MULTI-TEMPORAL DATA INTEGRATION FOR DETECTION OF CHANGES REGARDING LANDSLIDES IN SERBIA

Jelena Matić Varenica [a], Darko Vučetić [a]

[a] Republic Geodetic Authority, Sector for Topography and Cartography, Department of Photogrammetry and Remote sensing, Belgrade, Serbia – (jmatic-varenica, darko.vucetic)@rgz.gov.rs

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ABSTRACT

Landslides are one of the most frequent and constant deformations on the Earth's surface and have very important social and economic consequences on human society. Although the one of the biggest landslides in Europe is located in Serbia, monitoring of landslides represent rather a registration of its condition usually after landslides move causing drastical changes on the Earth′ s surface and damage on houses and infrastructure. In 2007, the project "Production of digital orthophoto (DOP) in the Republic of Serbia" was implemented in Serbia through a donation of the European Union. By RGA's official Law on state survey and cadastre, a continuation of the process started in 2007 was planned as well as cyclical aerial data acquisition in future. Also, the implementation of NSDI project in 2009 can promote the cooperation with other responsible and interested parties dealing with spatial data and even strengthen monitoring, providing great benefits for society. In this study, a new methodology has been developed for identification, determination of some characteristics and monitoring of landslide-prone areas using Photogrammetry with 3D GIS. A small area in the south of Serbia, Trstenik, has been selected for this study. The work-related information have been obtained from a set of two digital elevation models (DEM) and orthophotos which are created from different aerial image sets captured in 1978 and 2008 and from complementary spatial data acquired from other institutions.

1. INTRODUCTION

Landslides, defined as the movement of a mass rock, debris or earth down the slope can be triggered by a variety of external stimuli (intense rainfall, earthquake, change of water level, rapid erosion, etc.) that have the influence on stability of slope-forming materials. These movements can be periodical, constant or sometimes instantaneous and in settled areas can cause property damage with both direct and indirect costs. The multi-temporal monitoring of landslides is a fundamental tool for their designation and spatial or temporal evaluation, on the basis of which the assessments and predictions of their activities can be made. Detecting the changes in the geometry of interested areas is crucial in any methodology applied in the process of monitoring. Landslide monitoring is usually accomplished by field-based geodetic, geotechnical or geophysical techniques, providing only the point-based measurements of landslides. Nowadays, together with technology progress, developed countries are improving the existing or establish new methods and facilities for monitoring and preventing hazards using the area-based techniques, such as photogrammetry, laser scanning or remote sensing. Although many landslides are located in Serbia, even one of the biggest landslides in Europe (Umka), their traditional point-based monitoring by geological institute is not performed regularly even in usable areas, since it requires resources, often not available.

In 2007, the project "Production of digital orthophoto in the Republic of Serbia" (CARDS project) was implemented in Serbia through a donation of the European Union. The main goal of the project was to create the digital orthophoto (DOP) for the whole territory of Serbia. The resolution of DOP is 40cm for the whole territory of state, 20cm for semi–urban areas and 10cm for urban sites. Since the CARDS project was successfully completed, the interest in the effective use of all current, high-quality data obtained (digital images, DEM and DOP) and the promotion to other responsible and interested parties has became more important. In that sense, RGA became very active in discovering the potential of products it has and adequate presentation of their appliance to all interested parties dealing with spatial data. This paper describes a part of the research done by RGA in order to develop the method for effective and economical monitoring of landslides in Serbia by using available spatial data.

In the present research, photogrammetric technique was applied for detection of changes in the selected landslide area. Aerial imagery is a very powerful tool for landslide monitoring since it offers a synoptic view of a landslide that can be repeated at different time intervals. The historical aerial images are of fundamental importance not only for qualitative analysis of the territory but for a quantitative assessment as well. Appropriate comparison of photogrammetric surveys of an investigated zone from different years allows the identification of geometric changes occurring during the time interval (Wlastra *et al*. 2007).

To support the identification and morphological characterization of landslides, stereo-pairs of high-resolution aerial images captured in 1978 and 2008 were applied. Digital elevation models and associated digital ortophotomaps were produced and interpretation was done within the Geographic Information System (GIS) environment. Primarily, the comparison of two digital elevation models obtained from different aerial image sets was performed to assess the variations of the most active parts of landslides in the selected study area.

Knowledge of the location, type and distribution of landslides occurring over time on a territory is an essential tool for forecasting the future events. The method described here is developed as an optimal solution, having in mind the degree of technological development of the country and availability of resources. It should be applied for monitoring and assessment and help in prevention of hazards that influence the human society and assist in its sustainable development.

2. STUDY AREA

The study area is situated at a hilly region in the vicinity of the town of Trstenik in the south of Serbia, extending from 21° 00' E to 21° 02' E and 43° 37' N to 43° 38' N (Figure.1). This area covers approximately 2 km^2, the average elevation is 195 m above sea level. The slope angle is 9° on average and 57° at maximum.

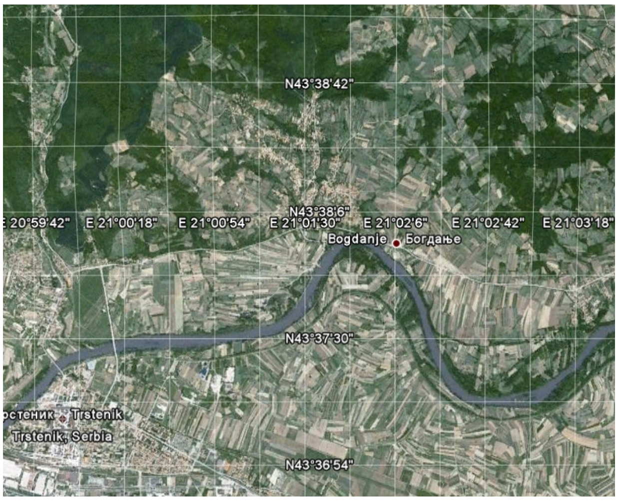

Figure 1: The area of interest near Trstenik, Serbia. © SPOT Image Copyright 2011

First reason, for choosing this area for testing the method, was based on information gathered from maps published by the Serbian company "Geozavod-HIG" Ltd. and the Republic Foundation for Geological Investigations showing slope instable zones and landslides in Serbia.

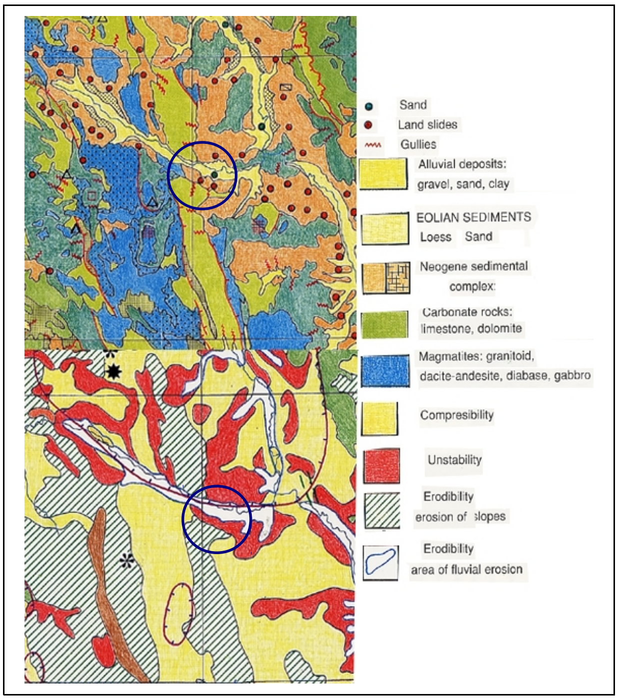

Figure 2. Used geological maps with highlighted study area

The region nearby Trstenik is within the evidenced zone of slope instability because of specific unconsolidated soil materials (alluvial deposits, neogene sediment complex and eolian sediments). The terrain is characterized by erodibility of slopes, fluvial erosion, banks crumbling, and moreover, it is within the earthquake-prone area. There are a lot of active landslides even in the settlement areas. Detailed engineer-geological researches are highly recommended to be undertaken with the aim of detecting a cause and establishing a solution for landslide readjustment.

Figure 3. Examples of landslides within the settlement Bogdanje near Trstenik (www.geologija.org)

The second reason was availability of two sets of aerial images covering this part of evidenced zone of slope instability; high-resolution digital aerial images captured in 2008 and archived large-scale aerial images captured in 1978.

3. MATERIALS AND METHODS APPLIED

For the purpose of research, grayscale aerial images captured in spring 1978 were used for cadastral survey renewal within the cadastral municipality of Trstenik. The camera Opton D-7082 Oberkochen, type RMK A 21/23 with focal length of 208 mm and image size of 23x23 cm was used. Flying height was approximately 950 m and photo scale around 1:4500. Photograph negatives were scanned in 1600 dpi resolution with HP scanner (pixel resolution of 16 μm) that corresponds to the ground resolution of approximately 7,2 cm. This resolution is quite sufficient for the reference production scale of 1: 1000. Furthermore, high resolution digital images were used (approximately pixel resolution of 8,9 cm), captured in the early summer 2008 corresponding as well to the reference production scale of 1:1000. Vexcel, UltraCamX digital camera with focal length of 100,5 mm and image size of 9420x14430 pixels was used. Availability of these two data sets enables us to investigate the landslide kinematics over a 30-year period.

All of the photogrammetric work described in this paper was processed on a Digital photogrammetric stations using Leica Photogrammetry Suite (LPS) software, version 9.2. LPS has a user-friendly interface guiding the user through the various steps of defining the interior orientation of the images, point measurement, bundle adjustment, automated extraction of DEMs and creation of orthophotos. ORIMA, Automatic Terrain Extraction, Terrain Editor and MosaicPro modules were used.

Reference coordinate system used was UTM/ETRS89. Exterior orientation parameters for aerial images captured in 2008 were already defined, both DEM and DOP, since their production was a part of a realized CARDS project. DEM is generated with grid spacing of 5 m and it contains breaklines that closely describe characteristic structural lines of terrain. For the purpose of this research, DEM from 2008 was additionally controlled and edited wherever it was necessary in order to achieve the best possible representation of terrain surface. The results of block aerotriangulation (AT) for the epoch 2008 can be seen in Table 1.

	X [m]	Y [m]	Z [m]
$RMSE_{GCP}$	0.032	0.026	0.025

Table 1. Results of AT for the epoch 2008

Height accuracy of DEM from 2008 is 0.18 m and the positional accuracy of DOP is 0.11 m.
GCPs for orientation of images from 1978 was necessary to be defined, but without going on to the field and extra expenses. It was decided that determination of GCP will be performed through a search of common and stable points that can be recognized on images from both sets. This was a difficult task because large changes in topography and slope surface had occurred. The method adopted in this paper to solve the orientation problem and to register the multi-temporal three-dimensional models is based on identification of a sufficient number of points, located outside the landslide bodies, and visible on multi-temporal stereoscopic models. Some apparently stable points were rejected because large residuals were found after block aerotriangulation. Finally, 7 common points between both epochs were selected, which was quite sufficient since we used 6 images from the epoch 1978. From those 7 GCPs, 6 were used as full orientation points and one as a planimetric orientation point. The result of block aerotriangulation for the epoch 1978 can be seen in Table 2.

	X [m]	Y [m]	Z [m]
$RMSE_{GCP}$	0.28	0.28	0.39

Table 2. Results of AT for the epoch 1978

Mass points for DEM of 1978 epoch are generated as points of triangulated irregular network with the searching grid size of 5 m. The automatic terrain extraction method provided within LPS was not able to generate the DEM accurately in many places, especially in the forested areas. Therefore, to ensure a correct matching in cliff areas (scarps, roads, water bodies), many manually measured breaklines were generated and editing of some terrain mass points was carried out. Unfortunately, independent accuracy control of produced DEM could not have been performed.
Afterward, regular DEMs were derived from both epochs. Both DEMs were produced using a grid spacing of 1m within ERDAS Imagine software module Data Preparation by using Surfacing tool. The grid spacing of the DEMs was defined with respect to pixel dimensions, scale of the images and the size of the correlation window used during image matching.
And finally, orthophoto for the epoch 1978 was generated. Seamlines between images were corrected manually and color balancing was done through image processing options within MosaicPro module of LPS.

4. IDENTIFICATION AND CHARACTERIZATION OF LANDSLIDES

All products obtained through photogrammetry can be used for visualizing and analyzing the geomorphologic changes occurring in the potential landslide zones in a number of different ways. In this study, DEM of difference, displacement vectors and animations were evaluated (Wlastra *et al*. 2007).
A grid surface representing the change of terrain structure was created by subtracting two regular DEMs of different epochs from each other. The process was done within ERDAS Imagine software module Interpreter by using tool Change Detection.
Such a surface of change quantifies the effects of geomorphologic processes. The areas experiencing removal of material will be indicated by depressions, while the areas receiving material are indicated by peaks on the surface of differences. There were detected two landslides where the change of terrain configuration is presented by a variation of its heights up to 15m.

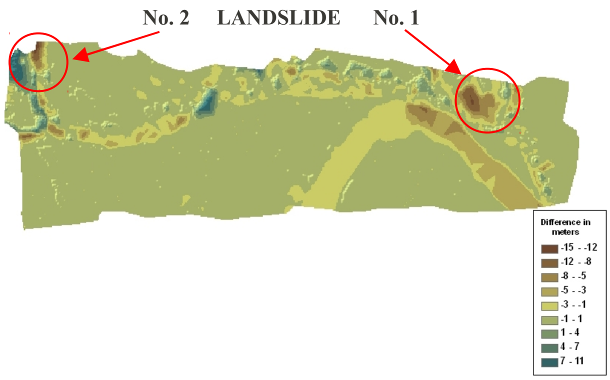

Figure 4. Differences between two DEMs obtained from aerial images captured in 1978 and 2008

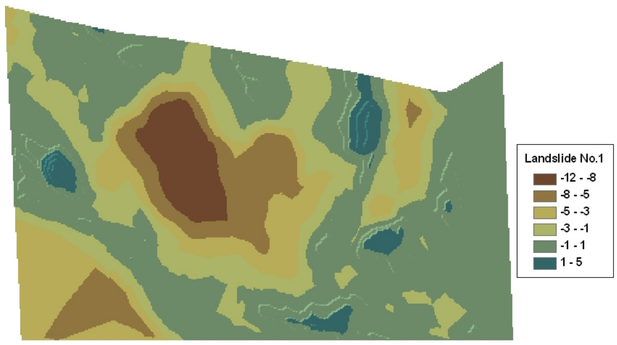

Figure 5. Detected Landslide No.1

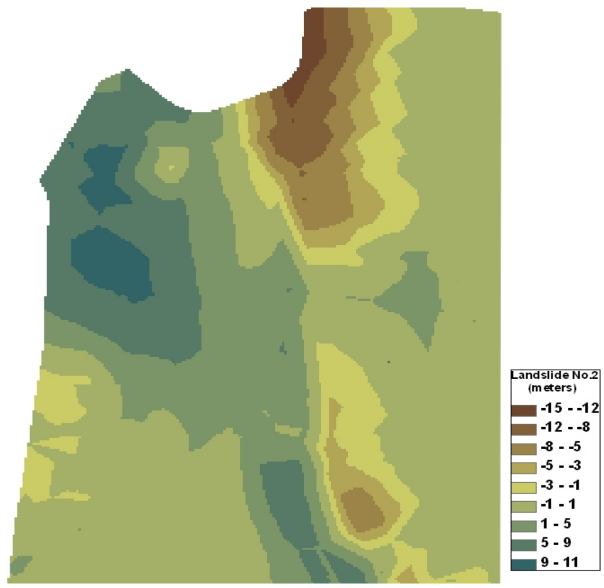

Figure 6. Detected Landslide No.2

The methodology also comprises a digitizing of landslide scarps using multi-temporal stereoscopic models, and therefore this technique is really a 3D interpretation. Within stereoscopic models, identification and digitalization of characteristic structural lines of landslides (scarp, bottom etc.) could be done with much better accuracy than on DOP, but the obtained data could be used for a valuable visual representation of horizontal movements of terrain surface. As can be seen in Figure 7, a maximal horizontal movement of the terrain surface within the zone identified as Landslide No.1 is 146 m in the south-east direction for the period of 30 years. Nearby this large landslide, a settlement where houses and roads had suffered great damages is situated. Taking into consideration the size and deepness of movement, this landslide can be classified as "deep-seated landslide" (Kostadinov S., 1996).

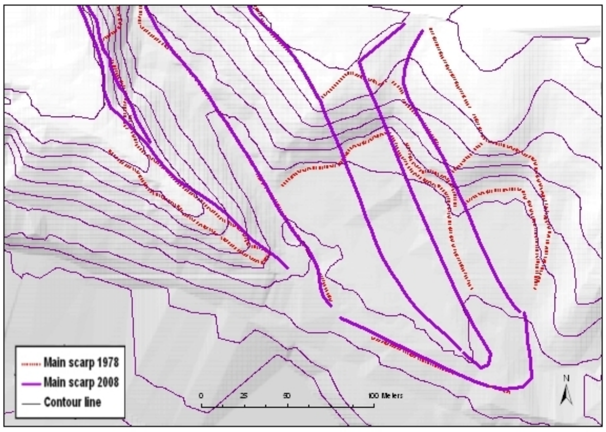

Figure 7: Representation of horizontal movements of terrain surface between 1978 and 2008 (Landslide No.1)

A range of vector data can be derived either from multi-temporal stereoscopic models or from multi-temporal orthophotos in the concerned area, depicting the existing infrastructure, objects and morphology before and after landslides and defining geometrical boundaries of the affected area. Those historical data could serve for the generation of various thematic maps or representations such as landslide activity maps.
In addition, together with DEM, a digital orthophoto was produced to give a photographic representation, with metric characteristics of the situation in a landslide area at a defined time. Modern digital photogrammetry and GIS programs can also generate highly effective three-dimensional views that combine the expressive potentials of orthophotos and three-dimensional data of DTM. Representations in this paper were done within ESRI's tool ArcScene.

Figure 8. DEM combined with DOP from 1978 epoch representing study area

Figure 9. DEM combined with DOP from 2008 epoch representing study area

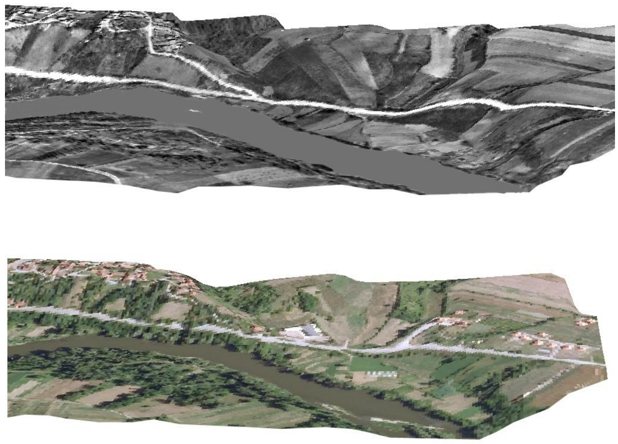

Figure 10. Representation of Landslide No.1 using data from 1978 and 2008 epochs

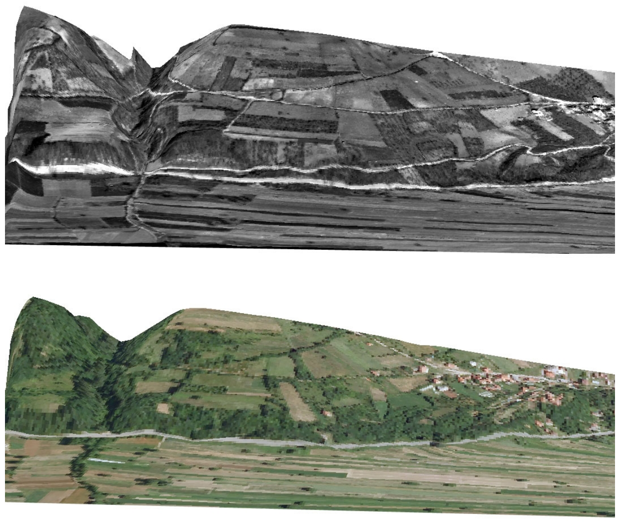

Figure 11. Representation of Landslide No.2 using data from 1978 and 2008 epochs

5. CONCLUSIONS

Photogrammetry is a technique that through great technological development in the recent years has obtained an enormous potential giving important contribution to many disciplines. It is evident that photogrammetry could be used in monitoring applications where derived data sets could give insight into the landslide displacements for risk assessments, volume computation, and structural model validation in order to be used for various development activities of society. It offers several advantages over conventional surveying methods:

- Designation of landslide area and its characteristics can be determined easily, correctly and effectively;
- It is a surveying technique that generates data without direct object contact, providing a possibility to monitor the objects that are unreachable or dangerous to be reached by surveyor;
- It provides flexible framework in the sense that all necessary data are obtained at once, permanently, and could be implemented in any time thereafter;
- It is a cost-effective method compared with ground survey of wide areas;
- Photogrammetric products almost completely refer to the object space (digital elevation models, orthophotos, maps, profiles etc.) enabling complete spatial analysis of observed entity;
- Photogrammetry technique enables efficient coverage of wider area of interest offering data for larger investigations (e.g. regarding surroundings), more easily integrable with other spatial information.

This research has shown that archive images in combination with the new one could provide very wide range of data, both quantitative and qualitative; however, the quality and usefulness of such data mainly depend on the quality of the available material.

Since cyclical aerial data acquisition with the same or better characteristics over the whole territory of the Republic of Serbia was planned by RGA's official law on state survey and cadastre, it would provide significant qualitative and updated material in future, such as DEM and DOP of high accuracy, for the monitoring of changes on the Earth′ s surface, such as landslides. With very small efforts and in economical way, those data can be useful for a variety of purposes in any institution dealing with spatial data.

Although there are other methods that can be used for monitoring of slope displacements, such as laser scanning of terrain surfaces, RGA does not have such kind of data and from this point of view it cannot be predicted when the whole territory of state will be scanned or would it be periodically performed. It is certain that particular finances will not be separated in the near future by municipalities or state only for laser scanning of landslide zones, especially if they are in non-settled areas.

REFERENCES

Kostadinov S., 1996. *Torrential flows and Erosion,* Belgrade, Published by Forestry Faculty, University of Belgrade;

Kraus, K., Waldhäusl, P., 1994. *Photogrammetry: fundamentals and standard processes*, 1. Dümmler Verlag, Bonn, 397 pp.;

Kyoji Sassa, Hiroshi Fukuoka, Fawu Wang, Gonghui Wang, 2005. *Risk Analysis and Sustainable Disaster Management*. Springer, Berlin;

Paolo Tarolli, Giulia Sofia, Giancarlo Dalla Fontana, 2010. *Geomorphic features extraction from high-resolution topography: landslide crowns and bank erosion*, Natural Hazards, Springer, Berlin;

Todorović A., 2006. *Landslides*, Belgrade http://www.geologija.org/articles/geo.php?t=2 (in Serbian) (accessed 24 March. 2011);

Walstra J., Dixon N. and Chandler J.H., 2007. *Historical aerial photographs for landslide assessment: two case histories*. Quarterly Journal of Engineering Geology and Hydrogeology, 40, 315 - 332. doi: 10.1144/1470-9236/07-011;