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Temporal-spatial models of landslide development using photogrammetric methods (examples from selected landslides)

Summary:

The aim of the study was to reconstruct the stages of development of selected landslides by applying photogrammetric methods. A digital photogrammetric station was used, which made it possible to acquire information from historical aerial images about the change in landslide range and horizontal and vertical displacements. An important methodological goal of the work was to determine the usefulness of low-altitude photogrammetry with the use of an unmanned aerial vehicle (UAV) to monitor the activity of landslides. Based on the sequence of aerial and UAV images of different topicalities, an attempt was made to determine the directions of development of landslides on slopes. Quantitative data on the displacements from different periods were used to develop spatial-temporal models.

The study covered landslides located in areas of various origins, where there is the greatest concentration of landslide movements in Poland. In the north of Poland, the research was carried out on a cliff section of the Baltic Sea coast at Jastrzębia Góra. In central Poland, the research covered a landslide in Dobrzyń on the Vistula River and a landslide on the side of a lignite open-pit. The remaining four landslides are located within the Magura Unit in the Polish part of the Carpathians.

The study is based on photogrammetric materials from different periods. These are both archival aerial images, DTM and images from UAV. The oldest aerial images come from the landslide at Dobrzyń on the Vistula River. They were taken before the formation of Włocławek Lake in 1959. Georeferencing of the archival aerial images was made based on a photogrammetric network, which was measured in the field mostly by the GNSS method. The photogrammetric processing of the data made it possible to trace the development of the landslides in 41 measurement periods.

Two approaches were used to describe the evolution of the landslides. The use of these methods depended on the features of surface cover of the individual landslides. The first one is related to the changes in landslide range and horizontal displacements, and the second one

is related to vertical changes and their volumes. Horizontal changes were obtained from optical imaging and from their stereoscopic interpretation. Based on the difference in coordinates of the location of characteristic objects, horizontal displacement vectors were determined, showing the variable dynamics of colluvium movement within the landslides. The effectiveness of this method was related to the availability of such objects on the landslide surface. The landslides located in the Carpathian Mountains, the surfaces of which were covered with many such objects, e.g. rock blocks, show greater possibilities for measuring small displacements with the use of UAV. Measurements that are based on characteristic points were not possible in the landslides located in the opencast mine and at Dobrzyń, while in the case of the Jastrzębia Góra landslides, these were possible only to a limited extent.

The second approach in describing the evolution of landslides is related to vertical changes. These changes were detected based on differential terrain models (DTM) generated from 52 DTMs of different topicalities. On their basis, the zones of colluvia detachment and accumulation have been determined. The volumes of surface changes have not been calculated for all measurement periods. Calculation of the volumes for the entire landslide area was possible only in a few cases. This was due to the lack of complete information on the elevation of the landslide area because of the vegetation cover and the wrongly classified point cloud. In most of the landslides, the volumes in the accumulation zone were greater than the volumes for the detachment zone. The difference resulted probably from the lower compaction of the landslide material in relation to the material untouched by landslide processes.

In the case of the landslides at Kasinka Mała, Dobrzyń and the opencast mine, the situation is the opposite, because parts of the colluvia were deposited in the aquatic environment beneath the landslide.

By using the sequence of aerial images and the changes detected in the range of the landslides, it was possible to determine the likely directions of their development. It has been shown that the bedrock lithology in the case of the Carpathian landslides is crucial for the dynamics and nature of the displacements. Based on the detailed DTM from UAV, the main directions of colluvium movement have been identified within the landslides. In the upper part of the landslides in the main scarp zone, the vertical component is dominant in the colluvium displacement, while in the middle and lower zones, the horizontal component

contributes more to the displacement. This allows determining the probable course of the slip surface.

The research confirmed the usefulness of digital photogrammetry in obtaining archival information about the surface of landslides. The images taken during the period when no other surface measurements were carried out turned out to be especially valuable. Time analysis in the case of the Dobrzyń landslide shows that currently at least 5% of the landslide area is under water. The method that involves the use of UAV images has proved successful in assessing and quantifying the activity and horizontal and vertical displacements. The data obtained by this method are characterized by a horizontal accuracy of about 10 cm and a vertical accuracy of about ±20 cm, which makes them suitable for monitoring the activity of landslides devoid of vegetation.

The research allows drawing the following conclusions:

1. The landslides at Lachowice and Milówka, which developed on thickly bedded sandstones, are characterized by a rapid displacement that is well reflected in optical and DTR images. The main reason for their activity was the rainwater infiltration and the erosional undercutting of the slope on which they developed. After a short-term, increased activity, the landslides reached the equilibrium state.

2. The landslides at Szymbark and Kasinka Mała, which developed mostly due to the presence of variegated shales, did not reach the equilibrium state. Horizontal (Szymbark) and horizontal and vertical (Kasinka Mała) displacements occur permanently on their surface.

3. The landslides that developed on the cliff section of the coast at Jastrzębia Góra have a crucial impact on the rate of cliff top recession, which was 2.2 m/year on average in the period from 1997 to 2019.

4. The landslide at Kasinka Mała is characterized by high spatial variability of displacement dynamics. Gravitational movements in the upper and middle zones of the landslide occur in the landslide channels with sharp edges. This is caused by the presence of two stable sandstone packages. In the zone where two landslide gutters merge, continuous horizontal displacements at an average speed of 4.9 cm/day are recorded.