell up to 192 mm of rain.

The intense rainfall in SR triggered numerous landslides. In general, these were relatively shallow landslides, evolved in deluvial sediments, which use to happen during intense rainfall in tropical regions. However, these landslides did not occur only within the areas susceptible to sliding (reactivation of older landslides), but also on so far "safe slopes". The same situation in more accentuated form was observed in the Flysch Belt in Moravia (Marschalko, 2002).

In the area of Ľubovnianska vrchovina Upland (Flysch Zone) there occurred extensive planar shallow landslides in July in 1997 and 2001 as well as in 2004.

To analyse the rainfall in this region there was depicted a course of cumulative lines of the effective precipitation (method from the Chapter 2) from months May to July within years 1997-2005 from the Plaveč rain-gauge station (Fig. 2).

The daily effective precipitations, which were the triggering mechanism of landslides, reached on July 8, 1997

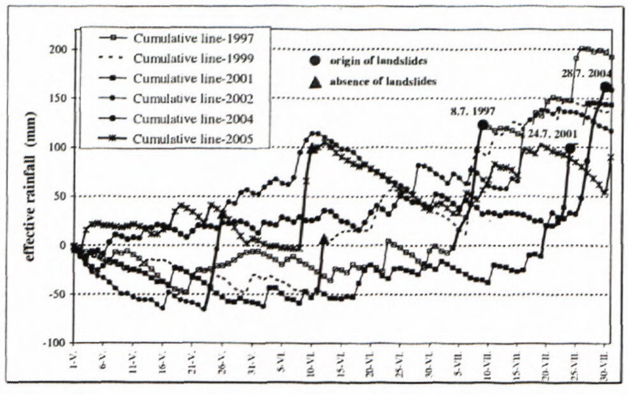

Fig. 2. Cumulative lines of the effective precipitation for the months of May-July for 1997- 2005 from the Plavec rain-gauge station.

- 54.5 mm, on July 24, 2001 – 60.2 mm and on July 28, 2004 – 50.16 mm. Almost the same amount of effective precipitation was recorded also in 1999 and even twice – June 12, 1999 – 55.32 mm and July 7, 1999 remarkable 66.22 mm. The landslides did not occur in further days with intense precipitation (July 16, 2002, June 9, 2005 - daily cumulative amounts 68,9 mm!). From the above it is obvious that the single daily effective precipitations, although of intense character, were not an immediate cause for landslides development.

However, the analysis of effective precipitation in days preceding the landslides development indicated a variable state of rock massif saturation. The Tab. 1 depicts the sum of the effective precipitation preceding the days with intense effective precipitation.

From the data in the Tab. 1 it follows, that the sum of the effective precipitation preceding intense precipitation (5 and 10 days) recorded on June 12, 1999, July 7, 1999, July 16, 2002 and June 9, 2005 shows a negative value. This means that there prevailed evapotranspiration above rainfall and it was released humidity from the near-surface parts of the rock environment. Therefore a part of intense precipitation only supplemented the missing humidity. On the contrary, the positive values of the effective precipitation sum before intense precipitation (5 and 10 days) on July 8, 1997, July 24, 2001 and July 28, 2004 speak for relatively high saturation of the rock environment.

Based upon these analyses there is possible to state that the shallow landslides may occur in the Ľubovnianska vrchovina Upland, provided 5 days before effective precipitation, which sum exceeds 50 mm in one day (precipitation, which triggered the landslide), the sum of effective precipitation is higher than 45 mm.

4. Influence of the effective rainfall and melt-water from snow upon the groundwater table fluctuation at the landslide site Bánoš

The landslide evolved in spring 1999 on the southern slopes of the altitudinal point Bánoš near Banská Bystrica, Central Slovakia, within the Tertiary sediments (Kopecký and Ilkanič, 2001). There was analysed at this site the influence of so-called effective rainfall and the effect of water originating from melting snow, upon the ground-

Tab. 1. Cumulative lines of effective precipitation for months May-July in the years 1997- 2005 from the Plaveč station.

	8. 7. 1997	12. 6. 1999	6. 7. 1999	24. 7. 2001	16. 7. 2002	28. 7. 2004	9. 6. 2005
Effective precipitation on very date of event (mm)	54.47	55.32	66.46	60.22	53.10	50.16	68.90
Sum of effective precipitation 5 days before the event (mm)	46.77	-8.70	-21.92	47.86	4.65	47.39	-1.60
Sum of effective precipitation 10 before the event (mm)	51.42	-17.56	-39.13	60.67	-3.76	48.04	12.60

water table variations. For this analysis there were used the groundwater table measurements from the nearby area, which preceded the slide development.

It has been shown that using the suggested method of cumulative line of the effective precipitation there is possible to correlate relatively well the relation between the effective precipitation (rainfall and water from melting snow) and groundwater table fluctuation.

Provided there are at hand measurements of groundwater table at any site, it is possible based upon data on the groundwater table rise and intensity of the effective precipitation to construct a correlation diagram (Fig. 3), which can serve together with relevant climatic data for groundwater table fluctuation modeling.

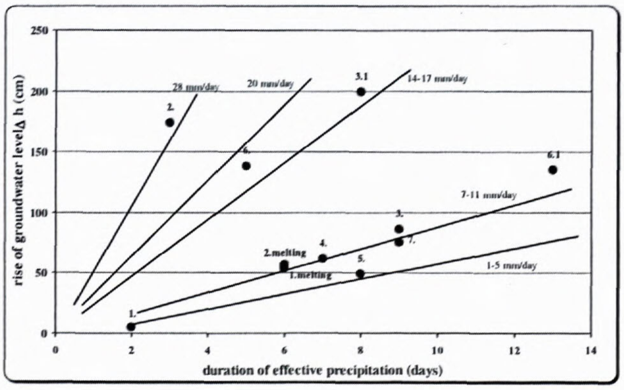

Fig. 3. Dependence of groundwater level rise upon the period duration of effective precipitations and their intensity (locality Bános).

This way we can define also state of stress in the slope and the conditions under which the slope failure occurred. The stability calculations at the Bánoš site have shown that the maximum value of the groundwater table, at which the slide evolved, is almost identical with the groundwater table acquired by modeling with the values of the effective precipitation.

It is necessary to point out that the accuracy of correlation diagrams depends upon frequency of relevant data collection. This is valid for the effective precipitation intensity, mainly.

We have also to point out that the method of the cumulative line can be applied mainly for near-surface groundwater table horizons, where the groundwater table reacts upon the intensity of the effective precipitation with relatively short retardation. Than for deeper groundwater table horizons there is inevitable to determine influence of other factors, which transform incoming impulse from the effective precipitation.

5. Snow melting and intense precipitation in March to April 2000 in Slovakia

From the results of the inquiry (Kopecký, 2002) it follows, that the March to April 2000 was the further period when the major part of Slovakia was hit by landslides. Within this period the landslides were registered mainly in the Laborecká and Ondavská vrchovina uplands, in the Kysuce, Liptov and Orava regions.

The water value of snow cover and cumulative rainfall amounts could tell us a lot about the extreme state, which evolved due to combination of snow cover melting and intense precipitation.

Under the water equivalent of snow cover (WESC) we understand the water amount, which is accumulated in snow column (in mm of water column). In the Tab. 2 there are the data on the WESC occurrence probability and their up to now maximum identified values and comparison with the data from 2000.

Also these data show that during the winter 2000/2001 there was actually accumulated a noteworthy snow cover, which contained a significant water volume, which was released from the snow melting.

The Tab. 3 presents data on monthly precipitation totals in March 2000 from selected stations.

5.1 Landslides in flysch formations developed at the margin of the Chočske vrchy Mts.

The development of these landslides was studied in detail based upon the climatic data (precipitation, temperature, relative air humidity, snow cover thickness, WESC) from the stations Liptovská Mara, Liptovská Ondrášová and Bobrovec. In March 2000 there developed or were reactivated:

- 9 landslides in Kalameny
- large earthflow in Malatiná
- landslide in Leštiny, which threatened the building of local dairy
- landslide in Veterná Poruba and Jakubovany

The Fig. 4 illustrates the course of cumulative line of the daily effective precipitation from this period. Besides this it shows the true precipitation totals and effective precipitation, which is divided into effective precipitation from rain and effective precipitation from melting snow cover, whereas their determination was rather complicated as we have already stated in the Chapter 2 (precipitation type, temperature, snow cover thickness, WESC).

A steep slope of the cumulative line of the effective precipitation was caused in periods 2.2-7.2. and 22.3.-29.3.

Tab. 2. Data on the water content of the snow cover from selected climatic stations.

Station	WESC occurrence probability (mm) once per .... years					Max.	value	year	2000
	2	10	50	80	100				
Plaveč	52	104	151	165	172	135 mm	22. 2. 1963	126.0 mm	31. 1.
Oravská Lesná	171	318	452	490	509	396 mm	10. 3. 1956	401.6 mm	20. 3.
Huty	83	189	285	312	326	272 mm	10. 3. 1952	166.0 mm	20. 3.

Tab. 3. Monthly precipitation totals from selected stations in March 2000.

Station	Long-term mean valid for March (mm)	Precipitation total for March 2000 (mm)	% of long-term normal
Čadca	56.0	156.0	278
Liptovská Mara	32.6	89.3	273
Nižná Polianka	41.0	92.0	224

29.3. due to snow melting and within 8.3.-11. 3. 2000 due to rainfall. It is obvious that by "classical" depiction of real precipitation it would not be possible to grasp the influence of the melting snow upon groundwater supply. Here comes into action a retarded impact of snow precipitation during melting period; in classical scenarios this part of precipitation was taken into consideration at the very time of their fall out. We have also to mention that the snow cover height was not the same at all sites (various volumes of the effective precipitation from melting snow) and moreover, the snow melting did not occur at all places simultaneously, but it was retarded due to effect of the altitude and slope orientation.

The influence of the effective precipitation upon the groundwater table level fluctuation is assessed in the Chapter 4. In March 2000 at the Liptovská Mara landslide there were identified in some piezometric gauges the maximum levels since 27 years of observations. This fact could be also approximated to the extreme stress state of the groundwater table within the surroundings, with consequent slope stability decrease.

A fact that the precipitation affected also deeper-situated groundwater table resulted in development of landslides of slip-type with deeper slip planes (8-20 m).

The first snow melting (Fig. 4) occurred by the beginning of February and the released effective precipitation saturated the zone of aeration and partially caused the rise of groundwater table level. During March 8 and 9 there fell in total 37 mm of the effective precipitation, which resulted in immediate rise of the groundwater table, because the zone of aeration had been already saturated. During this phase there developed the landslides in Jakubovany and Leštiny. From March 22 till March 29 there occurred total melting-down of the snow cover and was released a notable amount of the effective precipitation (ca 70 mm). This snow thawing triggered the landslides development in Malatiná (Fig. 5), Veterná Poruba and Kalameny.

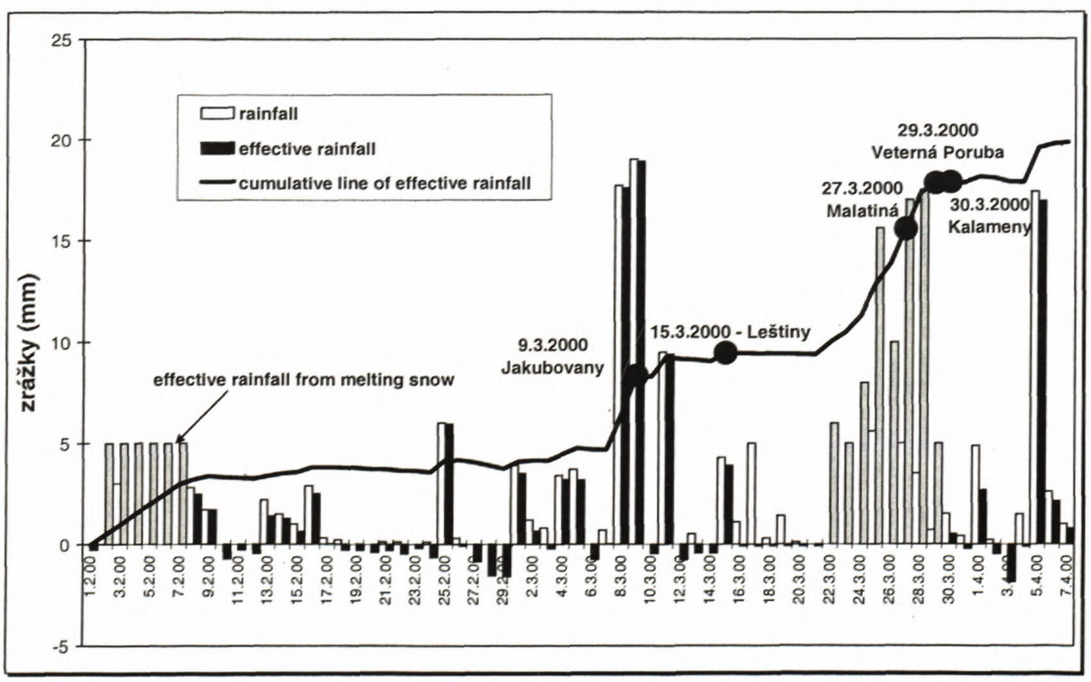

Fig. 4. Influence of the effective precipitation from rain and effective precipitation from melting snow upon the slope deformation evolution in spring 2000.

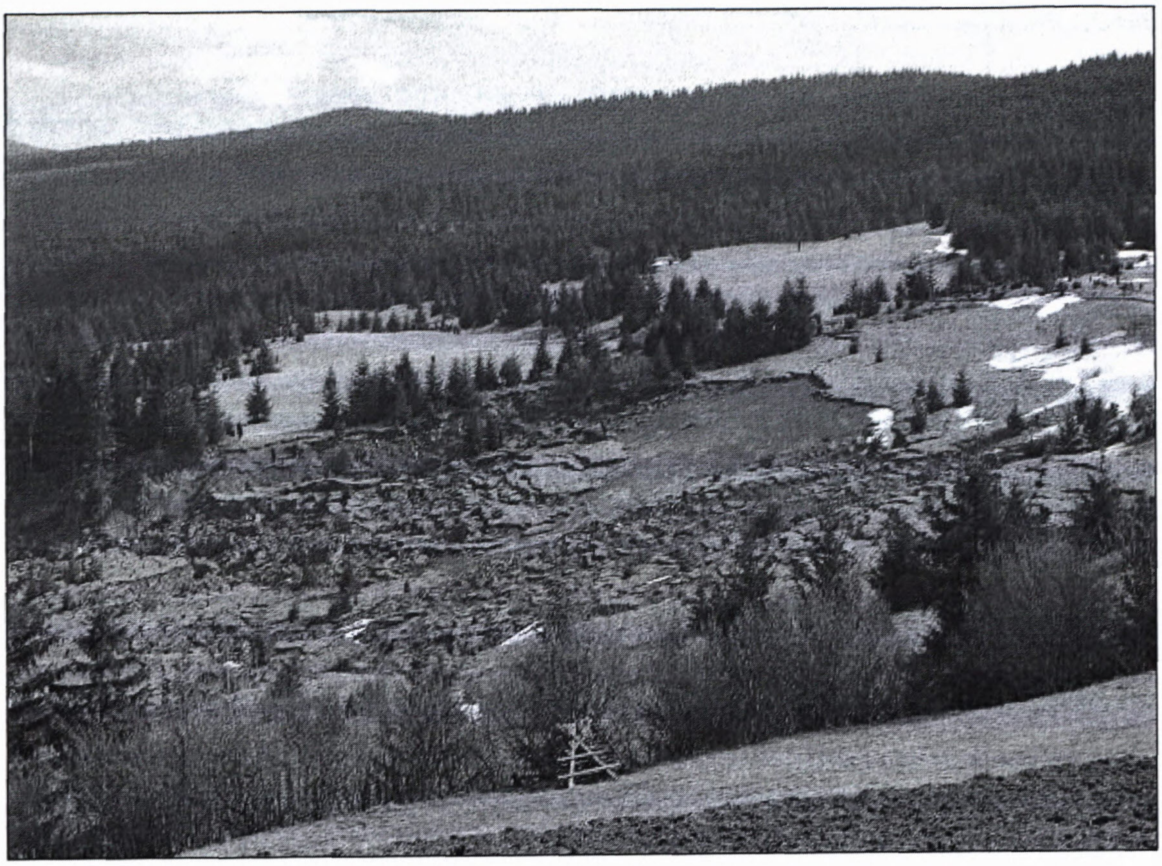

Fig. 5. Landslide near the Malatiná village (27. 3. 2000).

Fig. 6. Water-pipe in accumulation of landslide near Hrinova dam (April 2000).

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5.2 Landslides developed in spring 2000 in other regions of Slovakia

On April 6, 2000 there evolved a landslide near the water treatment work – Water Reservoir Hriňová (Kopecký, 2003), which damaged an important group water pipeline supplying with potable water 60 000 inhabitants (Fig. 6). According to the data by SHMÚ (Slovak Hydrometeorological Institute) the monthly precipitation total in March within the area of interest equaled 112.7 mm, which corresponds to 298% of the long-term mean. At the same time it melted down by the beginning of the second decade of March the snow cover and water equivalent equaled to 70 mm.

By March/April it developed a landslide near Zázrivá, which destroyed a forest stand.

Based upon the information collected from various sources there were documented 56 cases of slope deformations throughout SR within this period.

This research was funded by the grant No 1/2148/05 of the VEGA Agency

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