6. Landslide Hazard Assessment Using Deterministic Analysis - a Case Study from the Chmiňany Landslide, Eastern Slovakia

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Abstract: In Slovakia, the most frequently methods used for the landslide hazard assessment in GIS environment are statistical analyses. The aim of this paper is to present the other, physically based or deterministic method. The landslide hazard assessment in the deterministic method is performed based on the direct calculation of the factor of safety of slopes, which is determined for each grid cell contained in a raster GIS map. The deterministic method is usually applied for local or site-specific analyses where sufficient data on geological, geotechnical and hydrogeological conditions is available. In this paper, an active landslide nearby Chmiňany Village, Prešov district, Eastern Slovakia has been selected. The detailed input parameters needed for the analyses have been obtained from the engineering geological and geotechnical investigations in relation with a proposed highway construction. Taking into consideration the cause of the landslide, identified as groundwater change, two scenarios of landslide activity have been investigated: scenario of dry slope and scenario that considers the maximum groundwater table level. The results of deterministic analysis in the Chmiňany Landslide allowed to define the different activity stages within the landslide body.

Keywords: landslide hazard • deterministic method • slope stability • spatial analysis • Chmiňany Landslide • parametric maps • Geographic Information Systems (GIS) •

6.1. Introduction

Various approaches to landslide hazard assessment have been developed and published in the literature. Most noted examples can be finding in Carrara, 1988; Van Westen et al., 1993; Terlien, et al. 1995; van Westen and Terlien, 1996; Aleotti & Chowdhury, 1999; Guzzetti et al., 1999; Dai et al., 2002; Zhou et al., 2003, Carrara & Pike, 2008; Alexander, 2008 and others. Each approach can be classified into the two main categories: qualitative and quantitative, which are further classified as: inventory, heuristic, statistic, and deterministic. Each type has advantages and limitations for its application to different scale and purpose of the analysis.

In Slovakia, statistical and deterministic methods have been commonly used, following the expansion of GIS. Statistically based approaches (bivariate and multivariate conditional methods) have been mainly applied for assessing and predicting of regional landslide hazard (Pauditš & Bednarik, 2002; Bednarik et al., 2005; Jurko et al., 2005; Pauditš et al., 2005, etc.), while deterministic approaches for local or site-specific analyses where sufficient data on geological, geotechnical and hydrogeological conditions is available. An example of landslide hazard assessment for two single landslides in Ľubietová and Veľká Čausa villages can be found in Jelínek, 2005 and Jelínek & Wagner, 2007, respectively. In both cases, the susceptibility relative hazard maps were produced for two selected scenarios based on the safety factor calculation. Petrýdesová (2012) has implemented the deterministic stability assessment of shallow landslides in regional scale for the area between Hlohovec and Sereď towns. By this method, it was possible to assess the stability of the youngest generation of shallow landslides corresponding to slip surface depth up to 5 m.

In the proposed paper, the deterministic method was applied to assess stability of the Chmiňany Landslide. The landslide hazard is determined using a slope stability model, resulting in the calculation of factors of safety for two scenarios of groundwater table levels – scenario of dry slope (without the considering of groundwater influence) and scenario for maximum groundwater table level.

6.2. Basic principle of the deterministic method

The deterministic approach using geotechnical model requires several simplifications; otherwise, the method would be very complex and almost impossible to give correct results. Basic requirements for obtaining acceptable results can be summarized in the following conditions:

- detailed and sufficient input data on geotechnical, hydrogeological, and morphological parameters and their spatial and temporal variability must be guaranteed;
- the main conditions that caused landslide must be known and identified;
- correct justification of a potential failure mechanism must be known.

It is further assumed that the geological conditions are quasi-homogeneous, failure occurs as a single soil layer, which is the result of a translational slide.

The fulfilment of the complete model requirements is very difficult, and this is the reason why the deterministic approach has only limited applications. The main problems are related to the heterogeneity of the environment and subsequent spatial variability and uncertainties in material properties. In most cases of slope analysis, uncertainty is associated with geotechnical parameters (soil strength), geotechnical models, and the frequency, intensity, and duration of triggering agents (Chowdhury & Flentje, 2003). Due to difficulties regarding availability of detailed input parameters, the method is usually applied on a large scale and over small areas. To eliminate these uncertainties, conventional deterministic models must be combined with statistical and probabilistic methods, which take into consideration spatial variability of land characteristics, material properties, or sampling error.

It is further considered that the landslide material slides along a planar slip plane parallel to the surface (Anderson, Richards, 1987, in Jelínek, 2005) and each soil layer is merged into one single layer. The simple infinite slope stability model is generally used in a GIS environment. This two-dimensional model calculates the slope stability for an infinitely large slip surface. Individual pixels of the input parametric maps are considered as "homogeneous units". However, the effect of the neighbouring cells is not taken into account. The model is used for the calculation of the stability of each single cell of the resulting landslide hazard map (van Westen, 1993).

Assessment of the landslide hazard of the selected area by deterministic method is expressed as a factor of safety (FS), calculated for all the slopes and final classes of landslide hazard are divided by the degree of factor of safety. Degree of FS is given by the ratio of the summation of the passive forces (acting as the sliding-resistance force) and the active forces (acting as the sliding-disturbing force). The forces acting at any point along the potential slip surface in the infinite slope model are illustrated in Fig. 6.1. If the safety factor is greater than 1 then the slope is considered as stable, while the factor of safety lower than 1.0 indicates unstable slope and a potential failure existence. However, the limiting value has been defined differently for various land use. For the urban zones has been used the limiting value of FS 1.5, for the agricultural land use, woodland, fields and meadows the limiting value is 1.1 and for other land use it's 1.0.

There are different ways to express the safety factor within the infinite slope model (Nash, 1987; Graham, 1984; Montgomery & Dietrich, 1994). The basic stability equation (formula 1.0) according to Brunsden & Prior (1979) in van Westen (1993) allows modelling of various stability scenarios. This formula is mainly used for the stability analysis of shallow translational landslides usually with a depth of slip surface to 5 m. An important parameter defining the impact of groundwater influence to stability conditions is parameter *"m"*. The parameter *"m"* is given by a ratio of groundwater table levels above the slip surface and a depth of slip surface.

$$FS = \frac{c_{ef} + (\gamma - m\gamma_w) z \cos^2 \beta \tan \varphi_{ef}}{\gamma z \sin \beta \cos \beta} \qquad (6.0)$$

Where:

c_{ef} - the effective cohesion [kPa];

φ_{ef} - the effective angle of shearing resistance [°];

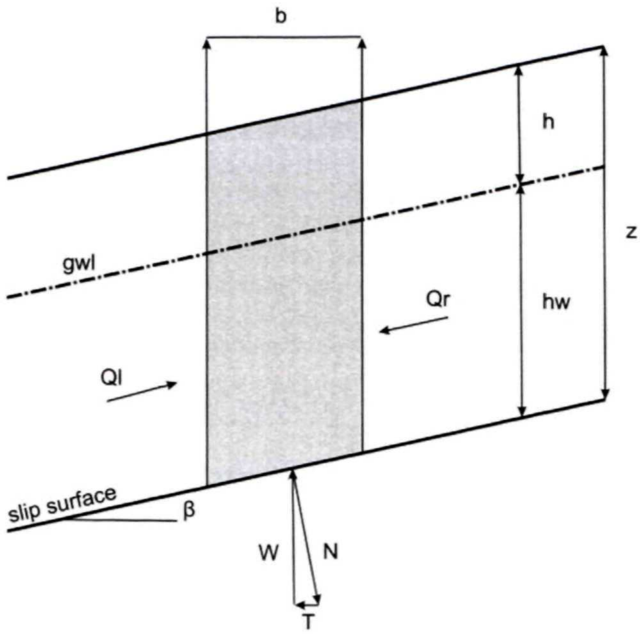

Fig. 6.1 Schematic view of the active and passive forces acting inside the slope, in an infinite slope model (in Jelínek, Wagner, 2007), where β - the slope angle [°], z - the depth of the slip surface [m], h - the depth of groundwater table [m], hw - the height of groundwater table level above the slip surface [m], b - the slice width, Ql and Qr are the side forces applied to soil column

γ - the unit weight of soil [kN.m^{-3}];

γ_w - the unit weight of water [kN.m^{-3}];

β - the slope angle [°];

z - the depth of slip surface below the terrain [m];

m-h_w/z - the ratio of the height of groundwater table level above the slip surface h_w [m] and the slip surface depth z [m].

If the pore-water pressure at the slip surface has been directly considered, then the parameter *"m"* in the equation 6.0 has been removed and replaced with parameter *"u"*, which can be calculated according to the formula 6.1 (Nash, 1987).

$$FS = \frac{c_{ef} + (\gamma . z . \cos^2 \beta - u) \tan \varphi_{ef}}{\gamma . z . \sin \beta . \cos \beta} \qquad (6.1)$$

$$u = \gamma_w . h_w . \cos^2 \beta \qquad (6.2)$$

Where:

c_{ef} - the effective cohesion [kPa];

φ_{ef} - the effective angle of shearing resistance [°];

γ - the unit weight of soil [kN.m^{-3}];

β - the slope angle [°];

z - the depth of slip surface below the terrain [m];

u - water pressure [kPa];

h_v - groundwater table level [m below terrain];

The resultant safety factors may be used for testing different scenarios of slope instability but not as absolute values. Corominas & Santacana 2003 recommended that the degree of slope instability in GIS-based approach must be considered globally, and the resultant safety factors calculated at each cell cannot be interpreted individually because they may give erroneous conclusions.

6.3. Methodology

The resulting map of landslide hazard (in our case stability maps) depends on a detailed knowledge of the studied site and on the quality of input parameters. The acquisition of these data is relatively difficult mainly in time and economic term. The data are usually obtained from engineering geological investigations, field surveys and laboratory analyses. All available data are collected, analysed and organized into a spatial database. The factors influencing the stability conditions are processed in a raster format with cell size 1 x 1 m containing the numerical values. To the process of deterministic analysis in GIS environment the parametric maps enter through the use of map algebra.

As already stated, the deterministic analysis requires the detailed input data. In case of the Chmiňany Landslide, the data were obtained from previous engineering geological investigations (Havčo et al., 2009; Lukács et al., 2012, Kopecký et al., 2013). The investigations included determination of physical and mechanical properties of soils (e.g. shear strength), the groundwater conditions, geological and morphological setting, etc. The collected data were represented as a single point (e.g. borehole); therefore the missing values were interpolated or extrapolated.

Given that the rainfalls in the Chmiňany Landslide represent an important triggering factor causing the sliding, two stability scenarios were modelled: the first scenario which does not consider the influence of the groundwater – dry scenario; and the second scenario that considers the maximum level of the groundwater obtained from the landslide monitoring. Final stability scenarios were compared and the influence of the groundwater upon slope stability determined.

Landslide hazard map created by deterministic analysis represents the different degree of stability of the area. Factor of safety was calculated for each cell of the raster map and according the final value of FS the landslide hazard map was divided into 5 classes (Tab. 6.1).

Tab.6.1 Classification of landslide hazard and stability state according to calculating of factor of safety FS

Factor of safety FS	Stability state	Landslide hazard
< 0.5	Unstable state	very high hazard
0.5-1.0		high hazard
1.0-1.25	Conditionally stable state	moderate hazard
1.25-1.5	Stable state	low hazard
>1.5		very low hazard

6.4. Selection and characteristic of study area

The Chmiňany Landslide was investigated in relation with a highway construction (D1 Fričovce – Svinia). Thus, the data obtained were sufficient for the deterministic analysis.

The investigated landslide is situated on a gentle slope south of the Chmiňany Village, near the current confluence of the Svinka River and Jakubovianka Brook. According to Nemčok, Pašek & Rybář (in Nemčok et al., 1982) classification, the landslide is classified as equidimensional landslide with size characteristics 450 x 565 m (Fig. 6.2). The landslide was reactivated due to combination of extreme rainfalls in 2010 and undercutting of the landslide toe (up to 4-5 m high) in relation to building of social houses. The other unfavourable factor was the suspension of highway construction within the PPP project when the topsoil was removed in a trace of the projected highway. The stability of landslide toe has been disturbed, which has been reflected in visible cracks situated approximately 5.0 m from the edge of the excavation.

Geological settings

According to the engineering geological zoning of Slovakia (Matula & Pašek, 1986), the Chmiňany Landslide belongs to the Region of Neogene Tectonic Depressions (Area of the Intermountain Basins). The geological structure consists of the Pre-Quaternary rocks represented predominantly by Inner-Paleogene Biely Potok Member (Gross et al., 1999). It is represented by layers consistings of claystones and sandstones alternating in different share; fewer by sandstones and conglomerates. The Quarternary sediments are represented by slope deposits, proluvial, fluvial sediments and deluvial-eluvial sediments, mainly clays and loams with various percentage of fragments. Proluvial sediments consist of varied and unsorted gravels, clays and loams with fragments and hard heads. Fluvial sediments are characterized by river plain sediments and terrace sediments - mainly gravels sporadically covered by loams and clays (Havčo et al., 2009).

Within the wider area are more than evident the mass movements and erosion leading to occurrence of slope deformations with different characteristics and size proportion. Appropriate conditions for the landslide occurrence are conditioned by relatively low permeability of Paleogene, or Pre-Quaternary claystones and weathered clayey loams. The easy-weathering Paleogene complexes form assumption conditions for the creating of thick slope deposits. The slope and Pre-quarternary deposits interface is extremely favourable for the formation of slip surfaces and often provides very useful engineering geological, geotechnical and hydrogeological conditions for activation, or reactivation of slope deformations (Havčo et al., 2009).

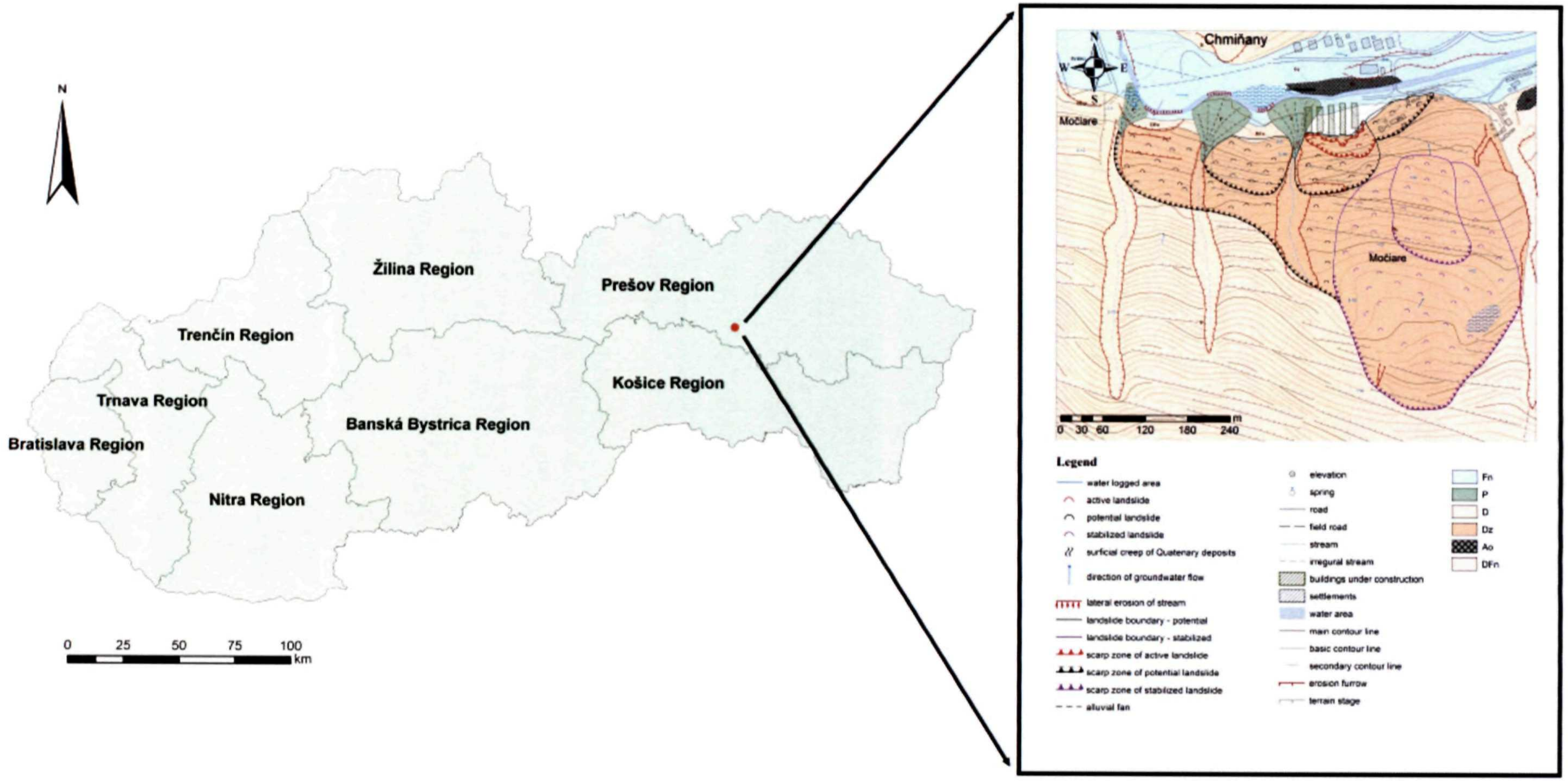

Fig. 6.2 Localization of the Chmiňany Landslide

Tab. 6.2 Basic statistical values of input parameters

	range	min	max	average	median	standard deviation
depth of slip surface z [m]	26.00	0.50	26.50	9.93	9.45	6.35
groundwater level - maximum h_{vmax} [m]	26.00	0.00	26.00	12.63	11.85	6.42
effective cohesion c_{ef} [kPa]	10.00	2.00	12.00	7.28	8.00	2.13
angle of internal friction φ_{ef} [°]	15.00	13.00	28.00	17.34	17.00	2.84
unit weight of soil γ [$kN.m^{-3}$]	3.00	18.00	21.00	20.68	21.00	0.84

6.5. Input parameters

The input parameter maps have been created using the method of spatial interpolation. GIS is now very powerful software that supports the hazard map creation, including interpolation/extrapolation of the original input parameters. Within the interpolation process, important are mainly density and distance of input data. Spatial distribution of monitoring objects used as an input parameter for each parametric or thematic map is illustrated on Fig. 6.3. In total, the data from 50 points (boreholes, sampling points) were used for the spatial analyses. These are summarized in Tab. 6.2.

Principle of IDW interpolation method

In the present paper the *IDW (Inverse distance weighting)* interpolated method was implemented in GIS environment. The IDW method represents the basis for several interpolation methods. It´s based on the linearly weighted combination of a set of sample points. The estimates cell values are the most intense to the value that is closest to them and this dependency decreases with increasing distance. The surface being interpolated should be that of a position-dependent variable. The basic geostatistical principle is applied - phenomena that are spatial closer together are more similar than phenomena that are more distant in space. The aim of this method is to determine the weights of data values based on the mentioned principle. The weights are determined by simple function that takes into account the distance from an unknown value - *function of inverse distance h (1/h)*. Disadvantage of the method is that it cannot calculate values higher or lower than the values of the input data. Assigned weights have been governed by a single spatial model - inverse distance modified using adequate power according to equation 6.3 (Hlásny, 2007):

$$ {}^*(x_0) = \sum_{\alpha=1}^{n} \left[z(x_\alpha) \underbrace{\frac{\left(\frac{1}{h_{\alpha 0}}\right)^p}{\sum_{\alpha=1}^{n}\left(\frac{1}{h_{\alpha 0}}\right)^p}}_{\omega_\alpha} \right] \qquad (6.3) $$

ω_α - weight of value source;

$h_{\alpha 0}$ - distance from position of value point x_α, to point with estimated value in the position x_0;

p - modified exponent.

6.5.1. Slope angle

Slope angle (rate of gradient altitude) is one of the main factors influencing the stability conditions of slopes. It determines the velocity of materials flow down the slope. Each slope has certain critical value of angle; the threshold exceedance changes the stability conditions and leads to sliding. This value depends mainly on the strength characteristics of soil forming the slope – angle of internal friction (φ) and cohesion (c).

The map of slope angle was created using the ArcGIS Spatial Analyst tools. It was derived from digital elevation model (interval 1°) with cell size 1 x 1 m. Value of slope angle has been calculated as maximum rate of slope angle and distance between given cell and eight neighbouring cells, i.e. the steepest slope has been defined - maximum change of calculated z-value and neighbouring cells (ArcGIS Desktop Help, 2014).

The resulting input map (Fig. 6.3) showed the relatively wide variability of slope angle with range from 0.01° to 36°. In the central part of the landslide, particularly in the area of the projected highway, the value of slope angle is relatively high. It depends upon the slope excavation – undercutting the slope toe. In the other parts the mean value of slope angle is 9.78°.

6.5.2. Map of groundwater table level

The groundwater table level in the Chmiňany Landslide is mainly bound to the near-surface zones with high permeability and also to the zones of weathering and loosening of rocks environment – zone of disruption and sliding. The groundwater in the Quaternary sediments is bound mainly to proluvial and fluvial sediments, to a lesser degree to weathering zone - slope sediments (Havčo et al., 2009).

The hydrogeological conditions in the equation 6.1 are accounted by calculating pore water pressure *u*, for two different scenarios, dry scenario and scenario that considers the maximum groundwater table level recorded during the landslide monitoring in the following periods:

- 2008-2010 - irregular measuring intervals (Havčo et al., 2009);
- 2011-2012 - at an average 4 time per month (Lukács et al., 2012);
- since 2013 - irregular measuring intervals (Kopecký et al., 2013).

Thus spatial distribution of the maximum groundwater table levels results in the different accumulation stages of groundwater inside the landslide body. The

Slovak Geol. Mag., 14, 1 (2014), 79 – 88

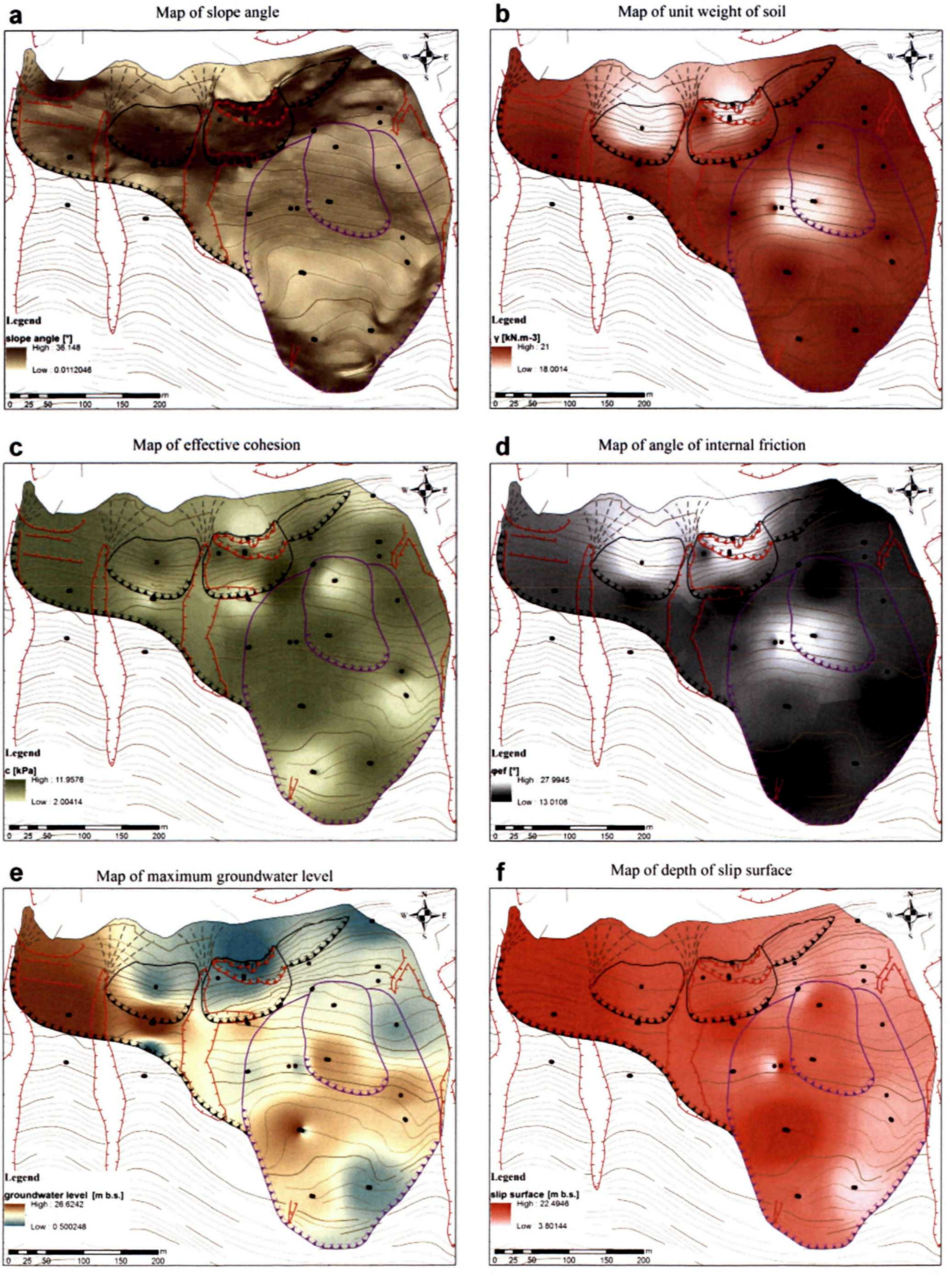

Fig. 6.3 Input parametric maps

western part is represented by block-type landslide where the groundwater table level is in depth more than 20 m. Similar situation is in the central part of the slope deformation (stabilized landslide), where the average depth of the groundwater is approximately 14 m. The higher values of the groundwater table level were measured in the boreholes situated in scarp zones of partial landslides, especially in partial landslides localized in toes of block-type landslides (North part of slope deformations).

Rainfall infiltration was localized in the area south of the landslide. Near the scarp zones of stabilized part of the landslide, depth of the groundwater was less than 7 m. The highest oscillation of the groundwater table level was measured just in the boreholes situated in this part - 13.92 m during the observation period 2008-2012 (Havčo et al., 2009).

6.5.3. Slip surface

Map of slip surface (Fig. 6.3) was created based on the data collected from the previous engineering geological investigations. The Chmiňany Landslide is a typical areal landslide which is characterized by several slip surfaces. Slip surfaces were created in deluvial clayey sediments in different depths. Three stages of slip surfaces were defined:

- 1st depth (horizon) of slip surface: 4-6 m below terrain;
- 2nd depth (horizon) of slip surface: 9-14 m below terrain;
- 3rd depth (horizon) of slip surface: 21-23 m below terrain.

Western part of the landslide is characterized by block failures where slip surfaces are localized in a depth of more than 20 m. This is defined as basal slip surface (3rd horizon). In this part the shallow slip surfaces absent. In the east part of the landslide, the all three horizons of slip surfaces were identified. In the central part, the basal slip surface was determined, which probably represents a presumed fault.

In the landslide body, three horizons of slip surfaces were determined. However, just one, generalized slip surface has been used for the analyses. If more than one slip surface has been determined in a borehole, the slip surface closest to the terrain has been used for the calculations. In case, when the slip surface was not determined in a borehole, the boundary between the Quaternary and Paleogene sediments has been accounted for instead.

6.5.4. Geotechnical parametric maps

In term of stability of slope, the geotechnical parameters of soils represent the important element of rock environment. In nature conditions the collapse of soil mass occurs in most cases by exceeding the shear strength of soils. Within the stability analysis, it is necessary to know the shear strength of soils, i.e. cohesion c [kPa] and angle of internal friction φ [°]. These parameters were obtained from the laboratory analyses of soil samples from slip surface of the landslide or numerical values were used from technical standards (such as STN 73 1001). In the study area the soil near the slip surface was classified as eluvial deposits with character of loams and clays with moderate value of shears parameters; they was classified as F6-CI/CL. Each geotechnical parametric map is shown in Fig. 6.3.

6.6. Stability models and results

The resultant landslide hazard maps represent the different degree of factor of safety within the landslide area. Because the safety factor in the final hazard map is assigned as a single value in every cell of a raster map, it is convenient to perform a reclassification of the calculated values (Jelínek & Wagner, 2007). The resultant hazards maps were reclassified into five classes safety factor: < 0.6; 0.6-1.0; 1.0-1.25; 1.25-1.5 and > 1.5. The areas where the degree of FS is less than 1.0 (classes 1 and 2) are considered as the areas with unstable conditions. Areas with intervals of ranges of FS <1.0-1.25> and <1.25-1.5> are considered as potentially unstable and the areas with the degree of FS greater than 1.5 are stable. Factor of safety calculated for each cell according to formula 1.1 and 1.2 get the following form (1.4) in a GIS environment:

FS = ("idw_c" + (("idw_gama" * "idw_sp" * (Cos("slope") * Cos("slope")) - "u") * Tan("idw_fi")) / ("idw_gama" * "idw_sp" * Sin("slope") * Cos("slope")) (6.4)

Where:

idw_c:	parametric map of effective cohesion compiled by IDW, spline and kriging method;
idw_gama:	parametric map of the unit weight of soils compiled by IDW, spline and kriging method;
idw_fi:	parametric map of effective angle of shearing resistance of soils compiled by IDW, spline and kriging method;
slope:	parametric map of slope angle
idw_sp:	parametric map of slip surface
u:	parametric map of pore water pressure calculated according to equation 6.2.

The calculated values of factor of safety are generally used for comparison of selected scenarios or to identify the unstable parts of the landslide. Due to limited number of boreholes and their spatial distribution in the Chmiňany Landslide, the most reliable values are the values closest to the measured ones. Final stability maps are illustrated on Fig. 6.4 and their comparison is listed in Tab. 6.3.

The result showed that the most unstable parts in the final maps are situated close to partial scarp zones, especially in the active part of the slope deformation. Exactly in this part where undercutting of landslide toe within the building process of social houses (Fig. 6.5) occurred. The total size of the area where the factor of safety was less than 1 (classes 1 and 2) for scenario without the influence of groundwater was approximately 0.02 km^2. When the

Slovak Geol. Mag., 14, 1 (2014), 79 – 88

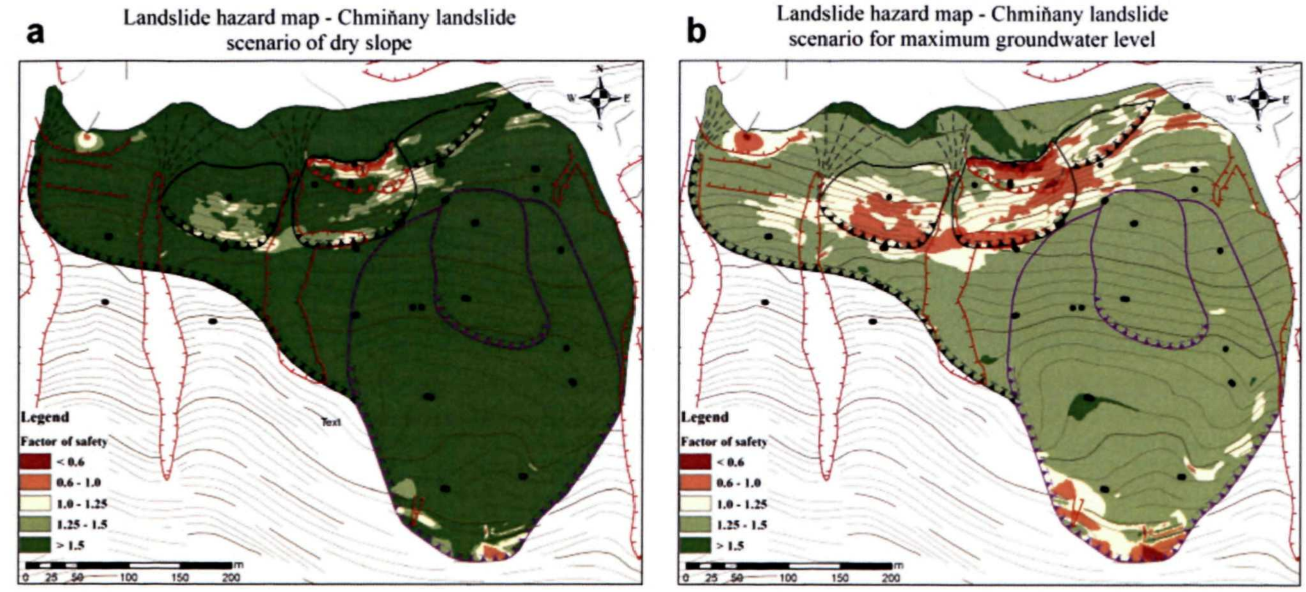

Fig. 6.4 Final stability maps: a, scenario of dry slope; b, scenario for maximum groundwater table level

Tab. 6.3 Spatial distribution of landslide hazard represented by factor of safety value

Class	FS	Scenario of dry slope		Scenario of maximum groundwater level	
		Area [km^2]	Area [%]	Area [km^2]	Area [%]
1	< 0.6	0.00	0.00	0.02	0.50
2	0.6 - 1.0	0.02	0.50	0.28	7.02
3	1.0 - 1.25	0.08	2.08	0.54	13.79
4	1.25 - 1.5	0.19	4.94	2.99	75.94
5	> 1.5	3.65	92.48	0.11	2.75

parameter of water pressure *u* represented the depth of maximum groundwater table level enters to the analysis, the area of class where the FS was less than 1.0 increased up to 0.3 km^2. The second relatively high change in degree of factor of safety was within the 5th class. In the dry slope scenario, there was a relatively high percentage of stable area - 92.48%.

Fig. 6.5 Active part of landslide - undercutting of landslide toe (photo: Kopecký, 2008, in Trangoš, 2013)

As for the verification, the results of inclinometric measurements from August 2012 to May 2013 were used. Trangoš (2013) interpreted the complex assessment of inclinometric measurements, which are illustrated in Fig. 6.6. The higher activity, which was equal with stability model for the second scenario, was measured just in the boreholes located near to the active part of the slope deformation. These were boreholes INK-7A and INK-14N, where the deformation values reached the size of 10 mm and more. This activity was demonstrated for shallow slip surfaces (to 5 m below the surface), which also enters to stability models. The factor of safety which has been calculated less than 1.0 has not been confirmed by inclinometric measurement in part near the main scarp zone. There was measured the deformation of only 1-5 mm interpreted as low activity.

Summary and discussion

Since, landslide hazard assessment using the deterministic method requires relatively high accuracy and variability of input parameters; it is therefore applied to the smaller areas with homogeneous geomorphological and geological conditions. According to van Westen (1993) this method is not suitable in small and medium scales by reason of absence of detailed input data, mainly data on physical and mechanical properties of soils and groundwater conditions.

GIS is very powerful tool supporting all processes of a map creation including the spatial interpolation of input parameters, data processing and analysing. The most important part of the landslide hazard assessment is the collection of data and preparation of input maps. The selec-

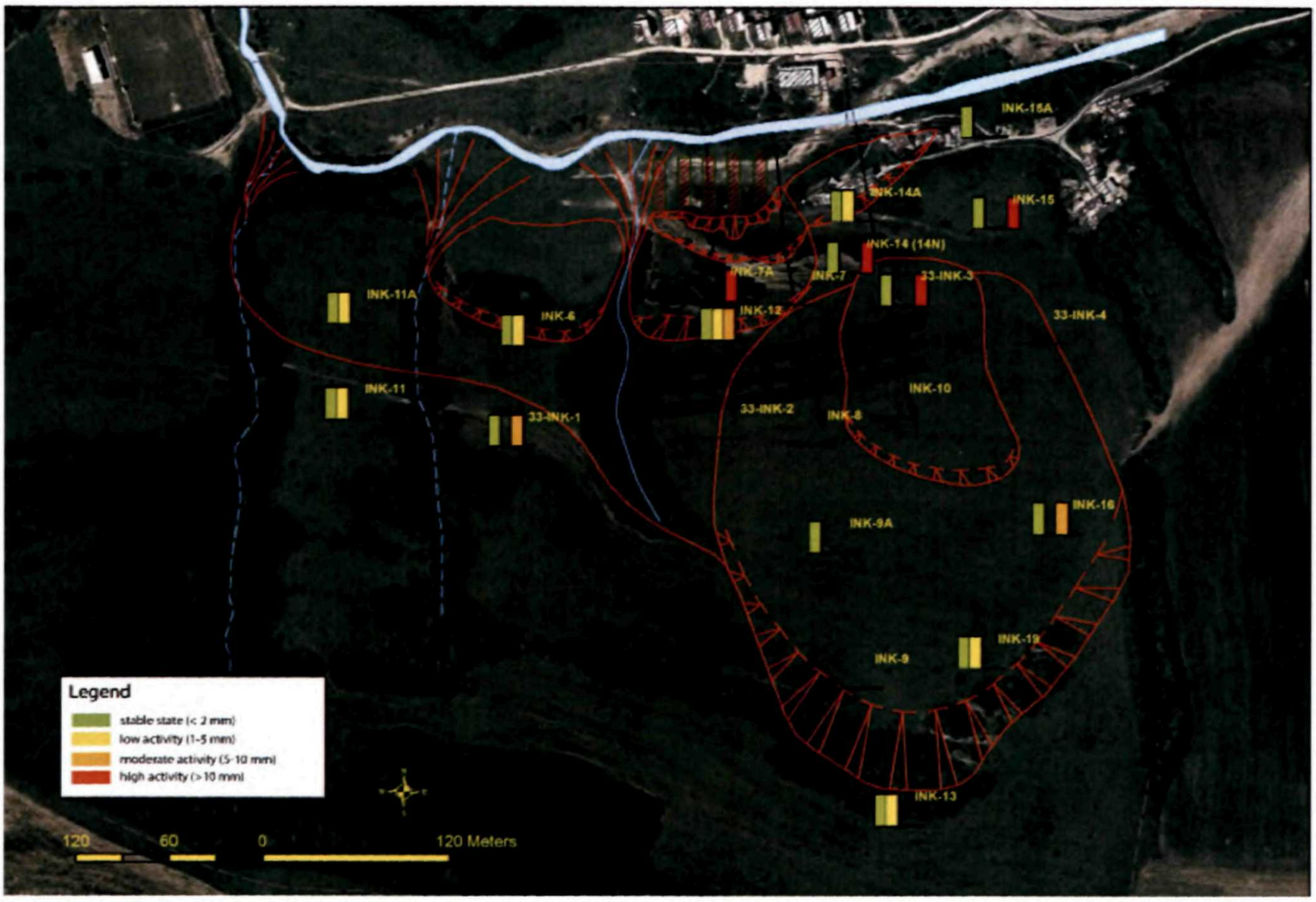

Fig.6.6 The results of inclinometric measurements expressed by point values from measurements realized by FNS CU during the time period August 2012 - May 2013 (Trangoš, 2013)

tion of interpolating method and its correct settings in GIS environment may cause a considerable subjectivity and an error in a preparation of input parametric maps. In this paper, we used the IDW interpolation method which has been considered as the basic interpolation method implemented in GIS environment.

The final degrees of stability calculated for each cell in GIS environment should not be interpreted individually, but globally as a whole unit. The final degree of stability could be used for testing different instability scenarios and their mutual comparison.

Using the deterministic analyses, it was possible to estimate the stability state of the investigated Chmiňany Landslide. This landslide is interesting mainly in relation to the construction of important highway in Slovakia (D1- Fričovce – Svinia section). The highway investigations provided data concerning the engineering properties of the soils, the groundwater conditions and other data necessary for the deterministic assessment. The unstable part (in the area of the undercut landslide toe) was calculated for both stability scenarios and which were verified by inclinometric measurements. Factor of safety higher than 1.3 was required for the highway construction, which represents classes 4 and 5 in the resultant hazard maps. Within these categories fall more than 78% and 97% of the investigated area for the dry scenario and the scenario without groundwater table level, respectively. The area with factor of safety in an interval 1.0-1.3 has been considered as conditionally suitable (class 3). The areas with FS value less than 1.0 are unsuitable for any constructions. This class occupies 0.5% of the total area for the dry slope scenario. This percentage is higher with groundwater influence; it increased up to 7.5% of the study area. At present time the unstable part is stabilized and there is still realized a continuous monitoring (inclinometric measurements, measurements of groundwater table level and yields of drainage elements).

By using the deterministic analysis it is possible to assess stability of a landslide for selected scenarios, as well as to assess different progress of slope deformations in the area.

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