Data collection and analysis for the GIS large scale geomorphic hazard and risk mapping in mountain towns and resorts. A case study in Predeal town, Curvature Carpathians

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The paper proposes a specific data structure of a GIS application for hazard and risk mapping in an urban area. Predeal town was selected to implement it because of its dynamic evolution during the last decade. This includes new spatial queries possibilities like the geomorphic risk and hazard visualization, mapping, analysis and management. The subsequent data comes from a GIS analysis of the landsliding hazard which used the Dempster-Shafer probability model. Field mapping was essential for the permanent data validation before the database implementation. All the urban area features (building, streets and all other networks) could be queried together with the geomorphic hazard data. This tool will be easy to be applied in the framework of the local administration activities regarding the urban sustainable development.

1. Introduction

This application main goal is to find a solution for solving an important problem for a lot of settlements in the Romanian Carpathians, the geomorphic risk. Data is essential for this approach and our paper focuses on this issue. The problem is really difficult because this data is available mainly in paper format, it is quite old and not valid every time (this is a source for errors). Similar approaches in the international literature focuses on different featured mountain areas and (Schick et al, 1999 in Israel, Edbrooke et al., 2003, in New Zealand, Gornitz et al., 2002 in New York City area, Giumaraes et al., 2003 in Brazil’s Rio de Janeiro area, Moon, Blackstock, 2004 in New Zealand, Pasuto, Soldati, 2004, in the Italian Alps, Pykonen, 2001, Lundkvist, 2005, in Sweden and Norway etc.).

2. The study area

Predeal town and mountain resort is the highest urban settlement in the Romanian Carpathians, situated in the Predeal Pass (saddle) and in the spring area of Prahova and Timis rivers (950-1160 m a.s.l.), on the main transcarpathian road and railway between Bucharest and Transylvania (main, double and electrified railroad, the E 60 highway). During the last decade, this small town having about 5700 inhabitants (2002) and more than 3500 tourist accommodation capacity, showed a real imobiliary boom. On a small built-up area of about 9.3 sqm, the population density is higher than 600 inhabitants sqm. The subsequent building density increased from about 30 to 44 houses sqm, between 1992 and 2002, according to the census data.

This small but important town developed in an active watershed area, and along the Prahova River in an upstanding small basin area, on three erosion glacis-slope levels (Mac, Rapeanu, 1995). Old researches (Valßan, 1939, Velcea, 1965, Orghidan, 1969 and other) confirm a very complex underground and surface drainage and a big number of springs on the neighboring slopes developed in Lower Cretaceous flysch (mainly marl-limestones, and marl-sandstones). This is a tectonic contact area along an important thrust line between two nappes of the Eastern Carpathians.

Since 1918, when Predeal turned from a border crossing settlement and custom point to
a small but picturesque town and resort (Tacu, 1927), a lot of engineering works appeared. The swamp and the lake which was the first spring of the Prahova River were drained and a lot of springs and gullies were captured and afforested. Along the railroad (built in 1879, doubled in the 30s, electrified in 1965) an anthropogenic system of drainage pits and canals transformed and replaced the swamps' humid geotope. This flat area became a rather anthropogenic local base level of erosion.

Recent researches (Oprea, Mihai, 2000) confirmed the same trend of evolution for the Prahova-Timis watershed. Timiş tributaries still develop their catchments to the northern half of the Predeal town urban area. Digital modeling of the stream frequency in this area (B. Mihai, 2005) showed average values of less than 30 m for the central and the southern Predeal town built-up area.

We validated this value using a GPS receiver and superposing points on small streams on the topographic plan (scale 1: 5000). Most of these gullies inside the built-up areas disappeared during the last 50 years after the reforestation in the northeastern districts and mostly in Valea Porcului catchments which is a tributary of the Timis River.

A topic which was no longer analyzed in the literature is the landslide occurrence in Predeal area. Geologic maps at 1: 50000 confirm but they did not map exactly the slipped areas. There are old landslide bodies covering about the entire slope. Supraficial slidings occurs on a lot of the deforested slopes where pastures developed before the development of the settlement after the Royal House of Romania cadastre plans were put into practice (Tacu, 1927). M. Ielenicz (1982) and later B. Mihai (2005) described and mapped these landslides (and solifluctions) at different scales, using classical and the GIS methods.

Recent landslides started after aggressive rainfalls in the summers of 2004 and 2005, in newly built areas of villas and small hotels. Clear cutting of old trees on dormant landslides for housing ground extension created in summer-autumn 2005 a huge problem for locals and investors. They have lost a part of their grounds and the building activity ceased. The Bucharest-Brasov motorway project will affect the southern Predeal town area, where we discovered a good potential for landslidings. Local authorities are now in a big dilemma. There is a big imobiliary pressure on the existing grounds and big, 4-5 floored houses, appeared on ground superposed on the landsliding bodies.

3. Method and materials

The GIS application we propose integrates a big amount of geographical information, which focuses on the urban area features and in the same time on the geomorphic hazards and the risk information is the result.

The elevation data were obtained after the geocorection of the existing topographic maps (1:5000) and from the urban master plan of Predeal (1:5000). The main problem was to obtain a reliable model at a 5 m resolution, for a better visualization of the geomorphic features. We considered it as a key feature for the hazard digital modeling and this is the reason of merging two sources of contour lines (5 m distance between contours for the topographic maps, and 2 m for the urban master plan). Validation was done through a GPS survey of some landslide features like ridges superposed on an ortophotography in a 3D display of the model.

Lithology was derived from the 1:50000 geologic maps, together with detailed geotechnical maps (1:2500), available for some built-up areas. Using control points surveyed on different rock outcrops it was possible to validate this data for the analysis.

Superficial deposits and the soil cover were mapped on the base of the lithological and geotechnical data available as well as through pedological sounding on soil and rock outcrops (1-3 m deep) together with a GPS survey of the sounding points. Validation was done after the topological transformation of the layer, through the overlay visual examination.

The landslide bodies were mapped first after their conversion to vector format of the subsequent data from the master plan maps (1:5000). Another data source was the geotechnical documentation of some districts, but these maps covered only a half of the built-
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up area with problems like the landsliding. Validation followed with a complete updating of these areas through a GPS survey. Finally all the landslide occurrences were recognized in field, and redrawn according to the field situation. It was possible to discover and map new landsliding areas and the slope susceptibility to landsliding was confirmed (8 bodies on less than 10 km²).

Torrents and gullies were mapped using the topographic maps at 1:5000, in order to generate a morphodynamic map of the area. Most of the former gullies and torrential channels are today inactive or active only during the short duration summer torrential rainfalls. Forests and dense grasslands covers almost all these catchments, except the northern limit of the urban area of Predeal, where gullies develops because of the Timis low local base of erosion situated at about 850 m (the town is higher than 1030 m). Validation was done through a GPS survey of the channels observed on the maps.

Street network changed together with the built up area during the last decade. The main problem was the lack of updating of the topographic maps and even of the urban master plan. Since 2001-2002 more than 50 houses were built and new streets developed. These are elements of urban vulnerability to geomorphic hazards and must be mapped exactly. A GPS survey was done in order to create new polygons within the street network layer. Field photos of each building completed the survey. Attributes concerns the features of streets (dimensions, degree of modernization). Street names were entered as attributes, through the conversion of the street axles into lines (vectors). Other attributes were the level of modernization or the degradation of every street.

Urban utilities networks (electricity, gas, water pipes, sewage, and cable for communication) are also vulnerability features. These were extracted from a special map of the master plan (1:5000) and checked through overlay with the topographic plan and the aerial photographs (ca.1:10000). These represents the situation in 2002, which was updated as possible through a GPS survey, like in the case of the water supply network which enlarged together with the new vacation houses and hotels.

The electrified railway from Bucharest to Brașov is the axis of the Predeal urban area. This was mapped without problems from the new master plan (2002) and validated through aerial photo interpretation and field check along the rails.

The Predeal’s built-up area was the most complex layer from the point of view of data acquisition and validation. This was generated after updating the existing maps. The Predeal town master plan showed in 2002 the situation of the 80s and this meant a big need of renewing this data. Aerial photo interpretation of older photos was not useful and the satellite Landsat scenes since 2002 were not useful in terms of their medium resolution (14.25 m, after the image sharpening procedure). The scale (1:5000) made necessary a new approach in the digital layer generation. Every house was mapped in terms of position, shape, size (floors), destination and age (decade of building, mainly). This mission covered all the town area (from the master plan) and GPS survey was used to put on the map each building and related feature. Digital photographs were used to check the field situation within the data digital conversion process. Validation was done later on with the help of aerial photos and fieldwork digital photos, using the reference of the street network. This layer was modeled using the virtual reality techniques and checked with the field reality (fig. 1).

Fig. 1 Predeal town. The Cioplea district (from south) in a 3D virtual reality scene
Land cover and the urban structures defines the effective land use in the urban area and influence the hazards occurrence. The local urban laws defined more than 20 classes within the master plan (1:5000) and these were converted into the digital format. Field survey and digital photography helped the validation process of this data volume.

Engineering works were mapped in order to be easily correlated to the hazard-prone areas. These are constructions of different typology like bridges, walls, small channel dams, drainage canals and pits for roads and railroad, embankments for railroad or roads etc. Their attributes relates mainly to the degree of preservation or degradation. This is the reason to introduce special signs (point topology) representing this feature.

4. Results

A geomorphic hazard susceptibility layer (Fernandez et al., 2003) is the result of a separate GIS analysis. The main problem in this respect was to find an objective method to generate a raster model of the land susceptible to landslidings. This includes all the slides, from the most superficial to the deepest, because all of them can affect the built up area and the urban infrastructure. Our research focused on finding a more objective approach in order to replace the empirical method which considered all the layers (models of the morphodynamic control factors) to have the same weight (B. Mihai, 2005).

A probability model approach could be more expressive because it considers the raster layers (morphodynamic control factors) to have different weights. The Bayesian model was used in our literature (Armas et al., 2004) for the landslide hazard assessment in the Subcarpathian Prahova valley area, with good results. In our case study, the main hazard triggering elements are the landslidings on the built-up area slopes and on the floor of the neighboring slopes. Our option was for the Dempster-Shaefer probability model. The landslide hazard maps in this flysch area, superposing on an important tectonic border, was obtained on the basis of a 5 m resolution Digital Elevation Model.

Using the IDRISI’s Kilimanjaro geostatistic analysis package we tried first to obtain for all the landslidings areas the degree of significance of each morphodynamic factor like the slope gradient, the rock type, the superficial deposits and the land cover. These factors have a different weight of evidence within the analysis (their sum is of 1.0 per pixel considered). For each of the factors considered as relevant for the landslide morphodynamics, we obtained four cartograms (fig. 2). Unfortunately it was not possible to obtain all the data layers, like for example the underground drainage. In this flysch area it has no continuity and springs appear almost everywhere on the slopes and to the slope toes. Valsan (1939) discovered this complex feature of the drainage in the neighboring area of the Prahova River springs (the big spring’s density). This is a real problem for the urban development, partly solved by the drainage stream engineering works (Velcea, 1965).

Lithology (fig. 2a) has a maximum degree of significance of more than 0.45. All slopes are theoretically potential areas for landslidings, because the rocks are represented by flysch (marls-limestones and marls-sandstones). This layer can be more relevant together with that of superficial deposits.

Superficial deposits (fig. 2b) have a degree higher than 0.60, the biggest values featuring mainly the glacis-slopes, which are covered by fine clayey materials of more than 1.5-2 m thick (along the main valley of Prahova River).

Slope gradient (fig. 2c), derived from the elevation data, has maximum degrees of significance between 0.61-0.65, corresponding to more than 70% of the Predeal’s town built-up area (almost all the slopes are favorable for slides).

The land cover features (fig. 2d) have a degree between 0.47-0.5; on more the biggest part of the built-up area. Afforested area has a low consistency within the built-up area. Only the stream thalweg of Valea Porcului has the lowest degree (0-0.1).
These gave the possibility for a selective and more objective data reclassification. The results of this operation were layers of different importance ("weight of evidence") to be introduced in an algebraic formula in order to generate the landslide hazard map for the entire township (fig. 3). According to different authors (Vames, 1984, Panizza, Piacente, 1993, Alcantara-Ayala, 2002, Lundkvist, 2005 etc.) the geomorphic risk is the result of the interference between the geomorphic hazard and the vulnerability. A simple query (data overlay) allows everyone to evaluate the risk for a house or another urban landscape element.
Fig. 3 Risk prone area visualization for the central area and the western districts of Predeal town and resort. An overlay of built-up features and main transport infrastructures. Dark areas show the highest probability for landslidings.

Fig. 4 3D model of the landslide (2 x exaggerations) area northern from Predeal (Cioplea Mountain). Aerial orthophotography superposed on a 5 m resolution DEM. Landslide features from GPS surveying.
5. Discussions

The large volume of digital data, made their acquisition process more and more difficult. This was the most time consuming stage. The existing information was only in an analogic format, on paper and their digital conversion took a lot of time. Errors of geometric correction appeared easily in case of some second-hand origin sources of information. For example topographic maps 1:5000 were of good quality because of their original format, obtained through the manual stereo restitution process, since the 70s. This is the source of smaller errors, of less than 4 m in the ground, as we evaluated for some Ground Control Points. The main problem is related to the urban master plan 1:5000 scale whose background is a cadastre map at the same scale. In this case errors varied from 4 to 6 m as we obtained from GCP field control. Aerial photos were used only for information validation, with the limit of their time. Some of them were orthorectified easily using their data and our 5 m DEM (for example the northern Predeal landsliding area, in figure 4).

Another important source of errors is the GPS surveying. Field survey used a portable receiver with the accuracy of about 4 meters. This could influence the data’s geometric features at larger scales than 1: 5000. Our interest is to use rather this method than the total station because of the huge volume of information like new houses, streets, landslides features and other. This was a time consuming work also because it was necessary to wait for a better signal quality, after a precise calibration on the topographic plan height points. The main errors were on the z axis (vertical) which put problems mainly in landslide occurrence area mapping.

6. Conclusions

Our project tries to bring to local authorities a performant tool for the urban area management. This is not a simple GIS data collection, where houses, urban networks and cadastre data can be queried. This focuses on geomorphic hazard and vulnerability assessment for each building and urban network, in the town area and might help the decision making process for this urban area sustainable development.

Mapping started from detailed topographic and thematic data at 1: 5000 and 1: 2500 scales (topographic maps, geotechnical maps, urban planning cartographic documents etc.). Data validation in field was done using GPS surveying during summer and winter.

The small urban area of Predeal contains eight landslide bodies, partly mapped by geotechnical engineers and updated by our research team. Hazard focused mainly on landslidings because stream-related processes are controlled by special developments and decreased in intensity after the forest controlled regeneration after 1950 in the neighboring catchments.

All of these data can be queried at large scale, together with the hazard map features and the landsliding area. The application does not stop here. The spatial query can bring the special assistance utilities like police, ambulance, pompiers, public telephone network etc. Each query for a dwelling and public building can provide also, information regarding the shortest needed rescue routes for special vehicles as well as the helicopter potential landing grounds (obtained also from separate GIS analysis).

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