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SUITABILITY OF DIGITAL ELEVATION MODELS GENERATED BY UAV PHOTOGRAMMETRY FOR SLOPE STABILITY ASSESSMENT (CASE STUDY OF LANDSLIDE IN SVÄTÝ ANTON, SLOVAKIA)

Miloš Rusnák, Ján Sládek
Slovak Academy of Sciences

Jaroslav Buša, Vladimír Greif
Comenius University in Bratislava

Abstract. Assessing the accuracy of photogrammetrically-derived digital elevation models (DEMs) from UAV is essential in many geoscience disciplines. The suitability of different DEM devised for slope stability assessment was evaluated in the example of the landslide in Svätý Anton village in Slovakia. Aerial data was acquired during a one-day field campaign in autumn 2014. The point cloud from 218 images (54,607,748 points) was manually classified into 7 different classes for filtering vegetation cover and buildings. Assessment of vertical differences between the UAV derived elevation model and real terrain surface was based on comparison of control points targeted by GPS (337 points) and unclassified and ground classified point cloud for raster elevation models with 1, 5, 10, 20 and 50 cm pixel resolution.

Key words: UAV photogrammetry, digital elevation model, accuracy, landslide

INTRODUCTION

Development of the small Unmanned Aerial Vehicle (UAV) in the last 5 years has led to their massive utilisation in different scientific disciplines; providing a time-effective and low-cost facility for landscape mapping [Fonstad et al. 2013, Sládek and Rusnák

Corresponding authors – Adres do korespondencji: Mgr. Miloš Rusnák, PhD., Mgr. Ján Sládek, PhD., Institute of Geography, Slovak Academy of Sciences, Štefánikova 49, 814 73 Bratislava, Slovakia; Mgr. Jaroslav Buša, assoc. Prof. Vladimír Greif, PhD. Department of Engineering Geology, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina, Ilkovičova 6, 842 15 Bratislava, Slovakia, email: geogmilo@savba.sk, geogslad@savba.sk, busa@nic.fns.uniba.sk, greif@nic.fns.uniba.sk

2013]. UAV's can carry several sensor types; but most commonly use digital cameras. Camera images provide high resolution orthophotos of study areas and 3D models of surface (meshes) with several centimetre resolution and accuracy. High resolution and precision models are important in assessing and modelling geodynamic processes, and they are particularly useful for studying landscape, land cover changes and vegetation [Johnson et al. 2004, Rango et al. 2009, Breckenridge and Dakins 2011, Laliberte and Rango 2011, Pacina and Holá 2014, Pacina and Sládek 2015], and also river planforms, riverine landscapes and lateral dynamic changes [Lejot et al. 2007, Hervouet et al. 2011, Flener et al. 2013, Niedzielski et al. 2016, Miřijovský et al. 2012, 2015, Miřijovský and Langhammer 2015, Tamminga et al. 2015].

Landslides create one of the earth's most dynamic geosystems, and it is therefore essential to generate precise spatial data for their evaluation and monitoring. Turner et al. [2015] define the following methods of creating landslide digital elevation models (DEMs); differential GPS (DGPS), total station survey, airborne LiDAR scanning, Terrestrial Laser Scanners (TLS) and UAV photogrammetry. However, they suggest UAV photogrammetry is the most appropriate method for real-time or near-real-time landslide monitoring and they describe the creation of a digital surface model (DSM) in 7 time horizons with 0.07 m accuracy. Niethammer et al. [2012] compared the accuracy of DSM from UAV photogrammetry and DTM derived by TLS with an average error 0.31 m in the vertical direction; and they highlight the significant influence of vegetation on the error in the direction of the z coordinates. In addition, Lucieer et al. [2013] and Turner et al. [2015] used the Structure from Motion algorithm (SfM) to monitor a landslide in Australia with 7.4 cm horizontal *Root Mean Square Error* (RMSE) and 6.2 cm vertical RMSE, and Carvajal et al. [2011] used a DEM with 0.12 m accuracy to monitor slope dynamics in a road embankment landslide.

Accuracy assessment is essential in deriving elevation models. Photogrammetrically-derived models create a surface envelope, and although this contains the uppermost vegetation cover, it is unable to capture terrain or relief shapes under dense vegetation cover. For DEM to be used in further processing, such as modelling and assessment, it is crucial to evaluate precision, accuracy and comparison with the actual topography terrain. The most frequently are DEM's derived from UAV photogrammetry compared (1) with elevation models generated by TLS [James and Robson 2012, Westoby et al. 2012, Obanawa et al. 2014]: (2) airborne LiDAR [Fonstad et al. 2013, Hugenholtz et al. 2013, Clapuyt et al. 2016] and (3) ground control points targeted by total station, DGPS or RTK GPS [Vericat et al. 2009, Harwin and Lucieer 2012, Turner et al. 2012, 2015, Tonkin et al. 2014, Ouédraogo et al. 2014].

The aim of this paper is evaluate the suitability of photogrammetrically-derived DEM from UAV and the effect of vegetation on slope stability assessment. The landslide in Svätý Anton village in Slovakia is the example used for these determinations.

STUDY AREA

The study was performed on a landslide area in the centre of Svätý Anton village in the Banská Štiavnica district of Slovakia; and located on the easterly facing slope near the busy 1st class road I/51 (Fig. 1). The landslide is located in the Štiavnicke

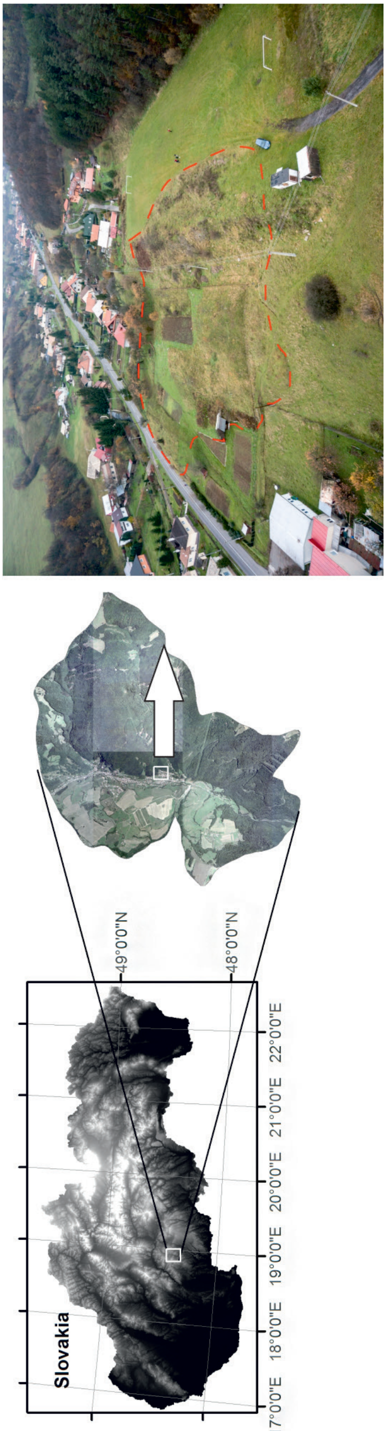

Fig. 1. Localisation of study area in Slovakia (Svätý Anton cadastre area) and slope deformation in central part of village on a UAV photo

vrchy Mountains, which are part of the Central Slovakia Neogene Volcanic Field area in the inner side of the Western Carpathians and are built by various types of volcanic complexes originated during Neogen volcanic activity (vulcanic epiclastic breccias and andesite rocks).

The landslide developed near the road from Banská Štiavnica to Prenčov and is 130 m long and 90 m wide. Vertical differentiation between crown and toe is 17 m with average 9° slope. The slope deformation is a landslide along composite slip surface and was mapped in year 1963. Landslide reactivation was triggered by loaded dump-rockfill placed in the upper part of the slope to level the local football field which was subsequently collapsed by a prolonged period of rainfall in 2010. A semicircular head scarp with developed tension cracks and fissures was created in the football field area with 30 cm vertical differention between stabile and sliding portions. A cellar with impaired statics in the transportation part caused divided landslide accumulation into 2 significant blocks: one above the cellar and the other near the road.

METHODOLOGY, DATA ACQUISITION AND DATA PROCESSING

Technology and data acquisition

The Mikrokopter Hexa XL– Hexakopter XL (HiSystems, GmbH) used in the landslide mapping is a six rotor flying platform with robust carbon aluminium frame. It is stabilised by inertial measurement units (IMU); including gyroscopes, acceleration sensors, altimeter and compass. This unit is attached to a GPS unit with standard 2 m precision. Flight endurance with 6600 mAh lithium-polymer batteries lasts up to 15 minutes. A compact mirrorless Sony NEX 6 camera with 16-50, f/3.5-5.6 lens was used for image acquisition, and ISO sensitivity, zoom and aperture were set at fixed values with exposure time less than 1/800 s.

The flight campaign was conducted on 12th November 2014 when the landslide was not densely covered by vegetation. A total of 18 ground control points (GCPs) irregularly placed in the slope surface was targeted by GPS R4 Trimble with RTK corrections (GPS and GLONASS). The GCPs' horizontal and vertical accuracy was 15–20 mm. Two sets of images were obtained from the UAV; first from 35 m above ground level (AGL) and the second 55 m AGL. Two take off positions from the landslide area – football pitch were chosen because of the 17 metres vertical difference between the upper and lower slope parts. These flight levels ensured identification of objects of similar size on images in the slope areas.

DEM computed by UAV photogrammetry was compared with terrain topography obtained by GPS survey. The control points were targeted by GPS R4 Trimble with RTK corrections in the following 4 profiles on the landslide body (Fig. 2a): (1) profile 1, 94 m long is situated in the accumulation part with 90 control point, (2) profile 2, 141 m long with 90 control points, crossed profile 1 and passed from the landslide scarp to the accumulation zone and (3) and (4), profiles 3 and 4 are parallel to profile 1 and traverse transportation zone (141 m and 87 control points) and the football field (188 m and 70 control points).

Data processing

The total 218 UAV images were processed in the Agisoft PhotoScan software. PhotoScan workflow at the beginning aligning the images and generating tie points. This software uses Structure from Motion algorithm (SfM) to reconstruct the actual surface from a large number of overlapping photos. The software locates matching features on each image and uses iterative bundle block adjustment to estimate image orientation, exterior orientation parameters and building model geometry. The GCPs are entered to aerotriangulation which enables precise calculation of the exterior orientation parameters and improves spatial georeferencing accuracy. The final step generates the digital surface model (DSM) by building the model texture and exporting a 3D model (mesh) or orthophotomosaic.

Photogrammetry produces only a surface envelope and cannot capture terrain under vegetation cover. This function is therefore left to LiDAR point cloud data which can penetrate vegetation canopy. The 54,607,748 points in the UAV point cloud data were manually classified in the following seven classes for filtering vegetation cover and buildings: (1) high vegetation (> 5m); (2) medium vegetation (1.5–5 m); (3) low vegetation (0.2–1.5 m); (4) ground; (5) water; (6) buildings; (7) unclassified points (Fig. 2b, c, d).

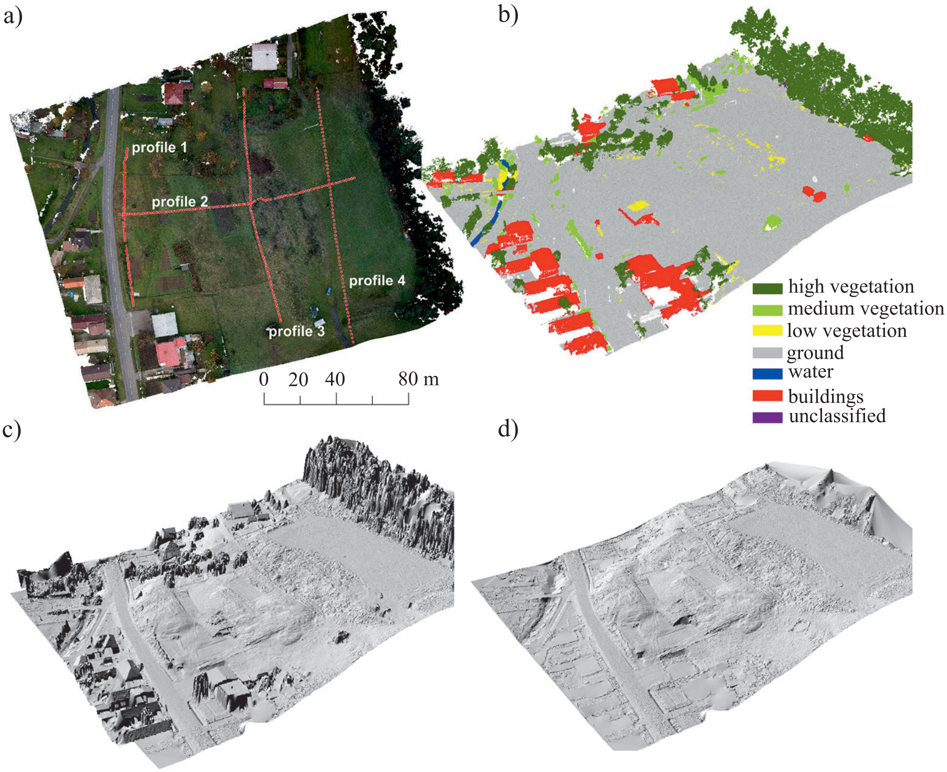

Fig. 2. Digital surface model (DSM) of landslide and localisation of control points in profiles (a), classified point cloud of 54,607,748 points (b) and difference between unclassified DSM (c) and DTM (digital terrain model) generated from ground class (d)

Vertical accuracy and effect of vegetation on vertical differences between the UAV derived elevation model and actual terrain surface was assessed by comparison of control points targeted by GPS (337 points) and unclassified point cloud (*all point cloud data*) or points classified as a ground (*ground point cloud data*). Dense point cloud, consisting of *all point cloud data* and *ground point cloud data,* was exported as raster elevation models with pixel resolutions of 1, 5, 10, 20 and 50 cm. The elevation model generated from *all point cloud data* was labelled the digital surface model (*DSM*) and the model from *ground point cloud data* was termed the digital terrain model (*DTM*). The Root Mean Square Error (RMSE) was calculated by equation:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (z_i - z_j)^2}$$

where:

n – the number of evaluated points,

z_i – the coordinate of the point on the DSM/DTM,

z_j – the coordinate of the reference surface (GPS measured in the field).

The result was statistically assessed by the PAST program.

RESULT AND DISCUSSION

The elevation model was initially assessed by overlapping and subtracting the DTM generated from ground point class and the DSM generated from all point classes (Fig. 3). The range of vertical difference is 29.451 m; with –9.698 m minimum, 19.753 m maximum and 0.744 m average vertical difference between DEMs in the study area. The most significant errors occurred in intensively human utilized areas due to buildings or high vegetation in gardens and forest edges. Although the landslide area contained the following classified objects; several trees (high vegetation), shrubs (medium vegetation), high grass (low vegetation but more than 20 cm) and a building (the cellar); the slope deformation was continuously covered by several centimetre-high grass which could not be classified. Thus, vegetation remains are the principal problem of photogrammetrically-derived DEM, and this limits its viability for the topographic mapping which is so important in geomorphic studies [Harwin and Lucieer 2012, Hugenholtz et al. 2013, Niethammer et al. 2012, Fonstad et al. 2013, Tonkin et al. 2014, Clapuyt et al. 2016].

Niethammer et al. [2012] associated the most significant errors with some small trees and bushes whose effect could not be reliably removed from the photogrammetric DTM, while Clapuyt et al. [2016] also identified elevation models errors in vegetated areas and Hugenholtz et al. [2013] further recommended UAV use in areas with minimal vegetation. However, the UAV derived DTM with high spatial resolution and accuracy provides significant potential in analysis of geodynamics processes [Niethammer et al. 2012].

The assessment of photogrammetric elevation model quality was based on GPS control points. The calculated vertical difference (RMSE) was approximately 0.425 m for DSM and 0.337 m for DTM (Table 1). Differences between terrain and surface models are mostly evident in outlier maxima and minima areas while other statistics parame-

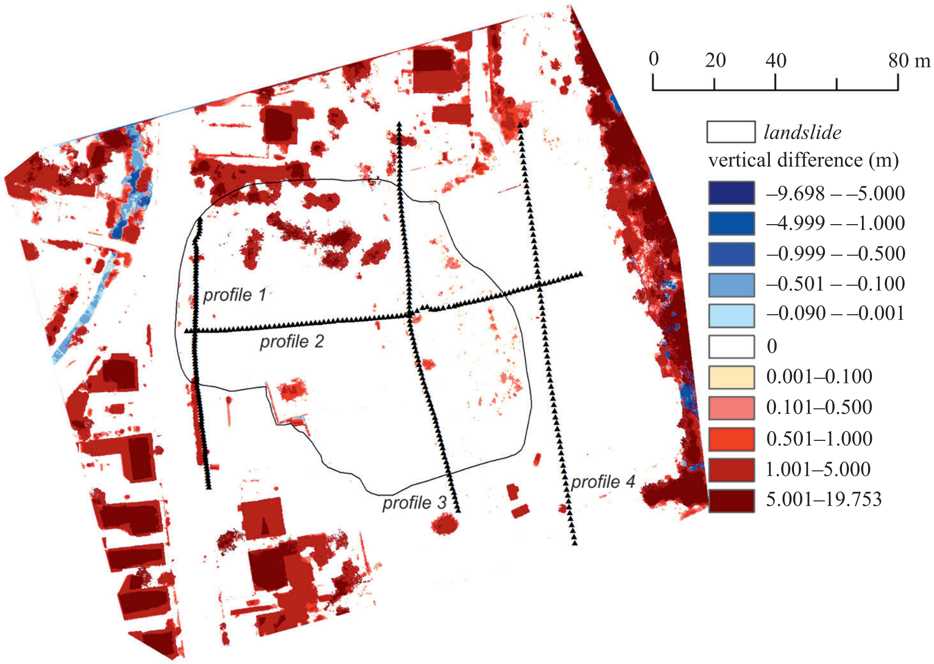

Fig. 3. Vertical difference between classified (digital terrain model, DTM) and unclassified (digital surface model, DSM) digital models

Table 1. Histograms of errors distribution for DSMs (digital surface models) and DTMs (digital terrain models) and root mean square errors (RMSE) for models with pixel resolution 1, 5, 10, 20 and 50 cm

	dsm 1 cm	dsm 5 cm	dsm 10 cm	dsm 20 cm	dsm 50 cm	dtm 1 cm	dtm 5 cm	dtm 10 cm	dtm 20 cm	dtm 50 cm
RMSE	0.413	0.425	0.414	0.434	0.438	0.338	0.337	0.337	0.340	0.334
mean	0.331	0.332	0.332	0.338	0.342	0.303	0.302	0.302	0.303	0.301
mode	0.224	0.231	0.233	0.291	0.244	0.228	0.231	0.233	0.291	0.244
median	0.273	0.277	0.274	0.277	0.276	0.265	0.266	0.267	0.269	0.265
Q25	0.223	0.222	0.224	0.221	0.223	0.221	0.219	0.219	0.217	0.215
Q75	0.405	0.406	0.405	0.417	0.418	0.396	0.396	0.396	0.403	0.390
min	–0.033	–0.033	–0.030	–0.029	–0.022	–0.152	–0.165	–0.145	–0.113	–0.045
max	2.956	3.478	2.931	3.072	2.870	0.770	0.748	0.793	0.876	0.833

ters of mean, median and mode remain similar. This reveals uniform statistic sample for DSMs and DTMs, because most control points characterize the point cloud class ground and fewer points are located in other classes.

Manually classified point cloud improves elevation model vertical accuracy in high and medium vegetation areas. The landslide is covered by grassland, which is difficult to classify, and the grass obstructs line-of-sight and makes measuring the terrain's real topography near impossible. Ouédraogo et al. [2014] confirmed differences of several centimetres corresponding to crop and vegetation elevation; and hence slope deformation covered by grass influences the vertical accuracy of DSM derived from UAV photogrammetry (relatively high vertical RMSE of DSM: 0.337 m). Therefore when is generated terrain topography to study geodynamic processes, it is important assess UAV photogrammetry precision.

Small differences between elevation models with different pixel resolutions are unexpected, but they highlight the lesser importance of pixel resolution on model accuracy. Here, all raster models were derived from dense point cloud with 0.025 m point spacing, and for pixel generation was used method average. The average pixel generation methods gave very small vertical differences between raster's with 1, 5, 10, 20 and 50 cm resolution.

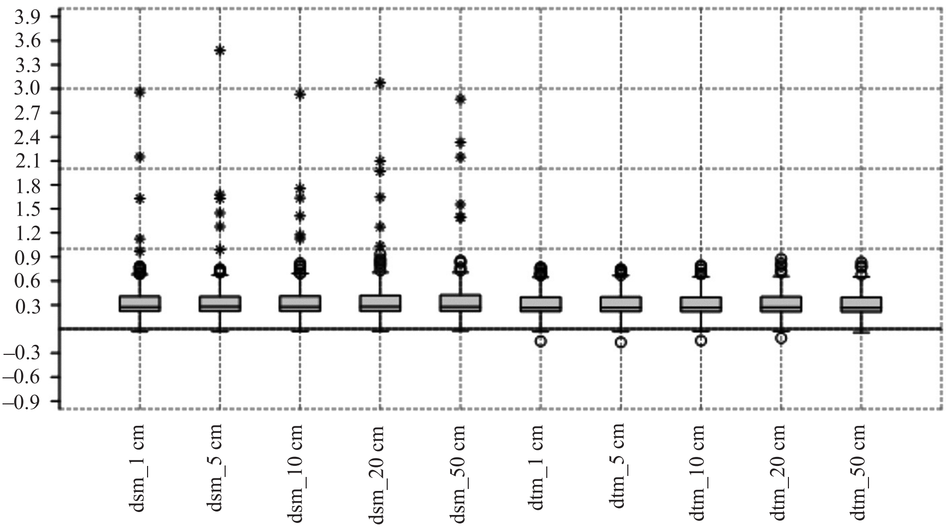

Fig. 4. Box plot graph with outliers of errors distribution for DSMs (digital surface models) and DTMs (digital terrain models) for models with pixel resolution 1, 5, 10, 20 and 50 cm

Although UAV is limited to some extent in slope stability assessment, because it cannot penetrate the vegetation and generate landslide terrain topography as well as airborne LiDAR scanning [Turner et al. 2015]. UAV represent a robust and repeatable technique for studying landscape processes and producing a precise continuous surface. It also reains necessary to identify the effect of vegetation on vertical error in studies where topography is analyzed from photogrammetrically-derived DEM. Tonkin et al. [2014] compared the vertical RMSE between densely vegetated areas of heather and shrubs with 0.796 m error and the sparsely vegetated areas of grass and exposed bedrock with 0.362 m error. Similar results were achieved in our study. The advantages of UAV technology over TLS and airborne LiDAR scanning lie in the relatively low acquisition price and the time saved [Niethammer et al. 2012, Sládek and Rusnák 2013]. Moreover, James and Robson [2012] compared laser scanner survey with UAV photogrammetry in three geoscience applications and proved that UAV produced comparable data and it reduced data collection time by 80%.

CONCLUSIONS

Photogrammetrically-derived models from UAVs provide significant potential in the study of landscape geodynamic phenomena, and they produce as highly precise spatial data as orthophotomosaics and elevation models. While UAV photogrammetry is most suited to modelling low vegetated areas, derived point cloud assessment can filter vegetation cover and buildings. Many new areas of investigation are now achievable. The high accuracy elevation models are required in engineering geology for slope stability assessment, especially where slope deformation elevation profiles enter analysis as in software GEO 5 from FINE company. Direct importation of generated profiles to the software environment from CAD and GIS systems is possible. The new version of available software, including calculation of stability in 3D space, open new possibilities for landslide stability assessment, because they emphasize importance of accuracy in generating elevation models entering into calculations. Nowadays are available discontinuous DEM created and interpolated from points targeted by total station or GPS and continuous and precise elevation models generated by TLS, airborne LiDAR and UAV photogrammetry.

Although elevation models from airborne LiDAR and TLS also allow high accuracy collection of spatial data, the use of UAVs is ultimately superior. One important advantage of UAVs is the little time consumed in data acquisition, but its greatest benefit is its low acquisition price compared with both LiDAR or TLS.

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PRZYDATNOŚĆ FOTOGRAMETRYCZNYCH CYFROWYCH MODELI WYSOKOŚCIOWYCH STWORZONYCH DZIĘKI UAV DO OCENY STABILNOŚCI STOKU (STUDIUM PRZYPADKU: OSUWISKO W WIOSCE SVÄTÝ ANTON, SŁOWACJA)

Streszczenie. Ocena dokładności fotogrametrycznych cyfrowych modeli wysokościowych (CMW – ang. *digital elevation models*, DEM) stworzonych dzięki UAV (ang. *unmanned aerial vehicle*) jest niezbędna w wielu dyscyplinach nauk o ziemi. Przydatność różnych DEM do oceny stabilności zbocza została poddana ewaluacji na przykładzie osuwiska w wiosce Svätý Anton na Słowacji. Dane lotnicze pozyskano podczas jednodniowej sesji terenowej przeprowadzonej jesienią 2014 r. Chmura punktów z 218 zdjęć (54 607 748 punktów) została ręcznie sklasyfikowana w 7 różnych klasach w celu filtrowania pokrywy roślinnej i budynków. Ocena różnic pionowych pomiędzy modelem wysokościowym UAV a rzeczywistą powierzchnią terenu opierała się na porównaniu punktów kontrolnych wskazanych przez GPS (337 punktów) oraz nieklasyfikowanej i klasyfikowanej chmury punktowej dla rastrowych modeli wysokościowych o rozdzielczości 1, 5, 10, 20 i 50 pikseli.

Słowa kluczowe: fotogrametria UAV, cyfrowy model wysokościowy, dokładność, osuwisko

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