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3. Landslide Inventory in Detailed Scale: Current State and Future Approaches

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Abstract. Accounting for annually recorded slope stability problems, but especially after the massive occurrence of landslides and debris flows in 2010, public and government interest has increased to identify sites with registered potentially dangerous slope failures. There have been efforts to include them consistently in the development of spatial plans and in the selection of building plots.

This aspect has also been reflected at the last amendments of the Geological Law No. 569/2007 Coll., in which requirement is set out of expression of the Ministry of Environment SR in a form of an statement to geological hazards and exploitation in the territory with adverse engineering geological conditions. From the above facts follows acute necessity of registration and inventory of landslides and a reassessment of their existing register with more detailed spatial accuracy meeting the requirements of spatial planning and the current trend in formation of detailed digital topographical documents (Primary Base of Geographic Information System), orthophotomaps, maps of real estate cadastre). Recently, there are at hand also technical possibilities of the so-called databases with spatial extensions, which are especially convenient for the purposes of slope deformations inventory.

Keywords: landslide inventory • very accurate digitization • spatial database/database with spatial extension • detailed topographic maps • Primary Base of Geographic Information System • cadastral maps • orthophotomaps • landslide hazard maps • open-source software

3.1. Introduction

Slope deformations in Slovakia occupy ca 5.25% of the total land area (Šimeková & Martinčeková, et al., 2006) and thus constitute a phenomenon that significantly influences the condition and efficient land use. They act as a constant threat, where structures are placed within a reach of a slope deformation without adequate measures. Potential landslides repeatedly cause damage to land, linear and other construction objects, engineering networks, as well as agricultural and forest soils.

In recent years, largely due to extreme climatic events, but also due to the influence of anthropogenic interventions, numerous landslides and earth flows were mobilized that have required declarations of emergency situations in the various municipalities across Slovakia (Liščák et al., 2010). For their stabilization considerable funds were allocated. Part of the emergency landslides resulted from the unconscious, but unfortunately sometimes wilful disregard of landslide susceptible areas already in the development of spatial plans, selection of building plots and construction of residential, economic and other objects by private entities without engineering survey, which inter alia, assesses stability conditions.

At present the landslide hazard and risk in some regions of Slovakia is also increasing due to amplified construction activity shifted from flat and slightly sloping hillsides and territories to more exposed areas. This trend is particularly evident in the villages of the mountainous regions of Slovakia. This is caused by a lack of suitable building land in flat areas, but also by often targeted location of buildings on the slopes due to the attractiveness of the environment (terrain with panoramic views, privacy, cleaner environment ...).

The inventory of landslides in the Slovak Republic has been carried out more or less systematically since the 60ies of the 20th century. Particular impetus for a systematic inventory gave disastrous landslide in Handlová, active at the turn of 1960/61, which inflicted enormous economic damage. Following the Handlová landslide a landslide register was established aiming on inventory of slope deformations across Slovakia. The Landslides Register of the Slovak Republic is administered by the Geofond Department of the State Geological Institute of Dionýz Štúr (SGIDŠ). Currently the Geofond registers about 18 000 slope deformations in Slovakia.

From 1997 to 2006 the Atlas of Slope Stability Maps of Slovakia at scale 1:50,000 was compiled representing a concise digital base map (the Atlas, Šimeková et al., 2014), which has processed using an unified methodology all previously mapped and registered slope deformations, including the development of a database in the form of passport of a slope failure. The passports provide a review of the relevant territorial affiliation of slope deformations, their stage of exploration, dimensions, engineering geological characteristics, constructions and other objects at risk, causes of their generation and eventual remediation.

Despite the fact that the Atlas of Slope Stability Maps today still represents the most comprehensive mapping and inventory work in the Slovak Republic, it demonstrates acute deficiencies in terms of time requirements. A particular challenge is poor positional accuracy of the applied scale of 1:50,000, in particular a positional incompatibility of obsolete topographic document (accessible in digital form as the state map series SVM-50) with the actual detailed topographic groundwork (e.g. orthophotomaps). The differences in positional superposition are often in the tens of meters. Slope deformations plotted and digitized into such incompatible (and inaccurate) topography can not be used as an input into the creation of detailed spatial plans and also, for example, in the evaluation and creation of landslide hazard maps in detailed scale according to today's requirements (Pauditš et al., 2014).

Currently, or in the near future national base map series ZB GIS shall be available to the public (Michalík, 2010; →http://www.geoportal.sk/sk/udaje/udaje-zbgis/). This detailed and very precise topographic document is compatible with other commonly used detailed map groundwork, including maps of the land register (KNC/KNE), accurate orthophotomap (Šrámková, 2004) and previously used maps at scales of 1:10,000 and 1:25,000 (state map works). In the future, ZB GIS map series will be likely binding as a digital topographic basis for all map scales ("scale-less"), so it is essential to customize also a database of slope deformations to these developments.

Based on the above, the Department of Engineering Geology SGIDŠ in cooperation with Landslide Register of Geofond, has begun in 2012 to build a GIS database of slope deformations in the fine-scale topography compatible with ZB GIS. This database will gradually integrate slope deformations of the older registers and various map data adapted to the scale and ZB GIS (working and terrain 1:10,000 maps of the Atlas, detailed maps available from the register of slope deformations of Geofond, fine-scale maps of the different projects kept in Geofond Archive) along with slope deformations mapped using precise GPS/GNSS devices, registered since 2010 (Liščák et al., 2010; Ondrejka et al., 2011).

The goal of this database is the reassessment of all previously registered slope deformations in Slovakia and their plotting into a detailed scale. The database will be continually updated and accessible to the public via information system GeoIS (→http://mapserver.geology.sk/zosuvy).

3.2. History of landslide inventory in Slovakia

The beginnings of compiling the Register of slope deformations (the Landslides Register) are associated with the catastrophic Handlová landslide in 1960, when 150 homes were destroyed along with 2 km long stretch of State Road 1/50, Southeast branch of the Handlová water pipeline, several lines of high voltage, etc.

The cases of the Handlová landslide and several others have shown that stabilization of active slope deformations is far more expensive than preventive measures. Another important finding has been the fact that the slope movements are recurrent in the areas of old landslides, mainly.

In the light of the above the next logical step in the research into slope deformations was their inventory; this effort divided into three stages covering a period of 1961-1991 has contributed to the development of a prominent school of Czechoslovak engineering geologists dealing with landslides around Nemčok and co. (for instance, Nemčok 1982). The history of landslides inventory is discussed in detail in the paper by Baliak et al. (2014).

3.2.1. Register of slope deformations in Geofond

The first massive mapping of landslides took place in the years 1961-1963 (based on the Resolution of the CSSR government), and focused mainly in the investment-important areas. The result was a final report to the General map at a scale of 1:1,000,000.

From 1965 maps with delineated landslides and area registration cards started to be submitted to Geofond. The records were stored on punch cards and drawn into maps at scale 1:25,000. The results of this phase of registration are stored in Geofond Bratislava, or in Geofond Prague.

The Landslides Register began to be used in practice in 1975 and especially for the needs of expression for capital investments in terms of landslide exploration.

In 1980 the reconstruction of the Register started. Old inventory cards have been restated to inventory passports. This approach was based mainly on internal work by Dr. Milan Špůrek of 1976, entitled "Guidelines for the registration of landslides and other dangerous slope deformations". Further on, the landslides and other dangerous geodynamic phenomena were plotted into maps at scale 1:25,000 according to agreed established rules. The new data sheet was extended to 80 data items, mostly numeric ones. For the purpose of phenomenon registering there were created several new coders and defined mandatory and optional items. These were particularly the localization phenomenon (map, map scale, etc.), basic data such as date of formation, grade of investigation, etc.

Important period in the development of the Register represent mainly 90ies, which were primarily linked to the development of information technology and especially graphics programs and database systems. Since 1990, the maps of scale 1: 25,000 have been graphically processed, simultaneously with the creation of the first digital maps and outputs from the Register. In 2002, the digitization methodology was prepared for the project Atlas of Slope Stability Maps SR at Scale of 1:50,000 (Šimeková & Martinčeková, et al., 2006) in order to build an information system in ArcView GIS 2.3. The Geofond participated in the project and was in charge of digital maps processing. All further changes in the Register were associated mainly with the development of database programs. In 2005, the Landslides Register was transformed from a dBase to Oracle database. The Register's considerable reconstruction occurred in 2010, when the change was related to the re-development of GIS and especially with the creation of geodatabases (ESRI platform system), which managed to combine the non-graphical data with the graphical ones.

While the Register's database was continually updated on new records, the Atlas of Slope Stability Maps has remained closed. Therefore, there appeared acute need to connect data in appropriate way. The problem arose when analyzing the Atlas, where imperfections were found in data integrity between adjacent map sheets – it often happened that the boundaries of graphical objects were incompatible. Although the task was solved in GIS the record sheets were separated from digital maps and data were not compatible in some cases.

A detailed analysis of various Register entries and Atlas of Slope Stability Maps as well as other incremental projects has led to a creation of common structure of the new database. Currently it consists of 84 fields, which are divided into larger groups like geology (geological formation, geological structure, ...), hydrogeology (hydrogeological conditions of the slope, ...), slope geometry (mean angle, slope aspect, ...), localization of the phenomenon, the basic data, the extent of the phenomenon and others (Tab. 3.2). For coded fields, there were created new coders or the original ones were amended (mostly by merging different values of the sources).

The database contains also an indication of the source data, which is very important for data displaying. The Register was drawn into the maps at scale 1:25,000, while the Atlas of Slope Stability Maps is based on scale 1:50,000. Currently into the Register enter various projects, which have been obligatory submitted to Geofond they are also mapped at different scales. This paper presents a new spatial oriented database, which is based on the scale of 1:10,000. The Register's geodatabase at scale 1:50,000 currently contain 17,879 graphical entities retrieved from different scales.

3.2.2. Atlas of Slope Stability Maps SR at scale 1:50,000

The Atlas of Slope Stability Maps SR at 1:50,000 (Atlas) covers the whole territory of Slovakia and contains entities from various archival sources, processed in digital form, of all previously registered and newly mapped slope deformations in topographic scale 1:50,000. Thanks to its complexity and accessibility (the work is freely available on the SGIDŠ website) the Atlas offers a wide range of uses; however they are limited in several respects. The essential limitations are the general display scale and the positional incompatibility of the used topography with current detailed topographic documents. The Atlas's results and shortcomings are in more detail discussed by Šimeková et al. (2014).

3.3. The objective of landslides inventory at detailed scale

In view of the aforementioned shortcomings of existing practices in the registration and inventory of slope deformations in the Slovak Republic the SGIDŠ acceded to the systematic creation of a detailed database that should integrate graphic (or geographic) interpretation of slope deformations in the form of graphical entities in the map along with attribute data referred to in respective passports. This integration is implicitly provided by GIS technology in the so-called spatial databases.

Geographical location of slope deformation is plotted as detailed as possible, a necessary condition for positional accuracy to allow to identify individual parcels of the cadastre, where a slope deformation is present. This means that the smallest usable cartographic scale for inserting graphical entities in the database is 1:10,000 (or 1:25,000). Limit for the largest scale is not given, slope deformation is thus possible to display in a very detailed cadastre maps (KNC/KNE) and in geodetic site plans at a scale of 1:500. It follows that in the future it will be possible to visualize a slope deformation with respect to each specific building, of course, on sufficiently precise topographic documents.

The main objective of such detailed geographic database is to provide materials for:

- producing detailed land use plans,
- landslide risk assessment for specific parcels and property,
- basis for insurance companies, etc,
- producing detailed maps of landslide susceptibility, landslide hazard and risk.

Accounting for ZB GIS topography, to which detailed GIS database will be positionally adapted in the future, the landslides would be possible to display on maps of smaller scales (1:50,000 to 1:100,000), without loss of positional accuracy. This is made possible by the fact that the ZB GIS map series is referred to as "scale-less", that means, the current position of each object in the GIS system is constant; only the density of the visualized elements is modified relative to a given scale (contours step, for example).

In developing land use plans and detailed planning documentation each municipality will be able to take into account on the basis of spatially accurate GIS database published on the Internet, actual incidence of slope failures registered in a given area of interest, not only indicatively, as it was previously. Individual municipalities will have a real opportunity to include the occurrence of slope deformations and potentially dangerous territory in their spatial development concepts. Similarly, the database can also serve for insurance companies when assessing the possible future risk of landslide events within the conclusion of insurance contracts. The database will enable to direct potential customers and construction companies and developers in the future selection of building plots for the location of their property.

In addition to precise plotting of geographic location on the map the detailed database will be also beneficial in terms of improved attribute part of the database. Tabular data are designed as optimal synthesis of data used so far: passports in the Geofond registers, attribute data of the Atlas and attributes arising from new technological approaches to mapping and registration of landslides (e.g. GPS accuracy - position and altitude, the exact time during the mapping, an indication of the date when the slope deformation evolved, etc.). The aim is to provide to the public mapping services through the Internet, the most relevant and up-to-date information about the registered slope deformations and these data will be constantly updated.

Special emphasis was put in compiling a database meeting the requirements for issuing landslide hazard maps in detailed scale, because in recent years often in the formation of these maps computerized statistical methods are utilized. Spatial database as an index map of landslides is a necessary input variable in the compilation of the landslide hazard mapping by statistical methods in GIS environment (Pauditš and Bednarik, 2002; Pauditš, 2006; Bednarik, 2007). With this so-called binary (0/1) variable all input parametric maps are being compared in the process of calculating the weights of bivariate analysis and also the variable when compared with the quasi-homogeneous units in multivariate analysis. For this purpose, individual landslides in the database are recorded not only as sole surface entities, but also as linear entities – head scarps extended to the edges of transportation areas as well as transverse and longitudinal cracks in the landslides bodies. Such interpretation of a binary variable better reflects the area in which landslide occurred and allows to eliminate systematic error in evaluation of the areas that were affected by accumulation part of a landslide (Bednarik and Pauditš, 2010). These areas may be in terms of landslide susceptibility de facto stable – e.g. areas of alluvial plains with mild to zero slope grade.

3.4. Methodology of the database creation and its technical aspects

As was mentioned above, accounting for the deficiencies of the Atlas, in particular the positional uncertainty and incompatibilities arising from the use of digital topography SVM 50 (Špaček, 1999), we proceeded to the creation of the GIS database of slope deformations of fine-scale compatible with maps, or ZB GIS.

The database is the spatial one, this means that in addition to attribute data (mostly text, numerical and Boolean) in tables are stored graphic (or geographic) data, representing the geometry of the individual entities. The geometry storage directly in a relational database table is provided by the means of a so-called spatial extension, which writes the geometry into a database table using a coded sequence of alphanumeric characters. In addition to geographic coordinates of entities vertices, the character sequence contains also SRID (Spatial Reference IDentifier) that gives the exact way to set up cartographic projection of given table/coverage in GIS software. The database software used is PostgreSQL with PostGIS spatial extension, distributed via Internet under free GPL license (→http://postgis.org/).

The database runs on server, which allows concurrent access to multiple users in real time, and it is available also for editing (not read-only). The server environment technically solves potential conflicts that may occur due to concurrent inserting or updating. The database can be accessed from various common programs (Excel, Access, Internet browser, etc.). The graphical data visualization and direct editing allow GIS programs, e.g. Quantum GIS (→http://www.cigis.org) and Maplnfo Professional (from version 10.0 and higher →http://www.mapinfo. com).

In the main table in the database, which is also the bearer of extensive information on each recorded landslide (passports), the geometry of slope deformations is plotted in the form of polygons - the outlines of bodies of each slope deformation, including the accumulation parts. Head scarps, transportation and accumulation parts of landslides in these polygon entities are not separated in this table. Information on detachment-transportation parts of a landslide stores another table, where landslides are recorded in the form of lines of main scarps of the upper edges (MSUE), or head- transportation parts (Fig. 3.1), what is needed in terms of methodology of slope deformations entry in the statistical evaluation of landslide hazard (Clerici, 2002; Süzen and Doyuran, 2004). This table is linked to the main polygon table using SQL by 1:1 relationship.

In a special "cosmetic" database Schema, various hatch patterns and auxiliary graphic elements are stored, that are necessary for common landslide plotting and visualization. Both polygons (hatch patterns of sliding direction at main scarp surface) and lines (prescribed hatch of motion direction of landslides and earth flows, lower edges of the main scarps and others) are stored.

Each of these types of entities is stored in a separate database table, or for each category of graphical entities shown in Fig. 3.1, the separate database table (GIS layer) is established. Overview of GIS database table of slope deformations is shown in Tab. 3.1. The list of attributes (passport items), assigned to the main polygon table is taken mainly from the Atlas (Šimeková and Martinčeková, et al., 2006) and the Geofond Register, along with other useful technical aspects arising from the GPS records measurements and field mapping (e.g. GPS accuracy class record, average and lowest accuracy of GPS record, area and perimeter of a slope deformation, date and time of mapping (data collection), or date and time of digitizing, etc.).

The number of attributes is not yet final and will be amended in respond to emerging requirements, together with complementing database entries. Estimated finite number of attribute fields in the data sheet (passports) of the database is more than 150. Current overview of attributes (as of December 2013) is reported in Tab. 3.2.

Main advantages of the slope deformations inventory in the form of a spatial database with client/server architecture are:

- the possibility of concurrent access for inserting or updating graphical features and/or attribute data simultaneously for multiple users with possibility to set the user access rights to each user separately;

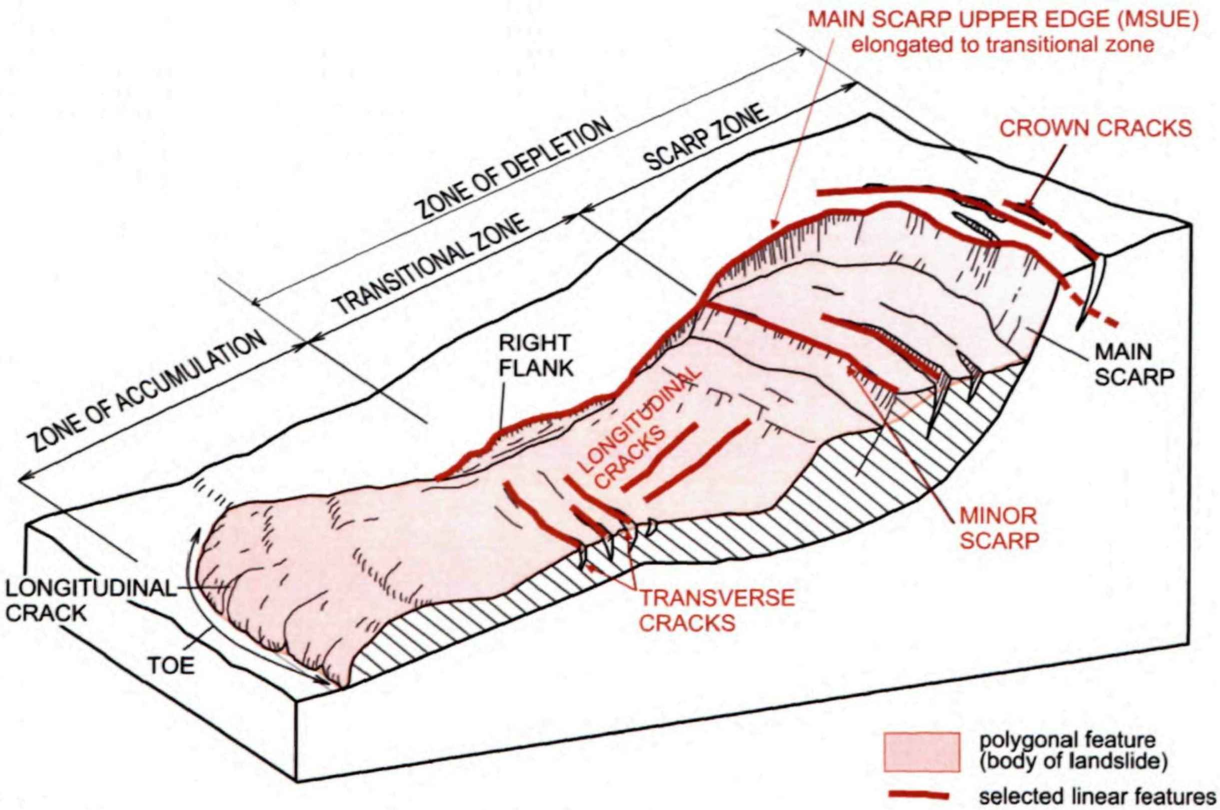

Fig. 3.1 Schematic presentation of the landslide elements, recorded into the database: polygon entities are stored in the main table gm10_zosuvy_poly, selected linear entities are stored in table gm10_ zosuvy_odlucne_hrany (Tab. 3.1)

Tab. 3.1 List of database tables

Table name	Description
gm10_zosuvy_ poly (polygon)	Outlines of landslide bodies (polygons) including accumulation parts, (main database GIS layer with attributes / passports of landslides).
gm10_zosuvy_odlucne_hrany (line)	Lines of main scarps and transportation parts, transversal and longitudinal crevasses in landslides.
srafy_ line (line)	Line hatch of slope deformations (in terms of Directive MoE SR. 3/99-3).
srafy_poly (polygon)	Polygon hatch (filled) of slope deformations (in terms of Directive MoE SR. 3/99-3).
kodovnik_sraf	Codes of hatch needed to adjust colour and attributes in printed maps of slope deformations.
mapinfo_mapcatalog	Auxiliary table for MapInfo communication with PostGIS database.
zm10_listoklad (polygon)	Map-sheet layout ZM 10 (1:10,000).
sm5_listoklad (polygon)	Layout of orthophotomaps, or map-sheets SM 5000 (1:5,000).
zm10_vodne_toky (line)	Water streams lines at scale 1:10,000 (derived from ZB GIS and topographic documents).
gps_trasy_gpx2d (line)	Rough field data: GPX and KML file type (Garmin devices, smart-phones, etc.).
gps_trasy_ssf3d (line)	Rough field data: SSF (3D) file type (Trimble devices).

- the possibility of using different software platforms to access and edit the database (GIS programs, MS Excel, MS Access, WEB browsers, etc..);
- the possibility of rapid selection using SQL standards, based on specified criteria according to recorded attributes;
- possibility of full SQL selection on the basis of geographical criteria and spatial functions (distances, overlaps, areas, etc..), in combination with selection on table attributes (e.g.: "select all earth flows exceeding an area of 5 ha within 200 m buffer zone from the nearest river in the village Zbora which threaten 1st class roads", etc...).

3.4.1. Digitization of field maps

The field maps, usually processed within the Atlas (Šimeková & Martinčeková, et al., 2006), are processed primarily on the basis of ZM 10 at a scale of 1:10,000. The slope deformations mapped in the field were plotted directly into topographic documents of a scale 1:10,000 or into copies of working field maps from previous surveys and mapping works. Reference to the source is recorded in the attribute table of slope deformation (Tab. 3.2).

Tab. 3.2 Attributes (database fields) of the slope deformation main table (as of 2013)

Field /Attribute name	Data type	Description
registracne_cislo	integer	Label of a registered landslide in database created in the scope of the Landslides inventory 2010 (Liščák et al., 2010).
ku_nazov	varchar(75)	Name of cadastre, in which landslide is situated, or its head scarp in the case of several cadastre areas affected by a landslide.
datum_mapovania	date	Date of landslide mapping.
cas_mapovania	varchar(75)	Start and end time of landslide mapping.
minut_zaznamu	integer	The duration of GPS record (in minutes) of landslide outline mapping.
kvalita	double precision	Assessment of landslide mapping quality and accuracy: 1 - GPS measurement with the highest possible accuracy (up to 2 m), 2 - GPS measurement with accuracy 2-7 m, 3 - GPS measurement with accuracy 7-25 m, 4 - point GPS measurement with accuracy up to 5 m, 5 - point GPS measurement with accuracy up to 25 m, 6 - landslides plotted into the map 1:10,000 without GPS record, 7 - landslides plotted into the map 1:25,000 without GPS record.
hoz_avg	double precision	Mean horizontal accuracy of GPS record.
hoz_worst	double precision	Worst horizontal accuracy of GPS set of records.
rcvr_type	varchar(50)	Type of the applied GPS receiver.
kategoria_sev	varchar(5)	Socio-economic classification of the risk induced by sliding: R1 - low risk, R2 - moderate risk, R3 - high risk, R4 - very high risk, potential threat to lives and property (Liščák et al., 2010).
plocha	double precision	Area of landslide in ha.
obvod	double precision	Perimeter of landslide (outer line) in m.
idsrf	varchar(75)	Code of the geological basement of landslide corresponding to unified database legend GeoIS (SGIDŠ, 2006, (→http://mapserver.geology.sk/gm50jsl
priemerny_sklon_svahu	double precision	Mean slope angle within landslide body (accumulation part included).
azimut	double precision	Mean aspect of landslide (azimuth, starting with N).
svetova_strana	varchar(5)	Symbol of aspect quadrant of landslide.
haz_dial	Boolean	Information on risk for a motorway (1 - true, 0 - false).
haz_cesta	Boolean	Information on risk for other roads (1 - true, 0 - false).
haz_zeleznica	Boolean	Information on risk for railway (1 - true, 0 - false).
haz_budova	Boolean	Information on risk for buildings (1 - true, 0 - false).
pricina_antropog	Boolean	Information, on the either anthropogenic factors (1) or natural factors (0) of landsliding.
sanacia_navrh	Boolean	Information, whether landslide is proposed for remediation (1 - true, 0 - false).
sanacia_real	varchar(75)	Year(s) of remediation (several years are separated by comma).
poznamka	memo	Notes to landslide.
geom	geometry (polygon, 100100)	PostGIS geometry (100100 is SRID/EPSG code of cartographic projection JTSK 03/ Krovak East-North with binding transformation key GKU for SR).
zaznamenal	varchar(125)	Name of geologist, who inserted record into the database (responsible for record correctness).
row_id	serial (primary key)	The record identifier.
stupen_aktivity	varchar(75)	Activity (active, potential, stabilized).
lokalita	varchar(175)	Designation of slope deformation.
mapovali	varchar(175)	Mapping geologists' names.
atlas_ss	integer	Registration number in Atlas (Šimeková & Martinčeková, et al., 2006), code of linking to attribute table in the Atlas database.
geofond	varchar(75)	Registration number in Geofond Register.
geomorfologia	varchar(25)	Index of geomorphological unit (in terms of regional division SR).
ig_stavba_svahu	integer(5)	Engineering geological characteristic of slope, expressed by index.
regionalna_ig_rajonizacia	varchar(175)	Regional engineering geological division, expressed by index.

ig_rajony	varchar(25)	Index of engineering geological zone.
hg_pomery	varchar(175)	Hydrogeological conditions of landslide.
vztahy_toky_nadrze	varchar(175)	Code of relation to streams and reservoirs.
pramene	integer	Presence and number of springs.
vyska_max	double precision	Maximum altitude within landslide body (derived from DMR).
vyska_min	double precision	Minimum altitude within landslide body (derived from DMR).
typ_sd	varchar(75)	Type of slope deformation.

The source maps ZM 10 with plotted slope failures are geo-referenced to the coordinate system S-JTSK (Krovak East-North), on the basis of the corners of map sheets, using a GKÚ binding transformation key for the SR territory (Droščák, 2011). The achieved accuracy (RMS error) including the error of transformation WGS84/ETRS89 - JTSK ranges from 30 cm to 2 m (60 cm on average).

Digitization of slope deformations in GIS environment runs directly on the basis of ZBGIS (Fig. 3.3), which can be downloaded or directly linked from Geoportal GKÚ SR via WMS technology (→https://zbgisws.skgeodesy.sk/zbgis_wms_featureinfo/service.svc/get), in order to adapt to its topographical features that should achieve in this map series proclaimed sub-meter accuracy. Morphology of a landslide must be digitized by an expert - a geologist with respect to key elements of topographic maps, especially water streams and relief represented by contour lines and/or hill-shading.

3.4.2. Slope deformations recently mapped and registered in the field

In addition to the base ZB GIS, or ZM 10, in the scope of the digitization of graphical entities in a GIS environment base orthophotos are also used with a resolution and accuracy of 1.5 m (IACS project; Šrámková, 2004), available to SGIDŠ from the entire territory of Slovakia. It is also possible to use freely disseminated satellite and aerial imagery from Google database, however, their positional accuracy varies considerably, due to the inconsistencies of resources used (error in documents of Digital Globe Company on Google Earth may reach for the territory of the Slovak Republic +/-25 m, while documents from the companies Eurosense/Geodis Slovakia achieve sub-meter accuracy. The orthophotos provide accurate information on the direct threat to civil engineering works: buildings, roads and railways, relevant for their record into table (passport) of a slope failure.

For technically flawless digitizing of polygon contours of slope deformations it is also necessary to respect the topological correctness on the joint of graphical entities, mainly due to further correct processing using GIS spatial analysis. The above mentioned GIS software allows so-called "topological editing" (avoid overlay, intersection). The topological correction can also be additionally made directly in database environment PostGIS.

Further technological progress in the inventory of slope failures has been made in connection with an excessive activation of slope deformations in 2010. The SGIDŠ geologists promptly made registration of 551 active slope deformations in the territory of Eastern Slovakia (Liščák et al., 2010). For the first time in the history of systematic inventory of slope failures and other geological objects in the Slovak territory they applied very precise, "scale-less" survey of slope failures and their morphological features using GNSS technology (Fig. 3.2; output on example of the Chmeľnica Village, Fig. 3.4). A component of the research was also compiling of a detailed database of registered slope deformations and their classification in terms of socio-economic significance.

Since 2010 the Department of Engineering Geology SGIDŠ has carried out all terrain mapping and registration of new slope deformations using precise GPS of GIS category (Trimble GeoXT 2005) with an option of signal refinement from the EGNOS device and use the DGPS corrections. Under ideal conditions, these devices can achieve sub-meter accuracy of a record (Ondrejka et al., 2011). Individual line and area features of slope failures are recorded and distinguished on the ground (head scarp, accumulation part, cracks, etc., Fig. 3.2).

This way recorded field data are processed within the so-called postprocessing and various subjective corrections in GIS programs and stored in a spatial database on PostGIS server. In the attribute table the details of the achieved positional accuracy are recorded (maximum error, average error, time of recording, device type, etc.) and the resulting quality grade 1-7 according to the following rules:

1. Landslides surveyed geodetically or with GPS devices of GIS categories (e.g. Trimble GeoXT) with the highest achievable accuracy (within 2 meters), or very accurate products of airborne survey (photogrammetry, laser scanning);
2. Landslides surveyed with GPS devices with an accuracy of 2-7 meters (equipment of GIS category or navigation devices and smartphones/tablets with GPS + GLONASS signal in the open air);
3. GPS measurements with an accuracy of 7-25 meters (GPS navigation devices and smartphones with restricted signal reception (due to forest vegetation, high-rise buildings); GPS devices without GLONASS reception, navigation devices in cars, etc.);
4. Spot GPS measurements with accuracy within 5 m;
5. Spot GPS measurements with accuracy within 25 m;

6. Landslides plotted into the map 1:10,000 without GPS survey, or orthophotomaps 1:5,000.

7. Landslides plotted into the map 1:25,000 without GPS survey.

The database stores these original field records without any adjustments in specific tables (gps_trasy_gpx2d, gps_trasy_ssfSd, Tab. 3.1) in separate database Schema.

Fig. 3.2 GPS recording of landslide main scarp in Spišské Vlachy village, during the field survey and mapping of new activated landslide after rapid rainfall event in June of 2010.

Fig. 3.3 View of graphic and attribute form of detailed database of landslides visualised on ZB GIS groundwork.

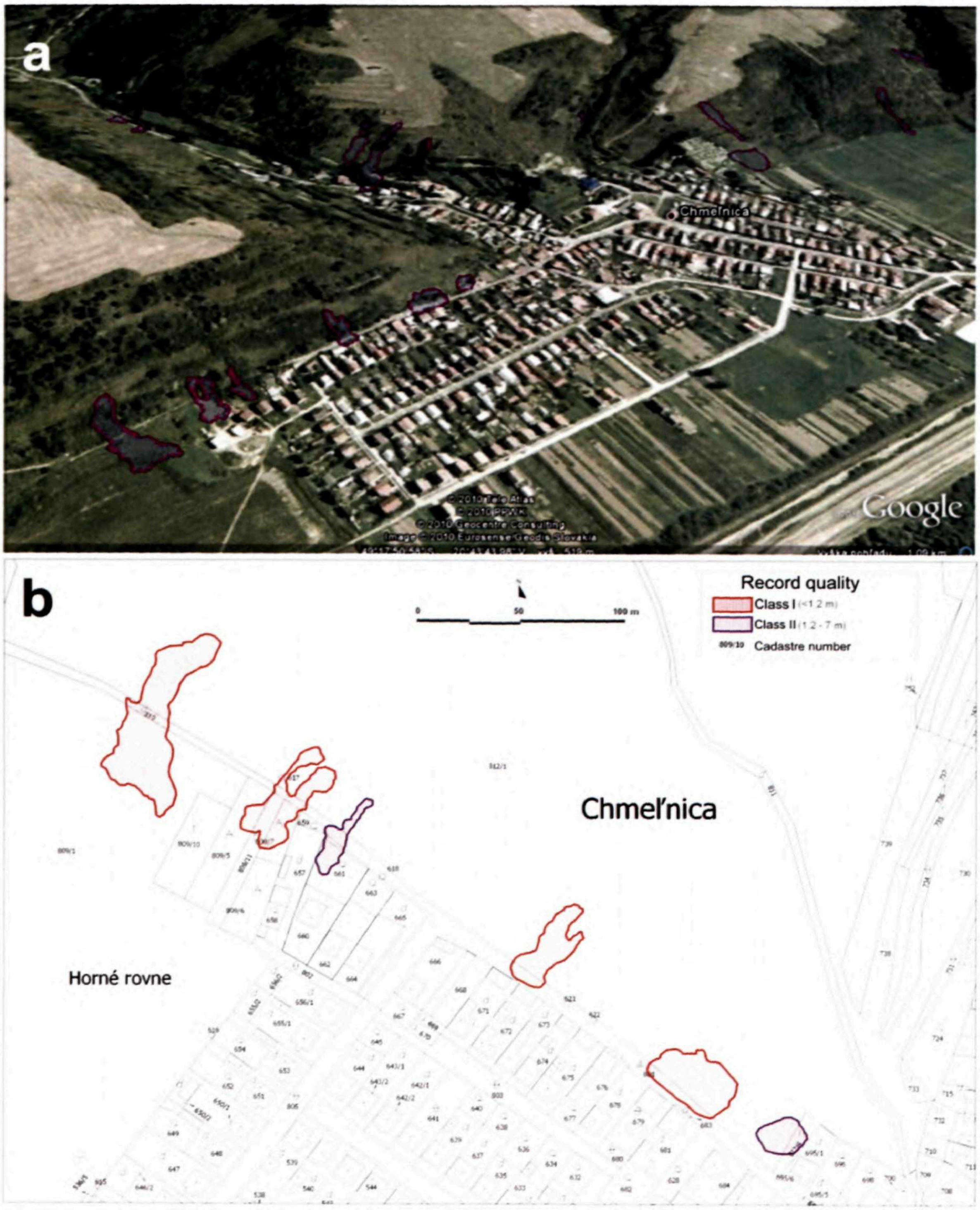

Fig. 3.4 Visualization of detailed landslide mapping on topographic groundwork: a) orthophotomap (Google Earth, 2010); b) KNC cadastre map.

5. Conclusions

The results of systematic mapping and registration of slope deformations, as one of the riskiest geological factors in Slovakia were completed in 2006 in a comprehensive map series "Atlas of Slope Stability Maps SR at Scale 1:50,000" (Šimeková & Martinčeková, et al., 2006, see also paper by Šimeková et al. 2014), assessing by unified methodology the whole territory of Slovakia. Despite the unquestionable importance of this work its practical use has revealed certain deficiencies derived mainly from general scale but also from its gradual "aging" (maps are not systematically complemented on emergency and other activated landslides or other newly registered slope deformations) and therefore they find limited use in engineering projects and spatial plans documents.

The above deficiencies of the Atlas can be eliminated by:

1. Building a GIS database of slope deformations in the fine-scale compatible with ZB GIS topographic basements. This database will gradually integrate slope deformations:

- registered in the Atlas, whereas the polygons of slope deformations are digitized from the working and terrain maps of scale 1:10,000 of the Atlas's initial documentation, as well as from various engineering geological maps of detailed scales, or other documents;
- new slope deformations registered within the geological projects after 2006, i.e. after the completion of the Atlas;
- slope deformations registered by SGIDŠ geologists in their expert visits to emergency landslides reported to MoE by local authorities or directly by the citizens.

2. New projects aimed at creating the landslide hazard maps in detailed scale based on reassessment of older relevant maps and a new field mapping, using new computer technology and software, oriented to the area with the greatest landslides risk.

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