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Application of remote sensing and GIS in Mt. Mangart landslide observation (Slovenia)

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Abstract

On 17 November 2000 a major landslide occurred on the slopes of Mount Mangart in the Upper Posočje region, Slovenia, as a direct consequence of extreme rainfall and assortment of several inconvenient circumstances. A research group was established immediately after the event to find possible causes of the landslide and monitor its consequences. As a part of these attempts also remote sensing and integration of remotely sensed data to GIS was used. In the paper usefulness of satellite images as one of the most convenient data source in natural hazard observation is demonstrated.

Satellite images were acquired within the "Space and Major Disaster" Charter, started just a few weeks before the event by the European Space Agency, the Centre National d'Etudes Spatiales and the Canadian Space Agency. Advanced image processing was performed carefully to analyze various aspects of the event. Before and after radar images were used to detect soil moisture and to observe the changes in water runoff. Optical images together with DEM were used for GIS analysis of areas affected by the slide. Land use maps, generated from processed imagery, proved to be highly useful for damage estimation.

Introduction

The use of remote sensing is becoming increasingly frequent in environmental studies. In the 1970s and 1980s satellite images were mostly used in simple interpretations or as a map background (Merifield & Lamar 1975, Rib & Liang 1978). However, more recently there are almost no serious environmental studies that do not include advanced image processing and analysis. Remote sensing has been successfully applied to forest fires detection, flood monitoring, deforestation studies, co-seismic displacement monitoring, pollution tracking in the atmosphere and the sea, weather devastation observation, pollution prevention, desertification and erosion observation and many more (ESA 2001, Cracknell 2000, Sabins 1997, Dixon 1995).

One of the most important applications of satellite technology can be found in the case of natural disasters, where satellite images can be used to provide advance warning for specific hazardous events (Gens & Genderen 1996, Guo et al. 2001), to monitor the concerned, or for a quick evaluation of the damage and therefore support the deci-

Figure 1. Location of the Mount Mangart landslide.

sion-making process in the rescue operations. Satellite and airborne imagery alone can offer an efficient contribution to natural resource management. Still, the most promising seems to be the application of remote sensing in combination with geographical information systems.

In the paper the use of remote sensing and geographical information systems in the Mount Mangart landslide observation is presented. A description of the "Space and Major Disasters" Charter is given, and details on image interpretation and analysis are described. Special attention is given to data integration and GIS modelling performed within the Mount Mangart landslide case study. At the end some general remarks and guidelines are presented.

The Mount Mangart landslide

Following several weeks of heavy rainfall, a major landslide occurred on the slopes of Mount Mangart in North-western Slovenia in the night between 16 and 17 November 2000. The landslide hit the village of Log pod Mangartom, claimed seven dead and caused immense damage.

After weeks of continuous rain on 15 November 2000, a mass of morainic material and slope gravel moved down to the Predelica gorge, blocked the water flow of Mangart stream and stopped there for several hours. One day later, in the early morning of 17 November 2000, a major landslide occurred on the slopes of Mount Mangart (Figure 1). The landslide rested for several hours and became saturated from the waters of the Mangart stream supplemented by the heavy rain. This, together with the local dynamics, caused the ground material to become "liquefied". Within a few hours the slide was transformed into a debris flow - a fast moving mixture of water, soil and other material.

It is estimated that about 1,000,000 m^3 of various material flowed downwards along the bed of the Mangart stream, hitting the village of Log pod Mangartom, and finally flowing into the Soča river.

Both landslides were most probably influenced by the specific geological composition of the ground, the considerable seismological activity of the nearby area and the intense rainfall. The mountain ridge west of Mount Mangart is composed of massive Upper Triassic carbonate that is in areas interrupted by clastic rocks, and some poorly permeable Carnian calc stoneware. In the Pleistocene, over the stepped bedrock, poorly permeable grounding glacial sediments rich with silt were deposited over the dolomite gravel. The bedrock of the landslide, represented by a block of poorly permeable carbonate-clastic succession, is situated between the fault-bounded blocks of massive and bedded dolomite.

A direct triggering mechanism of the landslide and consequentially of the development of the debris flow was the intense rainfall. The landslide scar in the upper part of the slope exposed a cliff in the bedrock topography, probably produced by faulting. Considering the geological situation in the area, it seems that the fundamental trigger for the landslide was the poorly permeable bedrock combined with the extreme weather situation. Low permeability of the bedrock caused the concentration of water in diamicts and thus a rapid increase in material-rich water tension. The end of this process caused a rapid "liquefaction" of the first landslide material into an immense flow with almost no solidity at all.

Satellite image interpretation

Shortly after the disaster a group of professionals was established in order to monitor the slide and propose solutions for its stabilisation. As the area was dangerous and further slides could occur at any time, the group relied on remote sensing techniques, both airborne and spaceborne. The actions to obtain and process satellite imagery started a few days after the landslide when the European Space Agency was contacted, and afterwards a request was made to the "Space and Major Disasters" Charter. The Charter was initiated following the UNISPACE III conference held in Vienna, Austria, in July 1999, by the European Space Agency (ESA) and Centre National d'Etudes Spatiales (CNES). The Canadian Space Agency (CSA), Indian Space Research Organisation (ISRO), and US National Oceanic and Atmospheric Administration (NOAA) joined the initiative later on. The Charter aims at providing a unified system of data acquisition and delivery to those affected by natural or man-made disasters. It was declared formally operational on 1 November 2000, less than three weeks before the events on Mount Mangart, and the landslide discussed in this paper was actually the first time it was activated.

After the problems which were to be analysed were defined, a plan of action was proposed by ESA and the Scientific Research Centre of the Slovenian Academy of Sciences and Arts. It was immediately submitted to the various space agencies for tasking satellites. In total 13 satellite images from 1992 to 2000 were utilised:

- five ERS (both ERS-1 and 2),
- two RADARSAT,
- four SPOT (two panchromatic and two multispectral), and
- two Landsat images.

In the analysis, an additional layer – a digital elevation model of Slovenia, produced using radar interferometry from ERS images and advanced modelling – was also used.

The first post event image, an ERS-2 scene, was acquired a week after the landslide. This was followed by two further acquisitions, the SPOT and RADARSAT images made during the second week. The images were supplemented by archive data taken under approximately the same conditions. All the necessary data and were distributed by mail as soon as possible. Nevertheless it took almost a month to gather all the necessary images. What suggests that in such cases electronic distribution would be highly desired and needed. After the images were received a visual inspection was made. The landslide was detected directly or indirectly in the images made after the event: ERS-2 (24 November 2000), RADARSAT (1 December 2000) and SPOT (29 November 2000).

Visual inspection was followed by geocoding and image interpretation. All scenes were georeferenced to the national system – that is the Gauss-Kreuger projection on the Bessel ellipsoid. Georeferenced satellite images were integrated into a GIS system, together with other already available referenced data (Landsat images, digital elevation model, etc.).

Within the project ERS images were used in two ways – to produce a digital elevation model and to observe the land properties at the time of the landslide. A digital elevation model for the area under investigation was made in the beginning of 2000, mainly to test the usability of ERS data in rough terrain and to support the observation of co-seismic activity after the 12 April 1998 earthquake (Oštir & Stančič 1999, Oštir 2000). In the area mentioned seven ERS-1 and 2 scenes were used from both the ascending and descending orbit. Partial elevation models and other height data sources, such as contour lines and a coarse digital elevation model with a resolution of 100 m, were used to produce a final digital elevation model InSAR DEM 25 (Oštir 2000, Podobnikar et al.

2000). The model has a resolution cell of 25 m; its overall accuracy is approximately 8 m, from better than 2 m in plains to more than 10 m in the mountains. Contemporary ERS images were used to observe land properties, mostly humidity in the time of landslide.

RADARSAT images, obtained in the frame of the Charter, offer very high spatial resolution (fine beam mode). They provided clearer results than ERS, despite the fact that the relief in the area of Mount Mangart is very steep and therefore causes severe problems to all radar satellites (layover and shadows) and considerably limits their use. The humidity observed on the RADARSAT image map is not as extensive as in the case of the ERS data. The reason for this lies in the fact that the second RADARSAT image was taken several days after the ERS image and that there was no significant rainfall in the meantime.

The interpretation of SPOT imagery gave a more detailed insight into the consequences of the disaster. Two panchromatic (21 August 2000 and 29 November 2000) and two multispectral (19 August 2000 and 29 November 2000) SPOT scenes were used to detect the landslide and to evaluate its impact on the natural environment. Figure 2 shows the scene acquired after the landslide. One can clearly see how the landslide changed the valley of Log pod Mangartom. The interpretation of SPOT images allowed us to obtain the most accurate information on the slide location and compare the situation before and after the event. However, as a consequence of the very low sun position in November (shadows were emphasised) the interpretation of SPOT data was not straightforward. In addition to the shadows the November image (Figure 2) contained snow in higher areas and the August image included some clouds.

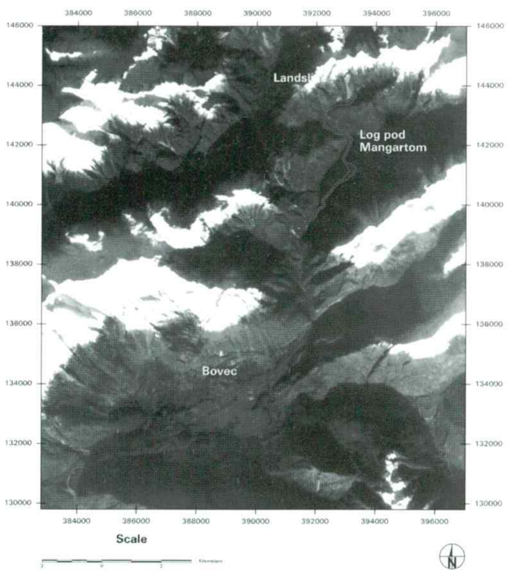

Figure 2. SPOT satellite map of landslide area (image was acquired on 29 November 2000).

Remote sensing data integration and analysis

Image interpretation can offer useful information; however, it is often used merely as a data source for the GIS analysis. Therefore all available satellite images have been integrated within a geographical database, together with the digital elevation model and land use map. Initially, the exact location of the landslide and its direct area of influence were determined. Due to the high spatial and spectral resolution of the SPOT satellite images (panchromatic and multispectral) acquired on 29 November 2000, these images were used to isolate both areas.

The estimated total area of the landslide, i.e. the area of the slipped land, is 25.7 hectares. The additional area of destruction in the valley is therefore estimated to be 50.1 hectares, summing to the total direct impact area of 75.8 hectares.

As described before, a digital elevation model InSAR DEM 25 was produced for the area using ERS satellite images with interferometric processing (Figure 3). From the elevations also a slope map was produced. Average elevation, slope and terrain orientation were computed for the landslide and its impact area; the results are listed in Table 1. The landslide occurred at an average elevation of almost 1400 m, at a very steep slope (24%) facing south-east (161°). The standard deviations for both slope and orientation are small, showing that the landslide area is very homogenous. On the other hand the impact area lies much lower, on average at approximately 800 m. It is also modesty inclined (19%) and oriented to the south-west (224°). The impact area is rather heterogeneous, with standard deviations from two to more than three times larger than that for the landslide.

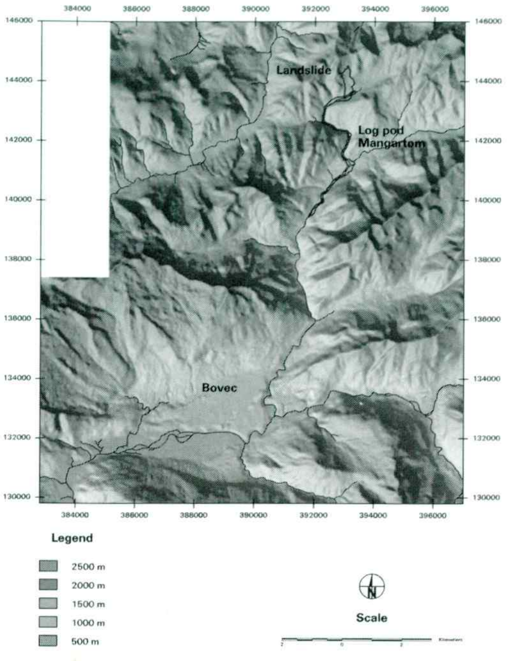

Figure 3. Digital elevation model of landslide area (InSAR DEM 25) produced from ERS images with radar interferometry and advanced modelling.

Table 1. Elevation, slope and orientation of the landslide and its impact area.

		Landslide	Impact area
Elevation (m)	Average	1386	824
	STD	109	243
Slope (%)	Average	24	19
	STD	6	12
Orientation (°)	Average	161	224
	STD	25	83

Aside the digital elevation model, land use is amongst the most important natural environment variables. The land use map for the area of the landslide was produced from a combination of Landsat and SPOT images. Classical supervised image classification method has been used in order to obtain land use (Sabins 1997). The land categories were divided into ten classes: urban, built-up, individual houses, coniferous forest, deciduous forest, mixed forest, bushes, water, agricultural, and open. Additionally advanced post-classification techniques – such as elevation modelling and forest mixing – were also used. The estimated thematic accuracy of the produced land use map is approximately 90%.

A detailed analysis of the changes in the environment was carried out. Table 2 and

Table 2. Land use categories in respect to the landslide and its impact area.

Class	Landslide area ha	%	Impact area ha	%
Urban	0.0	0%	0.0	0%
Build-up	0.0	0%	1.7	3%
Individual houses	0.0	0%	1.9	4%
Coniferous forest	1.0	4%	10.1	20%
Deciduous forest	18.6	72%	5.8	12%
Mixed forest	2.2	9%	5.4	11%
Bushes	0.3	1%	3.6	7%
Water	0.0	0%	4.0	8%
Agricultural	0.0	0%	9.4	19%
Open	3.6	14%	8.2	16%
Total	25.7	100%	50.1	100%

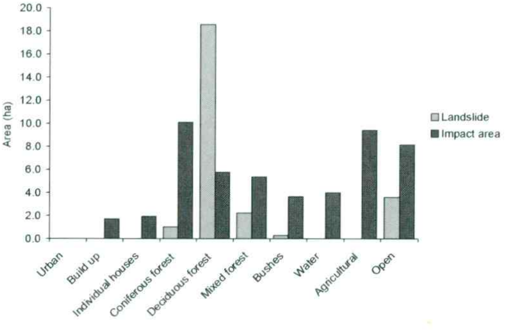

Figure 4: Land use classes destroyed by the landslide.

Figure 4 show areas that were destroyed by the slide in respect to land use. The landslide directly destroyed forests and a small amount of open areas, while other classes were not present. The impact area was more heterogeneous – forests covered almost half of it, but there was also a notable quantity of built-up land, individual houses and agricultural land.

Conclusions

The disaster below Mount Mangart is a classical case used to show the value of satellite remote sensing. The landslide happened in late November 2000 after several weeks of heavy rainfall and had such extent that it can be clearly detected with the available satellite sensors. SPOT optical images offered a good illustration of the situation and could be compared with the archived data in order to evaluate the damage. Multispectral optical data was supplemented with radar images, acquired on four dates before and after the event. Due to the rough terrain, it was hard to directly detect the landslide and its consequences on radar imagery;

however, the high humidity in the area could be observed even several days after the event.

To evaluate the landslide consequences a detailed GIS analysis of the available satellite images and other data was made. The landslide has been identified on several post event images, most notably on the SPOT panchromatic image, which was used to outline both the landslide and its impact area. The total damage area was estimated to be almost 76 hectares – 26 hectares representing the surface of the landslide and 50 hectares the impact area. The landslide occurred on steep south-east facing slopes, at an average elevation of approximately 1400 m. With respect to slope, elevation and orientation the area affected in the valley was lower and more heterogeneous. The evaluation of land use showed that the landslide occurred mainly in areas covered by deciduous forest (almost three quarters of its surface). The impact zone was again more heterogeneous, half of it being covered with forests. There was also significant damage in agricultural land and built-up areas.

The Mount Mangart landslide study has proven the value of remote sensing technology for monitoring natural disasters and it has in particular proved the usefulness of the "Space and Major Disasters" Charter. It has shown that remote sensing can be used to estimate the damage and under suitable conditions also in rescue operations. In rescue operations the processing speed is critical and near real time data distribution is needed. In the case of damage estimation the processing speed is less important than the accuracy and quality of results. It has been proven, that remote sensing enables mapping and analysing topographic and land cover changes caused by a catastrophic event within a considerably short period of time. We also believe that with advanced simulations it can be used to determine hazardous areas and predict the triggering conditions. Satellite remote sensing may therefore be one of the most important steps in the development of an early hazard warning system.

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